RESPIRATORY DYSFUNCTION IN CHRONIC NECK PAIN

A thesis submitted to the University of Manchester for the degree of
Doctor of Philosophy (PhD)
in the Faculty of Medical and Human Sciences

2011

ZACHARIAS DIMITRIADIS

SCHOOL OF MEDICINE
LIST OF CONTENTS

Title page .................................................................................................................. 1
List of tables ........................................................................................................... 8
List of figures ........................................................................................................ 11
Abstract ................................................................................................................ 14
Declaration ............................................................................................................ 15
Copyright statement .............................................................................................. 16
Acknowledgements ............................................................................................... 17

1.INTRODUCTION ................................................................................................. 18

2.LITERATURE REVIEW ....................................................................................... 22
   2.1 Functional anatomy of the cervical spine ..................................................... 23
       Functional anatomy .................................................................................... 23
       Muscular function ....................................................................................... 27
   2.2 Neck pain ..................................................................................................... 37
       2.2.1 Epidemiology of neck pain ................................................................. 38
       2.2.2 Risk factors for neck pain ................................................................. 40
       2.2.3 Neck pain mechanisms ..................................................................... 41
           Nociceptive pain ................................................................................... 41
           Neuropathic pain .................................................................................. 47
           Psychologic pain ................................................................................... 50
       2.2.4 Classification of neck pain ................................................................. 51
           Classification according to chronicity (acute-chronic) ......................... 52
           Classification according to causes (idiopathic-whiplash) ..................... 53
   2.2.5 Neck pain related conditions ................................................................. 55
   2.2.6 Manifestations of neck pain ..................................................................... 56
       Sensory function ......................................................................................... 57
       Muscle function ......................................................................................... 58
       Sensorimotor control .................................................................................. 60
       Psychological states ..................................................................................... 63
2.6.2 Respiratory muscle strength assessment ......................... 140
2.6.3 Blood gases recording .............................................. 142

3. AIMS ................................................................. 144

4. HYPOTHESES ....................................................... 146

5. METHODS ............................................................ 148
   5.1 Design .......................................................... 149
   5.2 Subjects ......................................................... 150
   5.3 Sample size calculation ......................................... 151
   5.4 Location of the study/access arrangements ................... 155
   5.5 Ethical considerations .......................................... 155
   5.6 Outcome measures ............................................. 156
   5.7 Apparatus and materials ....................................... 157
   5.8 Pilot study-familiarization ..................................... 167
       1st pilot study .................................................... 167
       2nd pilot study .................................................. 170
       3rd pilot study-familiarization ................................ 174
   5.9 Main study ....................................................... 175
       1st phase: meeting and approval ............................. 175
       2nd phase: interview and questionnaires ................... 177
       3rd phase: photograph ......................................... 177
       4th phase: respiratory assessment .......................... 179
       5th phase: cervical biomechanics assessment ............ 185
   5.10 Statistical analysis ............................................. 189

6. RESULTS ............................................................. 192
   6.1 Demographics .................................................... 193
   6.2 Pain and disability characteristics .......................... 194
   6.3 Neck muscle strength ......................................... 196
   6.4 Cervical range of movement .................................. 197
   6.5 Endurance of deep neck flexors .............................. 199
6.6 Forward head posture .......................................................... 201
6.7 Psychological states ........................................................... 202
6.8 Quiet breathing pulmonary volumes ...................................... 205
6.9 Forced expiratory volumes .................................................... 208
6.10 Respiratory flows ............................................................... 209
6.11 Maximal voluntary ventilation ........................................... 211
6.12 Respiratory muscle strength ............................................... 213
6.13 Partial pressure of arterial carbon dioxide ............................ 214
6.14 Respiratory function of the patients with chronic musculoskeletal non-spinal pain ......................................................... 216
6.15 Correlations of chronic neck pain deficits with respiratory function... 217
6.16 Principal component analysis .............................................. 227
6.17 Multiple regression analysis ................................................. 231
  6.17.1 Regression models with 4 predictors .................................. 233
     Prediction of peak expiratory flow ....................................... 233
     Prediction of vital capacity ................................................. 235
     Prediction of maximal voluntary ventilation .......................... 237
     Prediction of maximal inspiratory pressure .......................... 239
     Prediction of maximal expiratory pressure ......................... 241
     Prediction of partial pressure of arterial carbon dioxide ...... 242
  6.17.2 Regression analysis with all the potential predictors .......... 244
     Prediction of peak expiratory flow ....................................... 244
     Prediction of vital capacity ................................................. 245
     Prediction of maximal voluntary ventilation .......................... 245
     Prediction of maximal inspiratory pressure .......................... 246
     Prediction of maximal expiratory pressure ......................... 247
     Prediction of partial pressure of arterial carbon dioxide ...... 248

7. DISCUSSION ........................................................................ 250
7.1 Sample ............................................................................. 251
7.2 Non-pulmonary deficits in chronic neck pain ........................... 253
    7.2.1 Neck muscle strength ............................................... 253
    7.2.2 Cervical range of movement ....................................... 256
LIST OF TABLES

Table 2.1 Cervical muscles and their attachments…………………………….. 35
Table 2.2 Effects of hypocapnia in body systems…………………………….. 76
Table 2.3 Neck muscle strength in chronic idiopathic neck pain……………... 91
Table 2.4 Neck muscle activity and endurance in chronic idiopathic neck pain. 96
Table 2.5 Cervical range of movement in chronic idiopathic neck pain……….. 103
Table 2.6 Cervical proprioception in chronic idiopathic neck pain…………… 108
Table 2.7 Forward head posture in chronic idiopathic neck pain……………… 114
Table 2.8 Evidence for respiratory dysfunction in chronic neck……………… 123
Table 2.9 Reliability and validity of assessment tools for neck musculoskeletal impairments………………………………………………………… 127
Table 2.10 Intra- and inter-rater reliability of neck isometric dynamometry…. 129
Table 2.11 Intra-rater reliability of ultrasound-based motion analysis system... 133
Table 2.12 Test-retest reliability of mouth pressure meter…………………… 141
Table 6.1 Participants’ demographics………………………………………….. 194
Table 6.2 Pain and disability…………………………………………………… 194
Table 6.3 Classification of participants ………………………………………….. 195
Table 6.4 Neck muscle strength…………………………………………………... 196
Table 6.5 Cervical range of movement………………………………………… 198
Table 6.6 Endurance of deep neck flexors……………………………………. 200
Table 6.7 Forward head posture………………………………………………… 201
Table 6.8 Descriptives of psychological states………………………………… 203
Table 6.9 Anxiety and depression……………………………………………… 204
Table 6.10 Quiet breathing pulmonary volumes……………………………… 205
Table 6.11 Normative values and measurements error ……………………… 207
Table 6.12 Forced expiratory volumes……………………………………….. 208
Table 6.13 Respiratory flows…………………………………………………… 210
Table 6.14 Maximal voluntary ventilation……………………………………… 212
Table 6.15 Respiratory muscle strength………………………………………. 213
Table 6.16 Partial pressure of arterial carbon dioxide……………………….. 215
Table 6.17 Respiratory function in patients with chronic non-spinal musculoskeletal pain................................................................. 216
Table 6.18 Correlations between chronic neck pain deficits and respiratory parameters I................................................................. 218
Table 6.19 Correlations between chronic neck pain deficits and respiratory parameters II............................................................. 219
Table 6.20 Correlation matrix of principal component analysis.......................................................... 228
Table 6.21 Loading of each variable onto factors.......................................................... 229
Table 6.22 Correlation matrix for all the potential predictors.......................................................... 232
Table 6.23 Regression model for the prediction of peak expiratory flow....... 234
Table 6.24 Regression model for the prediction of vital capacity..................... 236
Table 6.25 Regression model for the prediction of maximal voluntary ventilation................................................................. 238
Table 6.26 Regression model for the prediction of maximal inspiratory pressure................................................................. 240
Table 6.27 Regression model for the prediction of maximal expiratory pressure................................................................. 242
Table 6.28 Regression model for the prediction of arterial carbon dioxide...... 243
Table 6.29 Regression model for the prediction of maximal inspiratory pressure (all the predictors)................................................................. 247
Table 6.30 Regression model for the prediction of arterial carbon dioxide (all the predictors)................................................................. 249
Table XIIIa Test-retest reliability of Zebris for “natural head position to flexion target” test (constant error)................................................................. 354
Table XIIIb Test-retest reliability of Zebris for “flexion to natural head position” test (constant error)................................................................. 354
Table XIIIc Test-retest reliability of Zebris for “natural head position to extension target” test (constant error)................................................................. 355
Table XIIIId Test-retest reliability of Zebris for “extension to natural head position” test (constant error)................................................................. 355
Table XIIIe Test-retest reliability of Zebris for “natural head position to flexion target” test (absolute error)................................................................. 356
Table XIIIf Test-retest reliability of Zebris for “flexion to natural head position” test (absolute error)……………………………………..
Table XIIIg Test-retest reliability of Zebris for “natural head position to extension target” test (absolute error)…………………………….
Table XIIIh Test-retest reliability of Zebris for “extension to natural head position” test (absolute error)……………………………………...
Table XIVa Descriptives of the three trials during the endurance test of the first pilot...........................................................................................
Table XIVb Reliability of the endurance test considering all the three trials…. 
Table XIVc Reliability of the endurance test considering only the last two trials...........................................................................................
Table XVa Descriptives of cranio cervical flexion test................................................................................................................
Table XVb Reliability of the cranio cervical flexion test................................................................................................................
Table XVI Differences in neck pain deficits using non-parametric statistics…
Table XVII Differences in respiratory function using non-parametric statistics.......................................................................................... 
Table XVIIIa Correlations between musculoskeletal deficits and respiratory parameters I (controls)...........................................................
Table XVIIIb Correlations between musculoskeletal deficits and respiratory parameters II (controls)...........................................................
Table XIXa Correlations between chronic neck pain deficits and respiratory parameters I (non-parametric).................................................................
Table XIXb Correlations between chronic neck pain deficits and respiratory parameters II (non-parametric)...........................................................
**LIST OF FIGURES**

<table>
<thead>
<tr>
<th>Figure</th>
<th>Title</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.1</td>
<td>Neck pain mechanisms for respiratory dysfunction</td>
<td>20</td>
</tr>
<tr>
<td>2.1</td>
<td>Cervical vertebral bodies</td>
<td>24</td>
</tr>
<tr>
<td>2.2</td>
<td>Cervical ligaments</td>
<td>25</td>
</tr>
<tr>
<td>2.3</td>
<td>Cervical muscles I</td>
<td>29</td>
</tr>
<tr>
<td>2.4</td>
<td>Cervical muscles II</td>
<td>31</td>
</tr>
<tr>
<td>2.5</td>
<td>Cervical muscles III</td>
<td>32</td>
</tr>
<tr>
<td>2.6</td>
<td>Topographical definition of neck pain</td>
<td>38</td>
</tr>
<tr>
<td>2.7</td>
<td>Pain transmission</td>
<td>42</td>
</tr>
<tr>
<td>2.8</td>
<td>Somatic referred pain</td>
<td>45</td>
</tr>
<tr>
<td>2.9</td>
<td>Muscular dysfunction in neck pain</td>
<td>59</td>
</tr>
<tr>
<td>2.10</td>
<td>Sensorimotor disturbances in neck pain</td>
<td>62</td>
</tr>
<tr>
<td>2.11</td>
<td>Lungs</td>
<td>68</td>
</tr>
<tr>
<td>2.12</td>
<td>Gas exchange</td>
<td>74</td>
</tr>
<tr>
<td>2.13</td>
<td>Pulmonary volumes and capacities</td>
<td>77</td>
</tr>
<tr>
<td>2.14</td>
<td>Flow-volume loop</td>
<td>79</td>
</tr>
<tr>
<td>2.15</td>
<td>Mouth pressures</td>
<td>81</td>
</tr>
<tr>
<td>2.16</td>
<td>Maximal voluntary ventilation</td>
<td>82</td>
</tr>
<tr>
<td>2.17</td>
<td>Neck pain mechanisms for respiratory dysfunction</td>
<td>87</td>
</tr>
<tr>
<td>5.1</td>
<td>Stadiometer</td>
<td>158</td>
</tr>
<tr>
<td>5.2</td>
<td>Weight scale</td>
<td>158</td>
</tr>
<tr>
<td>5.3</td>
<td>TCM40</td>
<td>160</td>
</tr>
<tr>
<td>5.4</td>
<td>Spirolab II</td>
<td>161</td>
</tr>
<tr>
<td>5.5</td>
<td>WinSpiroPRO</td>
<td>161</td>
</tr>
<tr>
<td>5.6</td>
<td>MicroRPM</td>
<td>162</td>
</tr>
<tr>
<td>5.7</td>
<td>Puma PC software</td>
<td>163</td>
</tr>
<tr>
<td>5.8</td>
<td>The Zebris CMS20 ultrasound-based motion analysis system</td>
<td>164</td>
</tr>
<tr>
<td>5.9</td>
<td>WinSpine recording software</td>
<td>164</td>
</tr>
<tr>
<td>5.10</td>
<td>Isometric neck dynamometer</td>
<td>165</td>
</tr>
<tr>
<td>5.11</td>
<td>Isometric neck dynamometer accompanying software</td>
<td>165</td>
</tr>
<tr>
<td>5.12</td>
<td>Pressure biofeedback device</td>
<td>166</td>
</tr>
<tr>
<td>5.13</td>
<td>Endurance test for the neck flexors (1st pilot)</td>
<td>170</td>
</tr>
</tbody>
</table>
Figure 5.14 Positioning for craniocervical flexion test
Figure 5.15 Craniocervical flexion test
Figure 5.16 Phases of the study
Figure 5.17 Craniovertebral angle
Figure 5.18 Electrode placement for recording PtcCO$_2$
Figure 5.19 PtcCO$_2$ assessment
Figure 5.20 Spirometry
Figure 5.21 Maximal respiratory pressures assessment
Figure 5.22 Cervical range of movement assessment
Figure 5.23 Neck extensor strength assessment
Figure 5.24 Neck flexor strength assessment
Figure 6.1 Neck muscle strength
Figure 6.2 Range of movement
Figure 6.3 Endurance of deep neck flexors
Figure 6.4 Forward head posture
Figure 6.5 Anxiety and depression
Figure 6.6 Quiet breathing pulmonary volumes
Figure 6.7 Forced expiratory volumes
Figure 6.8 Respiratory flows
Figure 6.9 Maximal voluntary ventilation
Figure 6.10 Respiratory muscle strength
Figure 6.11 Partial pressure of arterial carbon dioxide
Figure 6.12 Correlations between FEV1/FVC ratio and chronic neck pain deficits
Figure 6.13 Correlations between PEF and chronic neck pain deficits
Figure 6.14 Correlations between vital capacity and chronic neck pain deficits
Figure 6.15 Correlations between maximal voluntary ventilation and chronic neck pain deficits
Figure 6.16 Correlations between maximal inspiratory pressure and chronic neck pain deficits
Figure 6.17 Correlations between maximal expiratory pressure and chronic neck pain deficits………………………………………………………… 225
Figure 6.18 Correlations between partial pressure of arterial carbon dioxide and chronic neck pain deficits…………………………………….. 226
Figure 6.19 Factor plot for the chronic neck pain group………………………. 230
Figure 6.20 Regression model for peak expiratory flow……………………… 234
Figure 6.21 Regression model for vital capacity……………………………… 236
Figure 6.22 Regression model for maximal voluntary ventilation………….. 238
Figure 6.23 Regression model for maximal inspiratory pressure…………….. 240
Figure 7.1 Respiratory dysfunction model for patients with chronic neck pain…………………………………………………………………… 288
Figure XX Plots of standardized residuals with standardized predicted values…………………………………………………………………… 365
Figure XXI Histograms of standardized residuals…………………………….. 366
Figure XXII Diagnostics in regression models of more than 4 predictors…… 367
**Background:** Patients with chronic neck pain have a number of factors that could constitute a predisposition for respiratory dysfunction. However, the existing evidence is limited and not well established, and many questions such as the association of neck pain deficits with respiratory function remain unanswered. Thus, the aim of this study was to investigate whether patients with chronic neck have accompanying respiratory dysfunction and which are the neck pain deficits which principally predispose to these respiratory disturbances.

**Methods:** In this case-control observational study, 45 patients with chronic idiopathic neck pain (>6 months, at least once per week) and 45 healthy age-, gender-, height- and weight-matched controls were voluntarily recruited. A third group of 10 patients with chronic non-spinal musculoskeletal pain was also used, but only for future reference. Participants’ neck muscle strength and endurance were measured by an isometric neck dynamometer and craniocervical flexion test respectively. Range of movement was assessed by using an ultrasound-based motion analysis system. Forward head posture was assessed by obtaining lateral photographs and calculating the craniovertebral angle. Disability and neck pain intensity were assessed through the Neck Disability Index and Visual Analogue Scale. Psychological assessment was performed by using the Hospital Anxiety and Depression Scale, the Pain Catastrophizing Scale and the Tampa Scale for Kinesiophobia. Spirometry was used for assessing pulmonary volumes, flows and maximal voluntary ventilation. Respiratory muscle strength was assessed by using a mouth pressure meter. Finally, PaCO$_2$ was assessed by using transcutaneous blood gas monitoring.

**Results:** Patients with chronic neck pain were found to have weaker respiratory muscles than healthy controls (p<0.05). Their pulmonary volumes and maximal voluntary ventilation were also found to be reduced (p<0.05). Their mean respiratory flows were found to be unaffected (p>0.05), whereas their peak flows were reduced (p<0.05). Their partial pressure of carbon dioxide was also found to be affected (p<0.05), revealing existence of hypocapnia (PaCO$_2$<35mmHg). The neck pain deficits that were found to be mostly correlated with these respiratory parameters were the neck muscle strength, neck muscle endurance, kinesiophobia, catastrophizing and pain intensity (r>0.3, p<0.05). Finally, the regression models revealed that neck pain deficits and especially neck muscle strength can provide a quite generalizable accurate estimation of this respiratory dysfunction ($R^2$=0.28-0.52).

**Conclusions:** Patients with chronic neck pain present dysfunction of their respiratory system which can be mainly manifested as respiratory weakness and/or hypocapnia. Pain intensity, neck muscle weakness, fatigue and kinesiophobia seem to be the most important deficits predisposing to this respiratory dysfunction. The understanding of this dysfunction could have a great impact on various clinical aspects notably patient assessment, rehabilitation and drug prescription. However, further research is suggested mainly directed towards optimizing treatment protocols and developing classification systems improving clinical reasoning.
DECLARATION

No portion of the work referred to in the thesis has been submitted in support of an application for another degree or qualification of this or any other university or other institute of learning.
COPYRIGHT STATEMENT

i. The author of this thesis (including any appendices and/or schedules to this thesis) owns certain copyright or related rights in it (the “Copyright”) and he has given The University of Manchester certain rights to use such Copyright, including for administrative purposes.

ii. Copies of this thesis, either in full or in extracts and whether in hard or electronic copy, may be made only in accordance with the Copyright, Designs and Patents Act 1988 (as amended) and regulations issued under it or, where appropriate, in accordance with licensing agreements which the University has from time to time. This page must form part of any such copies made.

iii. The ownership of certain Copyright, patents, designs, trade marks and other intellectual property (the “Intellectual Property”) and any reproductions of copyright works in the thesis, for example graphs and tables (“Reproductions”) which may be described in this thesis, may not be owned by the author and may be owned by third parties. Such Intellectual Property and Reproductions cannot and must not be made available for use without the prior written permission of the owner(s) of the relevant Intellectual Property and/or Reproductions.

iv. Further information on the conditions under which disclosure, publication and commercialization of this thesis, the Copyright and any Intellectual Property and/or Reproductions described in it may take place is available in the University IP Policy (see http://www.campus.manchester.ac.uk/medialibrary/policies/intellectual-property.pdf), in any relevant Thesis restriction declarations deposited in the University Library, The University Library’s regulations (see http://www.manchester.ac.uk/library/aboutus/regulations) and in The University’s policy on presentation of Theses.
AKNOWLEDGEMENTS

The completion of this study, although a task undertaken by one person, is in reality an achievement based on the help of some people. Thus, I would like to thank:

My principal supervisor, Prof. Jacqueline Oldham, for her invaluable guidance, help and advice as well as for the perfect collaboration we developed during all the stages of the study.

My academical parents and co-supervisors in Greece, Dr Nikolaos Strimpakos and Dr Eleni Kapreli, for their support, advice and help during these three years as well as for their permission to adopt their innovative ideas as a base for the implementation of this new study.

My advisor, Dr. John McBeth, for his advices and contribution to the development of the study protocol.

The biomedical statistician, Dr. Steven Roberts, for his guidance and advices regarding statistical analysis.

The lung specialist, Dr. Foivos Kokkinis, for his advices regarding pulmonary function testing.

My colleague, Dr. Vicky Billis, for her clinical advices.

My aunt, Georgia-Margarita Dimitriadou, and my uncle, Dr. Iosif Michelogiannis, for their financial and psychological support as well as for the stimulus they gave me to occupy with health sciences and research.

My family for their financial and psychological support.

My colleagues, friends and relatives for their support and help during the sample recruitment.

The volunteers for their time and willingness to participate to this study.

The postgraduate administrator for School of Translational Medicine, Ms Christine Burns, for her help during all the procedural difficulties I faced during these years.

The University of Manchester and Technological Educational Institute of Lamia for the permission to use their facilities, equipment and resources.
1. Introduction
1. INTRODUCTION

Chronic neck pain is one of the most frequent musculoskeletal complaints. It is estimated that the 70%-80% of people suffer from neck pain at some time in their lives (Cote et al; 2003; Ferrari and Russell, 2003; Jull et al, 2008a) and up to 60% of the population may experience persistent and recurrent pain (Jull et al, 2008a). For the largest part of the previous century neck pain was of secondary interest in relation to low back pain. However, the increasing incidence of neck pain during this century, which can be justified by changes in work nature, increased use of motor vehicles and the advancement and increased use of computers, has led the last twenty years to a continuously growing interest and research regarding the clear understanding of causes, manifestations and management of neck pain (Jull et al, 2008a).

Patients with chronic neck pain may experience a number of accompanying problems which may predispose to or result from the neck pain experience. Reduced strength and endurance of neck muscles (Chiu and Lo, 2002; Harris et al, 2005), reduced range of movement (Rix and Bagust, 2001), altered proprioception (Cheng et al, 2010), adoption of bad head posture (Lau et al, 2009) as well as psychological states (Leino and Magni, 1993; Mantyselka et al, 2010) are all seem to be apparent in patients with chronic neck pain. These problems may lead sufferers to restrain from daily activities affecting their quality of life.

Kapreli et al (2008) proposed that patients with chronic neck pain might also have respiratory disturbances (Figure 1.1). According to this hypothesis, the impairments accompanying chronic neck pain may have their own contribution to the development of respiratory dysfunction. More specifically, the pain by itself may increase respiration due to noxious stimuli, whereas drugs for pain inhibition may suppress it. Furthermore, posture alterations, muscle imbalances and segmental instability caused by strength reduction of the neck muscles may result in thoracic spine instability that may cause changes in rib cage mechanics. Changes in rib cage mechanics may also be caused by deficits in proprioception because of joint deafferentation and changes in spinal motor patterns. This change in rib cage biomechanics may be further exacerbated by psychological states such as anxiety as well as kinesiophobia which may impede patients from movement execution with
consequential alteration of the biomechanics and breathing pattern. Biomechanics and breathing pattern alteration can be also caused by the increased neck muscle fatigability and decreased range of neck movement potentially resulting in further rib cage mechanics change. These changes in rib cage mechanics can finally lead to dysfunction of respiratory muscles.

Figure 1.1: Neck pain mechanisms for respiratory dysfunction.


Despite the fact that this hypothesis is supported by theoretically sound rationale, the evidence for its approval is limited and not well-documented. The existent studies (Makela et al, 1991; Perri and Halford, 2004; Nilsen et al, 2007) either have not been appropriately designed for investigating this hypothesis or they are lacking vigorous methodology. The only valid evidence about the existence of
respiratory dysfunction in chronic neck pain comes from a study by Kapreli et al (2009), but the results are preliminary and critical respiratory parameters such as blood chemistry have not been examined.

Further examination of the potential connection between chronic neck pain and respiratory dysfunction could provide information which could significantly influence assessment, rehabilitation and drug prescription in these patients. In terms of assessment, clinicians may need to incorporate respiratory assessment in a more global consideration of musculoskeletal disorders such as chronic neck pain. During rehabilitation, potential disturbances of respiratory function should be also taken into consideration when designing appropriate exercises for both neck and respiratory system. Finally, it may be also advised that drug prescription should be performed in a more attentive and controlled manner (Kapreli et al, 2008).

Thus, the current study was aimed at investigating whether patients with chronic neck pain have respiratory dysfunction including changes in partial pressure of arterial carbon dioxide which have never been examined previously. Furthermore, this study was aimed at putting together, for first time, all the musculoskeletal deficits and psychological states of patients with chronic neck pain in a model for predicting potential respiratory dysfunction.
2. Literature Review
2. LITERATURE REVIEW

This chapter, after describing the functional anatomy of the cervical area, provides information about the epidemiology, mechanisms, classification, causes, manifestations and management of neck pain. After this part of literature review, pulmonary function is described and then the theoretical background underlying the existence of respiratory dysfunction in patients with chronic neck pain is discussed and all the existing evidence supporting this hypothesis is provided. Finally, valid and reliable measurement tools of musculoskeletal, psychological and respiratory parameters are proposed for the examination of this relationship.

2.1 Functional anatomy of the cervical spine

This section is aimed at providing fundamental knowledge about the cervical area. The first part of this section gives short information about the anatomy, biomechanics, sensory capabilities and reflexes of the cervical area, whereas the second part focuses on individual function of cervical muscles.

Functional anatomy

The cervical (C) spine comprises of seven vertebrae. It is anatomically and functionally divided into the craniocervical and typical cervical region with the transition occurring at the motion of the C2-C3 segment (Jull et al, 2008a). The first two vertebrae are called the atlas (C1) and axis (C2) respectively and they present quite different anatomy from the typical cervical vertebra. The basic anatomical difference of the axis is the presence of the odontoid process which is a tooth-like projection and a necessary anatomical structure for the rotation of the cervical region. The atlas is much more different from the typical cervical vertebra and it looks like a ring bone having a very wide vertebral foramen and no bifid spinous process. The C3-
C6 cervical vertebrae have a similar anatomy, but the C7 exhibits more similarities to the thoracic vertebrae having as its main feature a long spinous process which is not bifid (Figure 2.1) (Palastanga et al, 2002).

Figure 2.1: Cervical vertebral bodies.

This figure shows the a) second (axis), b) first (atlas), c) third to sixth (typical) and d) seventh cervical vertebra. (Reproduced from Palastanga N., Field D. and Soames R. (2002). Anatomy and human movement, structure and function. Malta: Butterworth Heinemann, with permission).

The intervertebral discs hold together the bodies of vertebrae of the cervical region. However, they are thinner than any other part of spine because their force-absorption function is more important in the lower segments of spine which bear more weight. The bodies of the vertebrae are also held together by the anterior and posterior longitudinal ligaments which support the anterior and posterior aspect of vertebral column. The ligamentum flavum, the supraspinatus ligament, the ligamentum nuchae as well as the ligaments of atlanto-axial and atlanto-occipital joints are other
ligaments which significantly contribute to the stability of the cervical spine and to the maintenance of the erect position of head (Figure 2.2) (Palastanga et al, 2002).

Figure 2.2: Cervical ligaments.


The cervical spine has a complicated function as this region does not only consist of uncovertebral and zygapophysial joints, but also of atlantoaxial and atlanto-occipital articulations rendering the cervical kinematics of high interest. The cervical spine enables performance of all movements including flexion, extension, lateral flexion and rotation. The total flexion of the typical cervical region is about $25^0$ whereas the total extension is about $85^0$. Lateral flexion and rotation is about $40^0$ and $50^0$ to each side respectively. Separate examination of the joints of the craniocervical
region, due to their specific anatomical structure, reveals restricted flexion and extension of the atlanto-axial joints. Lateral rotation is restricted to $15^\circ$ to each side by the anatomical position of the odontoid process. Lastly, the atlanto-occipital articulations allow flexion and extension to a total range of $20^\circ$, with no more than $8^\circ$ of lateral flexion to each side and negligible rotation (Palastanga et al, 2002). The complicated kinematics of the neck can influence the related muscles altering their force-length curve which can have an impact on their properties and ultimately their function (Jull et al, 2008a).

Flexion in the cervical area begins and finishes in the lower cervical spine. The craniocervical and middle cervical area mainly contribute to the middle of neck flexion, but the craniocervical area moves in extension at the end of neck flexion. Neck extension is performed in a similar pattern to cervical flexion with the difference that craniocervical area reaches its maximum extension at the end of movement. At the initial stage of cervical extension there is a slight burst of extensor muscle activity in order for the movement to be initiated. The activity of neck extensors is then silenced and there is an eccentric contraction of neck flexors for controlling the movement until the end of movement. As the extension progresses the deep muscles become more activated. At the end of extension, the neck extensors are activated again in order for the neck to reach its maximal extension against the resistance posed by the elastic structures. The muscle activation during neck flexion follows a similar pattern, but the activation of neck flexors and extensors is reversed. Neck rotation and lateral flexion of the typical cervical regions present an ipsilateral coupling, whereas a contralateral coupling is observed in craniocervical region. This means that when neck rotates, the typical cervical spine ipsilaterally flexes, whereas the craniocervical contralaterally flexes. The muscle activation during these movements is complex and highly dependent on the intensity of contraction (Jull et al, 2008a).

The cervical region and especially the upper cervical region are very rich in muscle mechanoreceptors including muscle spindles, Golgi tendon organs and pacinian corpuscles. These mechanoreceptors are found in higher density in muscles than in ligaments indicating that mechanoreceptors in joints serve mostly a supplemental role to the abundant mechanoreceptors of cervical muscles (Jull et al, 2008a). Furthermore, deeper muscle regions are denser in such mechanoreceptors.
These facts suggest not only that the cervical area may provide important proprioceptive information, but that deep cervical muscles play an important role in proprioception, movement precision, control of head position and oculomotor function (Jull et al, 2008a).

Proprioceptive information from the cervical area coupled with vestibular reflexes play an important role in head position, visual control and balance through the cervico-colic, cervico-ocular and tonic neck reflexes. The Cervico-colic reflex helps the activation of neck muscles for the stabilization of head on the body. This reflex interacts with the vestibulo-colic reflex to further assist with head stabilization and avoidance of involuntary head displacements. The cervico-ocular reflex interacts with the vestibulo-ocular reflex for controlling extra-ocular muscles. Finally, the tonic neck reflex helps to change muscle activity of limbs when the body is moving in relation to head. This reflex is integrated into the vestibulo-spinal reflex for achieving postural stability (Jull et al, 2008a).

**Muscular function**

The muscles of the cervical region can be divided in three discrete categories according to their anatomical position. Thus, they can be divided into 1) muscles of the craniocervical region, 2) muscles typical of the cervical region and 3) muscles which coexist in both regions. Muscles of the craniocervical region are separated into the deep suboccipital group (rectus capitis posterior major, rectus capitis posterior minor, obliquus capitis inferior, obliquus capitis superior) which has an important proprioceptive role especially in relation to its connections with the visual and vestibular systems and the anterolateral craniocervical group (longus capitis, rectus capitis anterior, rectus capitis lateralis). The typical cervical area includes muscles which can be found posteriorly (semispinalis cervicis, cervical multifidus), anteriorly (longus colli) or laterally (anterior, middle and posterior scalenus). Finally, the muscles which run through both cervical regions include either the posterior superficial muscles (splenius capitis, splenius cervicis, semispinalis capitis, longissimus capitis) or the anterolateral muscles (suprahyoid, infrahyoid, sternocleidomastoid) (Jull et al, 2008a).
Many of the neck muscles are small and sometimes impossible to palpate. Nevertheless, they are of high importance for the alignment and the correct carriage of the neck and head. The attachments of each cervical muscle are presented in Table 2.1. Longus colli, sternocleidomastoid and anterior scalenus are the most important flexors of the neck (Figure 2.3). Longus colli is separated into three parts which are located laterally and on the front of the cervical and upper thoracic spine. Despite its main action being neck flexion, it can also help with lateral flexion to the same side and rotation to the opposite side although these functions are controversial (Palastanga et al, 2002). Sternocleidomastoid is a long strap-like muscle of the neck region and arises from two heads. Similarly to the previously discussed muscles, there is one sternocleidomastoid on each side. When one of these contracts, a lateral flexion of the neck to the same side and a neck rotation to the opposite side are performed. A combined contraction of both of these muscles causes both head and neck flexion (Palastanga et al, 2002). In case of the head and neck being fixed, the clavicle and manubrium sternal are elevated expanding the rib cage. This latter function indicates their usefulness as accessory muscles during inspiration (Palastanga et al, 2002; Jardins, 2008). Anterior scalenus is found deep to sternocleidomastoid. Similarly to sternocleidomastoid, there is a scalenus anterior on each side. When one of them contracts it causes lateral flexion of the neck and restricted rotation to the opposite side. When both of them contact the neck flexes (Palastanga et al, 2002). Additionally, anterior scaleni are accessory muscles of inspiration as having their upper attachments fixed assists to the elevation of the rib cage (Palastanga et al, 2002; Jardins, 2008).

Simultaneous flexion of the head and neck is not performed only by sternocleidomastoid, but also by longus capitis (Figure 2.3). Rectus capitis anterior is a short strap muscle and is the only muscle which can perform pure flexion of the head on the neck (Figure 2.3). However, the main function of this muscle is the stabilization of the atlanto-occipital joint during motion (Palastanga et al, 2002).
This figure presents a) the longus colli, longus capitis, rectus capitis anterior, b) sternocleidomastoid, c) anterior scalenus and d) medius and posterior scalenus (Reproduced from Palastanga N., Field D. and Soames R. (2002). *Anatomy and human movement, structure and function*. Malta: Butterworth Heinemann, with permission).
Apart from the anterior scalenus and sternocleidomastoid, there are also some other muscles with significant contribution to lateral flexion of the neck. These muscles are the medius scalenus (Figure 2.3), posterior scalenus (Figure 2.3), splenius cervicis and levator scapulae (Figure 2.4). Scalenus medius is the largest of the scalene muscles and is found between the anterior and posterior scalenus. If only one works, it causes strong lateral flexion of the neck to the same side, whereas if the upper attachments are fixed it contributes to inspiration by steadying or elevating the first rib. Posterior scalenus is the smallest of the scaleni and it is found posteriorly. Beside its function as a strong lateral flexor of the neck, it can contribute to inspiration by steadying the second rib when the upper attachments are fixed. Splenius cervicis, acting on its own, performs lateral flexion and slight rotation of neck to the same side. If the splenius cervicis of both sides contract together, they cause neck extension. Levator scapula is found on the posterior part of neck. When it works with trapezius, it elevates and retracts the pectoral girdle. Working again with trapezius, but with contraction of both levator scapulae, the neck extends. If only one levator scapulae contracts, the neck flexes laterally. This muscle also helps to the stabilization of the scapula (Palastanga et al, 2002; Jardins, 2008).

There are also muscles that laterally flex both the head and neck. These muscles are the sternocleidomastoid, which has previously been discussed as well as the splenius capitis (Figure 2.4), trapezius (Figure 2.4), erector spinae (Figure 2.5) and rectus capitis lateralis. Splenious capitis is found under the rhomboids, trapezius and sternocleidomastoid. An individual action of the splenious capitis leads to neck and head extension usually accompanied by lateral flexion and rotation to the same side. A simultaneous contraction of both splenius capitis leads to pure neck extension. Trapezius is a large, flat, superficial and triangular muscle which extends from the spine and skull to the pectoral girdle. Beside the other functions of the trapezius such as stabilization, retraction or lateral rotation of the scapula and elevation of the pectoral girdle, it also significantly contributes to neck motion. More specifically, when both of the trapezius act together they extend the neck and head, whereas when they act singularly they lead to lateral flexion of neck and head (Palastanga et al, 2002). The trapezius is also an accessory muscle of inspiration as it helps in the elevation of the thoracic cage (Jardins, 2008).
Figure 2.4: Cervical muscles II.

This figure presents the a) splenius capitis, inferior oblique, superior oblique and rectus capitis posterior major and minor, b) trapezius and c) levator scapulae (the upper of the three muscles) (Reproduced from Palastanga N., Field D. and Soames R. (2002). Anatomy and human movement, structure and function. Malta: Butterworth Heinemann, with permission).
Erector spinae is a large and strong mass of muscle which consists of several parts covering the biggest part of the spine. After the attachment of erector spinae to the iliac tuberosity and the inner lip of the iliac crest it is separated into three muscle columns; the iliocostalis, the longissimus and the spinalis. The most important function of erector spinae is when the three muscle columns on both sides act together in order to extend the thoracic and cervical spine, the head and the neck. Although this muscle is the major extensor of the spine it can also produce lateral flexion and rotation to the same side when the three columns of one side act together. Rectus capitis lateralis is a short strap-like muscle and the only one which can produce pure lateral flexion of the head on the neck to the same side. However, the main action of rectus capitis is stabilization of the atlanto-occipital joint during motion (Palastanga et al, 2002).

Figure 2.5: Cervical muscles III.

This figure presents the a) semispinalis (capitis, cervicis, thoracis), multifidus, b) iliocostalis (lumborum, thoracis, cervicis), longissimus (thoracis, capitis) and spinalis thoracis. (Reproduced from Palastanga N., Field D. and Soames R. (2002). *Anatomy and human movement, structure and function*. Malta: Butterworth Heinemann, with permission).
It has already been discussed that extension of the neck is performed by levator scapulae and splenius cervicis, whereas simultaneous extension of the head and neck can be performed by the trapezius, splenius capitis and erector spinae. However there are also some muscles which can perform extension of the head on the neck. These muscles are the rectus capitis posterior major, rectus capitis posterior minor and superior oblique. Rectus capitis posterior major is a small muscle and its function is the extension of the head on the neck. If only one of the rectus capitis works, the head rotates to the same side. However, its main function should be the stabilization of the atlanto-occipital joint during motion. Rectus capitis posterior minor and superior oblique are also small muscles and although they can extend the head on the neck, their main function is again the stabilization of the atlanto-occipital joint during motion (Palastanga et al, 2002).

The neck can also rotate by the semispinalis cervicis, multifidus, scalenus anterior and splenius cervicis. Semispinalis cervicis is one of the three parts of the semispinalis muscle. When acting bilaterally, this muscle extends the thoracic and the cervical spine. A unilateral contraction causes neck and trunk rotation to the opposite side. Multifidus is a longitudinal muscle and it can produce rotation, lateral flexion and extension at all the spinal levels. However, it seems that in the cervical region it is restricted to a rotational function. Nevertheless, multifidus seems to act mainly as a stabilizing muscle of the whole vertebral column. There are also muscles that rotate both the head and the neck. These muscles are the sternocleidomastoid and splenius capitis the function of which has been previously described. Lastly, rotation of the head on the neck can be performed by the inferior oblique and rectus capitis posterior major. Inferior oblique rotates the face to the same side. This muscle, similarly to any other short muscle of the cervical area, acts as an “active ligament” stabilizing the atlanto-axial joint (Palastanga et al, 2002).

The review of muscular functional anatomy reveals that each muscle has its own characteristics for corresponding to its functional role. Thus, cervical muscles can be classified according to their functional role as stabilizers or mobilizers. Stabilizer muscles are deep, mono-articular muscles with short levers and small moment arms or superficial muscles with broad aponeurotic insertions for a better distribution and absorption of force and load and act as leverage for load maintenance, static holding and joint compression. Their postural holding role is associated with an
eccentric deceleration or momentum resistance. Their dysfunction is associated with inhibition, excessive flexibility, laxity and weakness. Mobilizer muscles are superficial multi-segmental muscles with unidirectional fibres or tendinous insertions for better directing force for movement production. These muscles are responsible for repetitive or rapid movement and high strain loading and their dysfunction is associated with overactivity, reduced extensibility and excessive stiffness (Comerford and Mottram, 2001a). Cervical muscles can be also divided according to their load transfer role either to a local or a global muscle system. The local muscle system is composed of the deepest layer of muscles and its role is to control the spinal curvature and to maintain the mechanical stiffness of the spine for an appropriate inter-segmental motion. This system responds to postural changes and changes in low extrinsic load. The global muscle system is composed of superficial or outer layer of muscles lacking segmental vertebral insertions and it is able to produce large torques for movement production. This system responds to changes in the line of movement and changes in the magnitude of high extrinsic loads (Bergmark, 1989; Comerford and Mottram, 2001a). All of these classifications have led to the development of a combined classification of muscle roles. According to this, muscles can be classified as local stabilizers, global stabilizers or global mobilizers. The functional role of each muscle gives rise to important implications about the rehabilitation of its normal performance (Comerford and Mottram, 2001b).

Considering all of this information about neck muscles and their function, it can be observed that certain neck muscles such as sternocleidomastoids, trapezius and scaleni participate in both neck movement and inspiration. Furthermore, muscles such as the inferior and superior oblique and rectus capitis muscles (anterior, lateralis, posterior major and posterior minor) have a more stabilizing role contributing not only to the stability of cervical region, but also indirectly to the stability of the neighboring thoracic spine. Thus, deficits in the function of both mobilizer and stabilizer muscles may directly or indirectly affect chest biomechanics with a consequential change of force-length curves and adaptive changes of respiratory muscles (Kapreli et al, 2008). The association of neck biomechanics with respiratory function is more analytically described in Section 2.4 “Respiratory dysfunction in chronic neck pain”.
Table 2.1: Cervical muscles and their attachments (Palastanga et al, 2002).

<table>
<thead>
<tr>
<th>Muscle</th>
<th>Attachments (start point)</th>
<th>Attachments (end point)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Longus colli</strong></td>
<td>Lowest part: Front of the bodies of the T1-T3.</td>
<td>Lowest part: Anterior tubercles of the transverse processes of the C5-C6.</td>
</tr>
<tr>
<td></td>
<td>Middle part: Front of the bodies of the C5-T3.</td>
<td>Middle part: Front of the bodies of the C2-C4.</td>
</tr>
<tr>
<td></td>
<td>Upper part: Anterior tubercles of the transverse processes of the C3-C5.</td>
<td>Upper part: Anterior tubercle of the atlas.</td>
</tr>
<tr>
<td><strong>Sternocleidomastoid</strong></td>
<td>Sternal head: Upper part of the anterior surface of the manubrium sterni.</td>
<td>Lateral third of the superior nuchal line of the occipital bone.</td>
</tr>
<tr>
<td></td>
<td>Clavicular head: Upper surface of the medial head of the clavicle.</td>
<td></td>
</tr>
<tr>
<td><strong>Anterior scalenus</strong></td>
<td>Anterior tubercles of the transverse processes of the C3-C6.</td>
<td>Scalene tubercle on the inner border of the 1st rib.</td>
</tr>
<tr>
<td><strong>Longus capitis</strong></td>
<td>Anterior tubercles of the transverse processes of the C3-C6.</td>
<td>Basilar part of the occipital bone lateral to the pharyngeal tubercle.</td>
</tr>
<tr>
<td><strong>Rectus capitis anterior</strong></td>
<td>Anterior surface of the lateral mass of the atlas.</td>
<td>Basilar part of the occipital bone between longus capitis and the occipital condyle.</td>
</tr>
<tr>
<td><strong>Medius scalenus</strong></td>
<td>Transverse processes of the C1-C2. Posterior tubercles of the C3-C7.</td>
<td>Upper surface of the 1st rib behind the groove for the subclavian artery.</td>
</tr>
<tr>
<td><strong>Posterior scalenus</strong></td>
<td>Posterior tubercles of the transverse processes of the C4-C6.</td>
<td>Outer surface of the 2nd rib behind the attachment of serratus anterior.</td>
</tr>
<tr>
<td><strong>Splenius cervicis</strong></td>
<td>Spinous processes of the T3-T6.</td>
<td>Posterior tubercles of the transverse processes of the C1-C3 or C1-C4.</td>
</tr>
<tr>
<td><strong>Levator scapulae</strong></td>
<td>Transverse processes of the C1-C3 or C1-C4.</td>
<td>Medial margin of the scapula between the superior angle and the base of the spine.</td>
</tr>
<tr>
<td><strong>Splenious capitis</strong></td>
<td>Lower half of the ligamentum nuchae. Spinous processes of the C7-T4.</td>
<td>Posterior aspect of the mastoid process of the temporal bone.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Lateral third of the superior nuchal line.</td>
</tr>
<tr>
<td><strong>Trapezius</strong></td>
<td>Medial third of the superior nuchal line. External occipital protuberance of the occipital bone. Ligamentum nuchae</td>
<td>Upper border of the crest of the spine of the scapula. Medial border of the acromion. Posterior border of the lateral third of clavicle.</td>
</tr>
<tr>
<td>Muscle</td>
<td>Description</td>
<td>Attachments</td>
</tr>
<tr>
<td>---------------------------------------------</td>
<td>-----------------------------------------------------------------------------</td>
<td>-----------------------------------------------------------------------------</td>
</tr>
<tr>
<td><strong>Erector spinae</strong></td>
<td>Medial limb: Spinous processes of T11-L5 spreading on to their supraspinous ligaments and the median sacral crest. Lateral limb: Lateral sacral crest, sacroccygeal and posterior sacroiliac ligaments, posterior part of the iliac crest.</td>
<td>Iliocostalis: Inferior borders of the lower six ribs (lumborum), upper six ribs, transverse process of C7 (thoracis), posterior tubercles of the transverse processes of the C4-C7 (cervicis). Longissimus: Transverse and accessory processes of L vertebra, transverse processes of T1-T12, lower ten ribs (thoracis), transverse processes of T1-T6 and C2-C6 (cervicis), transverse processes of T1-T5, articular processes of C4-C7, mastoid process (capitis). Spinalis: Spinous processes of T11-L2 and T1-T6 (thoracis) (cervicis and capitis are poorly developed and are frequently blended with adjacent muscles).</td>
</tr>
<tr>
<td><strong>Rectus capitis lateralis</strong></td>
<td>Upper surface of the transverse process of the atlas.</td>
<td>Jugular process of the occipital bone.</td>
</tr>
<tr>
<td><strong>Rectus capitis posterior major</strong></td>
<td>Spinous process of the axis.</td>
<td>Lateral part of the inferior nuchal line of the occipital bone.</td>
</tr>
<tr>
<td><strong>Rectus capitis posterior minor</strong></td>
<td>Posterior tubercle of the atlas.</td>
<td>Medial part of the inferior nuchal line of the occipital bone.</td>
</tr>
<tr>
<td><strong>Superior oblique</strong></td>
<td>Upper surface of the transverse process of the atlas.</td>
<td>Interspace between the superior and inferior nuchal lines of the occipital bone.</td>
</tr>
<tr>
<td><strong>Multifidus</strong></td>
<td>Back of the sacrum and the fascia. Mamillary processes of the lumbar vertebrae. Transverse processes of the thoracic vertebrae. Articular processes of the C4-C7 or C3-C7.</td>
<td>Spines of all the vertebrae from the L5 to the axis.</td>
</tr>
<tr>
<td><strong>Inferior oblique</strong></td>
<td>Spinous process of the axis.</td>
<td>Posterior aspect of the transverse process of the atlas.</td>
</tr>
</tbody>
</table>

C: Cervical, T: Thoracic, L: Lumbar
2.2 Neck pain

Neck pain was for the largest part of the twentieth century of secondary interest in relation to low back pain. However, in the last twenty years, there has been an increasing interest and research in neuromusculoskeletal conditions causing neck pain. Neck pain currently rivals low back pain not only in frequency, but also in financial and social costs. The increasing incidence of neck pain during the twenty-first century may be accounted for by the advancement of technology which has led to a change in nature of work, by the increased use of motor vehicles or by the huge advancement and use of computers (Jull et al, 2008a).

Neck pain can be generally defined as “stiffness and/or pain felt dorsally in the cervical region somewhere between the occipital condyles and the C7 vertebral prominence” (Ferrari and Russell, 2003, p. 58). However, this definition does not imply that the cause of pain is in this area, but it is based only on where the pain is perceived (Bogduk, 2003a). The condition has been designated as neck pain, although in the past it was mostly known as cervical syndrome (Vlaikidis, 1995). The condition in the clinical context is also accompanied by pain referral to the upper thoracic region, dorsal spine regions, the jaw, the frontal-temporal region as well as to the shoulder and upper limb even in patients without any noticeable nerve root irritation or compression (Vlaikidis, 1995; Ferrari and Russell, 2003).

Neck pain is anatomically subdivided into upper and lower cervical spinal pain depending on whether the pain is located above or below an imaginary transverse line with which the cervical area is separated into two equal halves. Moreover, suboccipital neck pain, which is closely related with cervicogenic headache, is the pain located between the superior nuchal line and an imaginary transverse line passing through the second cervical spinous process (Figure 2.6) (Bogduk and McGuirk, 2006).
From the definition of neck pain, it becomes apparent that neck pain is perceived posteriorly. This is depicted to the fact that the most people describe the pain they experience on the front of their cervical spine as throat pain and not as neck pain. Nevertheless, some clinicians tend to use the term “anterior neck pain” in order to describe the pain felt anteriorly to cervical spine. However, the modifier “anterior” obviates a clinical condition which cannot be adequately described by the term “neck pain” by its own (Bogduk and McGuirk, 2006).

2.2.1 Epidemiology of neck pain

Neck pain is one of the most frequent musculoskeletal complaints and following low back pain is the second disorder in relation to annual workers compensation costs (Jull et al, 2008a). Neck pain is a symptom which has a higher incidence in women (Cote et al, 2003; Cote et al, 2004). The importance of this complaint is also depicted by the fact that 70%-80% of individuals suffer from neck
pain at some time in their lives (Cote et al, 2003; Ferrari and Russell, 2003; Jull et al, 2008a). However, 70%-80% of these patients suffer from mild neck pain, whereas only 20-30% experience pain of moderate or severe intensity. Disabling neck pain appears only in the 4.6% of population (Cote et al, 2003). Furthermore, at any time point approximately 10% of the population reports experience of neck pain for at least 7 days per month, whereas acute neck pain has an annual incidence of 20%-30% (Ferrari and Russell, 2003). The majority of the new episodes are described as mild and only a very small percentage presents disabling neck pain (Cote et al, 2004). The incidence of neck pain seems to differ among different geographic areas as Scandinavian countries present an one-year prevalence of neck pain of 36% in contrast to the remaining Europe where this percentage drops to 26% (Fejer et al, 2006). Neck pain may be also persistent and at least 22.8% of patients are expected to experience recurrent neck pain (Cote et al, 2004).

Webb et al (2003) provide information about the prevalence of neck pain in the United Kingdom. This general population study was performed with a sample collected from West Pennine, an urban area east of Manchester. According to the findings, neck pain appears to be second in prevalence following back pain. The prevalence of neck pain is higher in women and the one-month prevalence is estimated to be around 14%. This pain is intense in 7.8%, disabling in 7.5% and chronic in 5.9% of the population. 2.9% of this population also reported that they experienced a combination of intense, disabling and chronic pain.

In Greece, a population-based epidemiological study which was performed with a sample drawn from almost all over Greece (Andrianakos et al, 2002) leads to the conclusion that neck is the second most common pain body area following the back. The prevalence of neck pain was found to be about 4.8%. The lower percentage in comparison to the United Kingdom may be justified by the fact that Andrianakos et al (2002) only included patients with recurrent pain and radiological signs of spinal osteoarthritis, disc herniation, spondylolysthesis or any other chronic cause. Thus, it is apparent that patients with non-recurrent pain and many patients with postural neck pain may have been excluded. The prevalence in women was also higher than the prevalence in men. Neck pain prevalence was not found to be different between urban, suburban and rural areas. However, in urban areas neck pain had a higher prevalence in younger and middle-aged participants, whereas in rural areas neck pain had a higher prevalence in older participants. This finding may depict the fact that
people in rural areas mostly work in farms performing more physical work whereas people in cities have more sedentary occupations. Thus, people in urban areas may have mostly postural neck pain which appears in younger ages, whereas the work of people in rural areas may lead to spinal stress and this population may be more prone to arthritis which mostly develops in older ages.

### 2.2.2 Risk factors for neck pain

There is a great variety of factors that have been recognized to predispose to neck pain. Risk factors can be classified either as aetiological or as prognostic. Aetiological risk factors are factors that predispose asymptomatic individuals to neck pain, whereas prognostic risk factors are factors that predispose patients with acute to chronic neck pain (Bogduk and McGuirk, 2006). Aetiological risk factors may be psychosocial, mechanical or occupational in origin. Stress, depression, poor general health, female gender, obesity, neck injury history and high number of children have been recognized as significant risk factors for neck pain. Duration of sitting, twisting and bending as well as high quantitative job demands and low co-worker support have been also recognized to be related with neck pain occurrence (Ferrari and Russell, 2003). Bogduk and McGuirk (2006) recognize educational level, occupation, injury history, working with machines and stress at work as the most important aetiological factors, but refute smoking, socioeconomical status and prolonged sitting at work as significant factors. The authors explain the disagreement as a result of the fact that some factors appear to be significantly related to neck pain, but when are not looked at in isolation and multivariate analysis is performed they become insignificant. This fact shows that these factors indirectly related to neck pain and are themselves a product of more powerful factors. The same authors also conclude that there are no validated prognostic risk factors for neck pain, although they conclude that high initial pain intensity is the most important prognostic factor in whiplash injuries.
2.2.3 Neck pain mechanisms

Pain can be generally described as “an unpleasant sensory and emotional experience associated with actual or potential damage of a tissue or described in terms of such damage” (Seaman and Cleveland, 1999, p. 459). Pain can be experienced in the neck by different neurophysiologic mechanisms. According to the neck pain mechanism, pain can be classified as nociceptive, neuropathic or psychologic (Seaman and Cleveland, 1999). A clear understanding of the neck pain mechanisms can provide a sound scientific background for understanding the experienced problem and appropriately design therapeutic protocols.

Nociceptive pain

Nociception is in reality the physiologic component of pain (Figure 2.7). It normally serves as a protective mechanism when an intense noxious stimulus threatens to cause a tissue injury (Lamont et al, 2000). However, nociceptive pain may also arise when there are any injuries or diseases of somatic tissues or viscera such as of muscles, bones, joints or ligaments (Bogduk, 2003b) and is the most common type of pain met in clinical practice. Spinal nociceptive pain is usually described as deep, tender, dull, aching and diffuse (Seaman and Cleveland, 1999).

Nociceptive pain results from encoding of mechanical, thermal or chemical irritation into electrical impulses carrying this information to the Central Nervous System (CNS). This encoding is performed by specialized nerve endings called nociceptors (Lamont et al, 2000). Nociceptors can be found in any paraspinal tissue including skin, subcutaneous tissue, blood vessels, spinal joints, vertebral bones, spinal ligaments, dura matter, annulus fibrosus and fibro adipose tissue (Seaman and Cleveland, 1999). Skin nociceptors include either thinly myelinated Aδ fibers or unmyelinated C fibers (Bement and Sluka, 2007). Aδ fibers are believed to be mainly responsible for the “first pain” lasting only as long as the painful stimulus is activating the nociceptors. C fibers are considered mainly responsible for the “second pain” where pain persists beyond the termination of the nociceptors stimulation (Lamont et al, 2000). Nociceptive information is also carried from the afferent fibers of muscles.
and joints. This is performed either by the thinly myelinated afferents of group III or by the unmyelinated afferents of group IV fibers (Bement and Sluka, 2007).

Figure 2.7: Pain transmission.

This figure represents the transmission of pain signals from the peripheral nerve endings to the higher brain centers via the spinothalamic tract (Reproduced from Voight L.V., Hoogenboom B.J. and Prentice W.E. (2007). Musculoskeletal interventions; techniques for therapeutic exercise. U.S.A.: McGraw Hill, with permission)

A tissue injury may create noxious mechanical irritation and leads to a release of various chemical mediators of inflammation and nociception (Seaman and Cleveland, 1999). These chemical mediators can sensitize the related nociceptors leading to a phenomenon called “sensitization”. Sensitization is referred to an increase of spontaneous activity of nociceptors, a decrease in the pain threshold, an increase in
the responsiveness to this noxious stimulus or in changes of the receptive field size (Bement and Sluka, 2007). The sensitization may lead to some exaggerated pain conditions such as allodynia which is pain experienced by a stimulus which is normally non-painful and hyperalgesia which is an exaggerated pain experience produced by a stimulus which is usually painful (Seaman and Cleveland, 1999).

After the encoding of the stimulus into an electrical signal, this signal is transmitted to the spinal cord through the afferent axons that were previously discussed. The speed of transmission is different between these two afferent axons as the Aδ afferent fibers are thinly myelinated and have larger diameter conducting the impulses more rapidly. However, the slower conduction of the unmyelinated C fibers acts to reinforce the response of the Aδ fibers leading to a bigger duration of the stimulus (Lamont et al, 2000).

The travel of the nociceptive information from the periphery to the spinal cord finishes at the cell bodies of the afferent nerve fibers which are found on the dorsal root ganglia and their axons are extended to synapse with the dorsal horn neuron of the spinal cord (Lamont et al, 2000). In general, lamina I to VI constitute the part of the dorsal horn where the most of the afferent information terminates (Bement and Sluka, 2007). The most of the Aδ fibers terminate in the most superficial lamina I whereas a small percentage reach more deeply to lamina V. Most of the C fibers project to the lamina II which is widely known as the substantia gelatinosa. The afferent axons directly or indirectly connect to a) interneurones which participate in local processing, b) propriospinal neurons which are related to the segmental reflex activity and c) projection neurons which are the neurons responsible for the transmission of nociceptive information beyond the spinal cord to higher neural centers. These projection neurons can be also divided in a) nociceptive specific neurons which are stimulated only by the two afferent neural fibers and are concentrated on lamina I, b) wide dynamic range neurons which receive not only nociceptive information, but also innocuous stimuli from low-threshold mechanoreceptors and are predominant in lamina V and c) complex neurons found in lamina II that are not a well-studied neuronal group, but it is believed that their function is related to the integration of somatic and visceral afferent activity. The transmission of nociceptive information between neurons is performed through chemical signals mediated by excitatory and inhibitory neuropeptides and amino-
acids which are produced, stored and released in the terminals of afferent nerve fibers and dorsal horn neurons. Furthermore, the phenomenon of sensitization may also happen in this level (central sensitization) since sustained afferent impulses lead to changes of the response characteristics in the dorsal horn neurons (Lamont et al, 2000).

This neural level is also believed to be responsible for somatic referred pain (Figure 2.8). Somatic referred pain is a phenomenon where the pain is experienced in a body region innervated by nerves other than the ones that innervate the source of pain (Bogduk and McGuirk, 2006). Although there is no absolutely acceptable theory about the generation of somatic referred pain, the most prominent theory is convergence. According to this theory, an afferent from a spinal structure may converge on the same dorsal horn neurons that receive inputs from other body areas such as the head, upper limb, chest wall and interscapular region (Bogduk, 2003b; Bogduk and McGuirk, 2006). However, the cerebral cortex cannot differentiate between the origins of these inputs and consequentially ascribes the spinal afferent to whichever body area from the regions related to these dorsal horn neurons (Bogduk, 2003b). In reality, patterns of somatic referred pain are due to the segmental location of the primary source of pain. It has been observed that when the source is on the lower cervical area the referred pain appears to the anterior chest wall, interscapular region or upper limb, whereas when the source is on the upper cervical area referred pain appears in the head (Bogduk and McGuirk, 2006). Besides the convergence theory, there are also other theories explaining somatic referred pain. The older sclerotogenous referred pain theory is not conclusive, because although somatic referred pain follows a sclerotomal pattern of distribution, in clinical practice patients do not always fit to the pain maps provided by such a theory (Seaman and Cleveland, 1999). An alternative theory is the cord spillover theory. According to this theory, when an excessive pain signal enters the spinal cord, there is a spillover of this electrical signal to interneurones that come from innocent body areas. After this spillover, these other interneurones transmit pain signals to the brain which recognizes these innocent areas as painful. Another theory is that referral pain patterns occur in body areas that share a common embryologic origin, as the brain may have a mapping that continuous linking these areas (Muscolino, 2009). Nevertheless, although many
theories have been developed, convergence theory provides the soundest rationale and is the widely accepted theory for explaining somatic referred pain.

From the spinal cord pain signals are transmitted to supraspinal centers through projection neurons that directly or indirectly receive afferent information through interneurones. The spinothalamic tract is the most important of the ascending pathways for pain perception (Figure 2.7). The spinothalamic tract extends from the nociceptive specific and dynamic range neurons to the thalamus. The axons of spinothalamic tract may project either to lateral thalamic nuclei for the transmission of information from smaller and more discrete receptive fields or to medial thalamic nuclei for the transmission of information from larger and more diverse receptive fields. The latter are implicated in the motivational-affective pain component (Lamont et al, 2000; Bement and Sluka, 2007).

Figure 2.8: Somatic referred pain.


Besides the spinothalamic tract, there are also other tracts related to pain transmission. The first is the spinoreticular tract which mainly projects to nuclei throughout reticular formation, although some of them ascend to the thalamus. This
tract is mainly related to descending modulation of pain. The second is the spinohypothalamic tract which projects to hypothalamus and is related to the activation of the motivational component of pain and the initiation of autonomic responses (Lamont et al, 2000; Bement and Sluka, 2007).

Many supraspinal centers have been recognized to be related with the pain perception as nociceptive neurons have been found in the brainstem (medulla, pons, midbrain), diencephalon (thalamus and hypothalamus) and cerebral cortex. The brainstem plays an important role in nociceptive perception due to its connection to the reticular system and periaqueductal gray matter. The periaqueductal gray matter plays an important role on the descending modulation of pain and provides an alternative indirect pathway for pain signal transmission to the diencephalon. The reticular formation is a compilation of isodendritic neurons and sends collaterals to the spinal cord, other reticular neurons, sensory and motor nuclei of brainstem, diencephalon and cerebral cortex. The reticular system is very important for the integration of pain experience due to the fact that nociceptive signals stimulate reticular neuronal activity. Its ascending neurons mediate the affective-motivational dimension of pain due to their projections to medial thalamus and limbic systems. The limbic system influences the motivational component of pain and helps to the determination of purposeful behavior. The thalamus includes numerous nuclei and is a very important relay station for transmission of the pain signals to the cerebral cortex. The transmission of pain signals to the cerebral cortex plays a critical role in pain perception. The first and second somatosensory cortex, anterior insular cortex and anterior cingulated are all cortical areas that are targets for nociceptive information (Lamont et al, 2000). The primary and secondary somatosensory cortex are believed to be reliable for discriminating and localizing the pain stimulus, whereas anterior cingulated and anterior insular cortices are believed to mediate the motivational-affective dimensions of pain (Bement and Sluka, 2007).

Finally, pain is perceived after its modulation by a complex neuronal system. The most important of this system is the periaqueductal gray matter of the midbrain. The periaqueductal gray matter receives descending signals by cortex, amygdala and hypothalamus and ascending projections by medulla, reticular system and spinal cord. Its antinociceptive effects are believed to be mediated by opioids released as a result of periaqueductal gray matter stimulation. However, despite the importance of
periaqueductal gray matter for pain modulation, the contribution of rostral ventromedial medulla and pons, of cortical and thalamic structures as well as of spinal cord dorsal horns should not be underestimated (Lamont et al, 2000). The harmonic action of these inhibitory pathways lead to what is known as “endogenous analgesia system” (Bement and Sluka, 2007).

**Neuropathic pain**

Neuropathic pain can be generally defined as pain deriving from damage of the peripheral and central nervous system (Lamont et al, 2000). However, sensitization of C fibers is not included in the definition of neuropathic pain as this phenomenon is typically related to non-neural structures (Seaman and Cleveland, 1999). The prevalence of neuropathic pain has been found to be about 6.9% and it becomes more frequent in ages of more than 50 year-old (Bouhassira et al, 2008). This pain is usually described as intermittent, sharp, jabbing or lancinating with an accompanying burning and tingling sensation. Neural lesions may occur either peripherally or centrally classifying neuropathic pain either as peripheral or central neuropathic pain respectively (Seaman and Cleveland, 1999).

Peripheral neuropathic pain is generally generated when the axons of a peripheral nerve are stimulated in a point along their course by injury, mechanical irritation or inflammation (Bogduk, 2003b). An acute injury discharge may send an abnormal signal from axotomized afferent fibers. This discharge lasts for about 10 or more seconds and the collective effects lead to a massive abnormal signal which is transmitted to the CNS. This signal leads not only to an experience of intense pain, but also to neuroplastic changes in dorsal horn neurons. Some days after the initial injury discharge, a second wave of abnormal peripheral input is generated. The origination of the ectopic activity of this second abnormal input is located in the injured axons, the proximal axonal stump and the cell bodies in the dorsal root ganglion. This discharge is chronic and may reflect abnormal sensitivity to various stimuli (Lamont et al, 2000). Although, these signals are generated mainly from the axons, they are perceived as originating from the territory subtended by the injured nerve (Bogduk, 2003b). Peripheral neuropathic pain typically involves conditions
such as compression of nerve roots or dorsal root ganglia, entrapment of peripheral nerves, post herpatic neuralgia, tumor invasion, avulsion injuries, diabetic neuropathy and other metabolic, toxic and nutritional neuropathies (Seaman and Cleveland, 1999). A usual type of neuropathic pain is the cervical radicular pain which is a different phenomenon from cervical radiculopathy, although they occur concomitantly and are erroneously considered as the same condition (Bogduk, 2003b).

Cervical radiculopathy is a condition where there is a blockage of the conduction in spinal nerve axons by a problem which affects the nerve roots. The causes of this condition are considered to be any lesion that encroaches on the cervical nerve root or affects its blood supply. The most usual causes of cervical radiculopathy are cervical disc bulges and foraminal stenosis whereas tumors, nerve root cysts, angioma and arteritis are more rare causes of this condition. Cervical radiculopathy is most usually recognized by its clinical demonstration. When the dorsal root is affected numbness is presented in a dermatomal distribution. When the problem is on the ventral root there is weakness on a myotomal distribution. Reflexes may also be affected due to an interruption of the afferent or efferent arc, whereas paraesthesia is also apparent when the disorder is able to compromise the blood supply of the nerve root (Bogduk, 2003b).

Cervical radicular pain is caused by a disorder or irritation of a cervical nerve root. However, it is a different condition from cervical radiculopathy in terms of mechanisms and clinical presentation. Radicular pain is not due to a conduction block like radiculopathy. In reality this condition is the result of the ectopic generation of nociceptive impulses caused either by compression of a dorsal root ganglion or by inflammation of the nerve root. Furthermore, in contrast to radiculopathy, cervical radicular pain does not have numbness and paraesthesia following a dermatomal distribution. Radicular pain has a widespread distribution and is experienced extensively around the shoulder without any relationship to the corresponding dermatome. The fact that radicular pain may not be exclusively cutaneous may be justified by the fact that after an irritation of a cervical nerve root, the afferents of the deep somatic tissues it transmits are also affected. Thus, this pain is mainly felt in the tissues subtended by the affected nerve root. However, such a clinical pain behavior may lead to its confusion with somatic referred pain. The main characteristic for
discriminating between them is when pain radiates further distally in the upper limb, as somatic referred pain cannot extend beyond the upper arm (Bogduk, 2003b).

Besides peripheral, central neuropathic pain is also implicated as a mechanism of neck pain. Central neuropathic pain appears when the neurons found in the thalamus or dorsal horn are deafferentated or disinhibited and become spontaneously active. This condition may occur as a result of ischemia to the CNS or disruption of peripheral nerves or central tracts. These abnormalities have as a result the neurons to which the injured tracts or nerves previously relayed cease to maintain receptors, their membranes become unstable and they spontaneously activate (Bogduk, 2003b). Central neuropathic pain includes conditions such as spinal cord and cerebral vascular lesions, multiple sclerosis and other inflammatory lesions, viral myelitis, epilepsy, Parkinson’s disease, traumatic brain injury, spinal cord injury, cordotomy, syringomyelia, abscesses and tumors (Seaman and Cleveland, 1999). Brachial plexus avulsion is considered the most characteristic example of central pain in the cervical area. Syringomyelia is another condition that is technically considered a possible cause of cervical central pain and differs from brachial plexus avulsion in that peripheral afferents are intact. Pain from brachial plexus avulsion is almost exclusively observable when the avulsion of roots is proximal to the ganglion and it is of burning quality which is characteristic of central pain (Bogduk, 2003b).

Sympathetically Maintained Pain (SMP) is related to the involvement of sympathetic nervous system in pain recognition (Markenson, 1996). Although SMP is usually discussed with neuropathic pain due to its neural nature, this system is also related to nociceptive pain due to increase of tissue inflammation. Nowadays, for appropriately characterizing this condition, SMP is called Complex Regional Pain Syndrome (CRPS) which discriminates into CRPS I and CRPS II. CRPS I is related with reflex sympathetic dystrophy and CRPS II with causalgia which is a syndrome developing after an apparent nerve injury and involving large nerves such as the median nerve. Pain, oedema, blood flow abnormalities and abnormal sudomotor activity are characteristic signs of this condition (Seaman and Cleveland, 1999). The most important mechanism of this condition is that the continuously incoming afferents hypersensitize the dorsal horn of the wide dynamic range neurons. These neurons are connected with the lateral horn cells of the sympathetic system and after their hypersensitization send motor commands for vasoconstriction and peripheral
ischemia leading to hyperalgesia. Furthermore, the nerves that were previously unresponsive to sympathetic stimulation can now be excited due to changes induced in intact sensory nerves by injury (Markenson, 1996). In short, this condition could be characterized by the action of the sympathetic system which releases pro-inflammatory substances and contributes to development, severity and potentially to prolongation of the injury of tissue (Seaman and Cleveland, 1999).

**Psychologic pain**

Psychologic pain is the less investigated pain mechanism and is usually ignored in discussions about pain generation. Psychologic pain may be generated not only psychologically, but also as a result of tissue injuries and nociceptive mechanisms. This is the reason why the term “psychologic” seems to be preferable to “psychogenic” which prerequisites only the psychologic component of pain. The definition of pain as a psychologic state has as a result this psychologic component to be always apparent in nociception and neuropathic pain. Pain has been found to arise as a result of psychologic illness or of certain emotional factors. Anxiety and depression are known psychologic states that contribute to the pain development. The physiological mechanisms with which anxiety and depression may lead to pain promotion and enhancement are not well understood, but sound theories have been proposed, and it has been found that a reduction in anxiety and depression can lead to pain reduction (Seaman and Cleveland, 1999). Current evidence suggests that kinesiophobia and catastrophizing are also psychological states that associated with pain development, but their role is less understood (Sullivan et al, 2001; Branstrom and Fahlstrom, 2008).

Anxiety may change the reticular activity enhancing the supraspinal transmission of nociceptive signals. More specifically, anxiety can increase the level of adrenaline. The release of adrenaline leads to a stimulation of β₂-receptors leading to a pro-inflammatory cascade of events increasing the pain experience. Furthermore, anxiety is believed to affect the autonomous nervous system resulting in vasoconstriction of some muscle areas and promoting muscle injury. Anxiety may
also influence vessels and muscles via the central nervous system as it is associated with their function (Seaman and Cleveland, 1999).

Depression is also considered an important psychological state increasing the pain experience via a reduction of the activity of descending inhibitory pathways. Furthermore, increase in pain experience may arrive in a way similar to anxiety as depression is also hypothesized to affect autonomous nervous system resulting in vasoconstriction and promoting muscle injury (Seaman and Cleveland, 1999).

Kinesiophobia is also related with adrenaline release (Henry, 1986) with similar consequences to anxiety in terms of increased pain perception. Furthermore, kinesiophobia may lead to avoidance of movement and activities due to fear of pain or reinjury. This maladaptive response may lead to exaggeration of pain perception, immobility-based physiological consequences such as fibrosis and atrophy of the related injury and finally to prolonged disability (George et al, 2001; Landers et al, 2008).

Finally, catastrophizing may lead to more intense pain experience and increased emotional distress. The real reason for this psychological state is not absolutely understood and it is usually viewed as a cognitive distortion, as a belief, as an appraisal process, as an attentional process or as a coping strategy. Catastrophizing is closely related to the development of kinesiophobia since a tendency to catastrophize may lead pain sufferers to further restrain from movements and activities and it is usually believed that its contribution to prolonged pain and disability is based on this indirect effect (Sullivan et al, 2001).

2.2.4 Classification of neck pain

The classification of neck pain is a point of discussion among researchers. Beside its classification according to the pain mechanism (nociceptive, neuropathic, psychological), which has been already discussed in the previous section, neck pain has been also classified according to its chronicity and causes. This section is aimed at discussing how neck pain is classified according to these criteria.
Classification according to chronicity (acute – chronic)

Neck pain can be classified according to its chronicity as acute or chronic, and many times a subacute phase is also described. However, whilst chronic neck pain can be described as pain that persists after a normal healing time, there is a discrepancy in the literature about the duration of this time (Verhaak et al, 1998). Although this definition depends to a great extent on the decision of each researcher, chronic neck pain is mostly defined as a persistent pain for more than 3 or 6 months (Lamont et al, 2000). One of the most usual definitions of chronic neck pain is the one provided by Nachemson and Jonsson (2000). According to them, acute pain has 0-3 weeks duration of pain, it is considered subacute until the 12th week and if it persists for more than 12 weeks it is considered to be chronic. However, Jensen and Harms-Ringdahl (2007) consider that this classification is problematic as most of the patients with recurrent pain episodes are classified as chronic neck pain sufferers. Nevertheless, although the time point of three months is considered by most researchers as the critical point for the transition to chronic neck pain, the selection of an at least 6 month history of neck pain in order for the patients to be classified as chronic sufferers may be more generally accepted. Thus, the criterion of a six month history of neck pain with pain complaints at least once per week seems to be an appropriate criterion for classifying neck pain patients as chronic.

Acute neck pain usually derives from damage to soft tissues or inflammation. Acute pain serves an adaptive role by facilitating tissue repair and healing. This function may be achieved by hypersensitization of the injured area and the surrounding tissues so that any external stimuli are avoided and the reparative phase continues without any disturbance (Lamont et al, 2000). The prognosis of acute neck pain is highly favorable. Within ten years, the 43% of patients with acute neck pain are expected to fully recover, whereas 25% is expected to retain only mild symptoms. Furthermore, only 7% of these patients is expected to complain about severe neck pain (Bogduk and McGuirk, 2006).

Despite the care provided to the patients with acute neck pain, it is estimated that 20% of them will continue to have pain and sometimes this percentage may reach to 40% (Bogduk and McGuirk, 2006). Chronic pain is maladaptive and usually arises...
from sustained noxious input such as a chronic inflammation, but it may also be autonomous without any temporal association with the inciting cause (Lamont et al, 2000). Chronic neck pain is also different from acute pain in terms of having no useful biologic function or survival advantage leading to suffering, restriction of daily activities and increase of healthcare costs (Markenson, 1996).

Classification according to causes (idiopathic – whiplash)

Many conditions have been recognized as potential causes of neck pain. Bogduk and McGuirk (2006) describe in a very analytical and evidence-based manner the potential causes of neck pain. Vertebral tumors, discitis, septic arthritis, osteomyelitis, meningitis, epidural abscess and epidural hematoma are considered serious but rare cases of neck pain as their prevalence is estimated to be below 0.4%. Rheumatoid arthritis, ankylosing spondylitis, crystal arthropathies including gout, polymyalgia rheumatic, longus colli tendonitis, fractures and synovial cyst are also unusual cases of neck pain. Some of these diseases are not necessarily unusual, but they are systemic disorders that rarely affect the neck. Torticollis is another recognized condition leading to neck pain (Bogduk and McGuirk, 2006).

Diffuse idiopathic skeletal hyperostosis, ossification of the posterior longitudinal ligament, Paget’s disease, spondylosis and osteoarthritis are other potential causes of neck pain. However, Bogduk and McGuirk (2006) consider that the latter diseases are causes of questionable validity as there is evidence to suggest that these conditions do not lead to neck pain namely, that these degenerative changes occur with increasing age and in asymptomatic individuals and secondly because studies have failed to give consistent results about the significance of this disease as a predictor of neck pain. This conclusion and especially about spondylosis and osteoarthritis is really challenging as it is usual in clinical practice to associate degenerative joint diseases with pain.

Neurological conditions such as thoracic outlet syndrome, spinal cord tumors, nerve injuries, myelopathy and radiculopathy are also associated with neck pain. However, Bogduk and McGuirk (2006) also dispute the appropriateness of their acceptance since their cardinal presentation is loss of neurological function and not
neck pain. Neuromas and aneurysms, although uncommon, are the only neurological and vascular cases accepted as legitimate causes of neck pain.

Soft-tissue injuries, whiplash, cervical strain, psychogenic, postural disorders, fibrositis, myofascial pain, hyoid bone syndrome, sternocleidomastoid tendonitis and fibromyalgia are considered spurious or vague causes of neck pain. More specifically, in the absence of fracture, soft-tissue injury means nothing more that something has been injured. Whiplash describes only the injury mechanism and origin of pain and not its cause and course. Cervical strain is a totally vague definition which means nothing more that something is wrong with the neck producing pain. Psychogenic neck pain lacks diagnostic criteria and is usually applied when no other diagnosis has been recognized. Fibrositis and myofascial pain are not valid and reliable in terms of neck pain, and sternocleidomastoid and longus colli tendinitis has no valid diagnostic criteria. The contribution of bad postural habits to pain development is ambiguous and may be sometimes secondary to pain. Fibromyalgia is not a diagnosis that can be applied to patient with neck pain alone as it also prerequisities pain in other regions of the body. Finally, hyoid bone syndrome lacks valid diagnostic criteria since its diagnosis, based on the anesthetization of the greater horn of the hyoid bone has not been validated (Bogduk, 2003a; Bogduk and McGuirk, 2006).

It is estimated that 95% of neck pain patients may have a benign diagnosis such as mechanical neck pain, postural neck pain, muscular neck pain, neck sprain and myofascial pain syndrome. However, although such a benign diagnosis may be good for the patients in terms of mortality, their vagueness may lead patients and clinicians to search for a more clear pathological understanding of this pain (Ferrari and Russell, 2003). Thus, it seems a better classification of neck pain could be according to its pathologoanatomical causes. However, a pathologoanatomical diagnosis of neck pain is difficult to perform partially due to the central convergence phenomenon, the complexity of the innervations as well as the number of conditions which share similar symptomatology (Merrill, 1997).

Bogduk and McGuirk (2006) note that after discussing the causes of neck pain an interesting dichotomy arises. The first group of causes includes the detectable, serious but rare conditions (tumors, infections, crystal arthropathies, fractures, aneurysms and neuromas) and the other group includes common, non-serious and spurious or unknown causes (unknown, strain, whiplash). The authors argue that
when a pathologoanatomical diagnosis is not available, neck pain may be characterized either as “cervical spinal pain of unknown origin” which reflects a situation where pain comes from the cervical spine, but there is a lack of specific diagnosis or as “acceleration-deceleration injury” which does not presuppose a distinctive cause of pain, but it recognizes cervical pain with a particular attributed cause. This classification is in accordance with International Association for the Study of Pain. In contrast, the terminology used by the Australian Acute Musculoskeletal Pain Guidelines (2003) is “whiplash-associated neck pain” for pain attributed to trauma mainly caused by a motor vehicle accident and “idiopathic neck pain” for neck pain of no apparent cause. This latter classification is widely used and accepted in neck pain literature. However, Jull et al (2008a) argue that although this classification offers a convenient method for discriminating neck pain sufferers, it has the drawback that it falsely assumes some homogeneity for the different categories of neck pain and that offers little assistance to the individual management of neck pain.

2.2.5 Neck pain related conditions

Although neck pain is an entity on its own, it is usually related with conditions that necessitate special consideration and understanding in order to appropriately orientate the therapeutic approaches.

Whiplash-associated disorders are a common disabling condition that may occur after a motor vehicle collision (Jull et al, 2008a). In older years it was believed that the mechanism of whiplash was based on a simplistic flexion-extension model. However, it is currently believed that whiplash mechanism is more complex and is mostly a compression injury (Bogduk and McGuirk, 2006) leading to damage of zygapophyseal joints, intervertebral discs, vertebra, synovial folds, ligaments and nerve tissue (Jull et al, 2008a).

Although whiplash injuries share a quite similar clinical presentation to idiopathic neck pain, they can be differentiated due to some unique clinical manifestations. The first is the fact that whiplash patients may present central hyperexcitability. This differs from a simple hypersensitivity to nociceptive input to the fact that it additionally includes a decrease in pain threshold to pressure, vibration
and temperature stimuli. The second characteristic manifestation of whiplash is the more eminent psychological distress which may develop in post-traumatic stress necessitating psychological referral (Jull et al, 2008a).

Cervicogenic headache has been defined as “pain that is perceived in the head but whose source is actually in the cervical spine or which is innervated by cervical nerves” (Bogduk and McGuirk, 2006, p. 141). Cervicogenic is a secondary headache and is a different entity from primary headaches such as migraine, tension-type and cluster headache. However, the differential diagnosis of cervicogenic headache may be quite difficult considering the symptoms overlap between the different headache types (Jull et al, 2008a). Cervicogenic pain is predominantly nociceptive in origin as the sensory axons of 1st, 2nd and 3rd cervical nerves may converge on the neurons of the dorsal horns which also receive afferents from the trigeminal nerve and this convergence results in pain mediated by these cervical nerves. The most usual sources of cervicogenic headache include the lateral atlanto-axial joint, 2nd-3rd zygapophysial joints and 2nd-3rd discs, but the actual origin is not always possible to ascertain (Bogduk and McGuirk, 2006).

Cervicobrachial pain is a term used to describe cervical spinal pain in parallel with shoulder, arm or hand pain, whereas headache may also be a related symptom. Patients with such a condition present lower levels of general health and quality of life in comparison with patients who suffer only by neck pain. The cervicobrachial pain may be either somatic referred pain or neuropathic pain. The neurophysiologic mechanisms of both conditions have been already analytically described in Section 2.1.2 “Neck pain mechanisms”. However, vascular compromise with a consequential cyanosis in the periphery, edema and impaired capillary refill might also be included and is usually observed in thoracic outlet syndrome (Jull et al, 2008a).

### 2.2.6 Manifestations of neck pain

Neck pain is a multidimensional complaint which is accompanied by a number of other disabling symptoms. Sensory disturbances, changes in cervical muscle function, alteration of cervical sensorimotor control, disturbances in postural stability and head and eye movement control and psychosocial distress are usual
manifestations of neck pain. These manifestations may be presented in a different way in idiopathic neck pain and whiplash-associated disorders and their different nature should be carefully considered when discussing neck pain manifestations (Jull et al, 2008a).

**Sensory function**

Local cervical spine hyperalgesia is one of the sensory manifestations of both idiopathic neck pain and whiplash. This type of hyperalgesia is attributed either to the sensitization of peripheral nociceptors located in the injured structures of cervical spine or to the central sensitization of nociceptive pathways. Referred pain to other body regions is another sensory manifestation of neck pain and has analytically described in Section 2.1.2 “Neck pain mechanisms”. Generalized sensory hypersensitivity is another sensory disturbance presented in whiplash patients. In contrast to a simple local hyperalgesia, this disturbance is more widespread and may occur in many body areas including both upper and lower limbs. Thus, whiplash patients usually have lowered pain thresholds for heat, cold and pressure stimuli in areas which are not found close to the cervical area. Allodynia which is the sensation of pain from a normally non-painful stimulus is also considered a sensory disturbance observed in whiplash patients. The generalized sensory hypersensitivity and allodynia are attributed to hyperexcitability of the central nervous system. This hyperexcitability may be the result of sensitization of the spinal cord or of a loss of endogenous mechanisms of pain control. Cold hyperalgesia and altered activity of the sympathetic nervous system are also sensory disturbances that seem to be observed only in whiplash and not in idiopathic neck pain. These sensory disturbances are associated with neuropathic pain and may justify the notion that whiplash and cervical radiculopathy have similar mechanisms. The same happen with hypoesthetic changes in whiplash patients which potentially indicate dysfunction of Aβ and C fibres. The recognition of sensory disturbances is important not only in terms of assessment and management, but also because their existence is indicative for a poor outcome (Jull et al, 2008a).
Muscle function

Neck pain is accompanied by a multidimensional muscular dysfunction (Figure 2.9). Patients with neck pain present decreased muscle strength and endurance of both their neck flexors and extensors muscles (O’Leary et al, 2007; Rezasoltani et al, 2010). Alterations in cervical motor control have also been observed. More specifically, in neck pain there is an inhibition of deep cervical flexors (longus colli, longus capitis), whereas superficial neck flexors (sternocleidomastoid, anterior scalene) present increased activation. This observation reveals the compensatory role of superficial neck flexors in impairments of deep neck flexors (Falla, 2004). Although the neck flexors are the muscle group which has been mostly examined, the muscle activity of neck extensors is also increased (Johnston et al, 2008a). Patients with neck pain also present reduced ability to relax their superficial neck flexors and extensors after activation and this may indicate deficits in the sensory system or a change of the descending drive to the motor neuron pool (Falla and Farina, 2008). The feed-forward adjustments are also impaired in patients with neck pain. More specifically, the ability of cervical muscles to quickly co-activated after a postural perturbation is impaired, since superficial and mainly the deep neck flexors have been found to have a delayed onset. This impairment may finally leave the cervical spine prone to stain and further injury (Falla, 2004).

Peripheral adaptations are also apparent in cervical muscles of patients with neck pain. A significant increase in type IIC fibers has been observed in ventral and dorsal neck muscles of patients with neck pain. This is consistent with the transformation of slow-twitch oxidative type I fibers to fast-twitch glycolytic type IIβ fibers resulting in the reduced endurance of the cervical muscles in patients with neck pain (Uhlig et al, 1995). Atrophy and connective tissue infiltration of deep suboccipital muscles have also been documented (Elliott et al, 2006). Although this fatty infiltration is widespread along the cervical muscles, deeper muscles such as rectus capitis and multifidus are mostly affected (Jull et al, 2008a). Finally, disturbed mitochondrial function, reduced adenosine-triphosphate (ATP) content and reduced capillary-to-fiber ratio have also been observed in upper trapezius of people with trapezius myalgia (Kadi et al, 1998; Jull et al, 2008a). These changes may be related with the overload of low-threshold motor units (Jull et al, 2008a). These peripheral
adaptations of neck muscles provide confirmation and are in agreement with the electromyographic activity of neck muscles during neck pain (Falla and Farina, 2008).

Figure 2.9: Muscular dysfunction in neck pain.

This figure presents the effects of neck pain in muscle properties and motor control (Based on information provided by Falla and Farina (2008) and reproduced from Jull G., Sterling M., Falla D., Treleaven J. and O’Leary S. (2008a). Whiplash, headache and neck pain: research-based directions for physical therapies. China: Churchill Livingstone, with permission).

Although the cause-effect relationship between pain and motor control changes is not absolutely clarified, it seems that pain is one critical factor leading to changes in motor control of cervical muscles. Considering that nociceptors project into spinal motor neurons and the sensorimotor cortex, it becomes obvious that pain has a direct influence on motor neuron output through neuroplastic changes in the central nervous system with consequential changes in motor planning and muscle control (Jull et al, 2008a). Pain can lead to an inhibition of cervical muscles when they act as agonists. Furthermore, pain results in a dynamic reorganization of the coordination of cervical muscles. This reorganization is initially a useful mechanism as it minimizes the use of the painful muscles (Falla and Farina, 2008). Finally, pain may also lead to modified cervical afferents as it is reflected by deficits in proprioception, eye movement control and postural stability and it may finally further influence the motor control of cervical muscles (Treleaven, 2008).
However, pain by itself cannot explain electrophysiological manifestations and consequentially muscle activity behavior in patients with neck pain. The greater fatigability of cervical muscles may reflect changes in muscles composition. Changes in microcirculation may be also occur through vasoconstriction due to the increased activity of the sympathetic nervous system. Furthermore, an additional contributor to the alteration of motor control strategies is the changed metabolite concentration in the intercellular muscle interstitium. Fatty infiltration may be the result of a minor nerve injury or of an irritated nerve and may be perpetuated by changes in motor strategies. However, the fact that this infiltration is observed in the most muscles suggests that this degeneration is the result of a generalized disuse. The observed atrophy is consistent with fatty infiltration and mostly affects type I fibers. Additionally, the smaller amount of fatty infiltration in the more superficial muscles is consistent with the larger proportion of type II fibers which are more difficult to be transformed in other fiber types (Jull et al, 2008a).

**Sensorimotor control**

The sensorimotor control of patients with neck pain has been found to be seriously compromised (Figure 2.10). Problems in sensorimotor control may arise from abnormal afferent inputs from somatosensory, visual and vestibular systems. The somatosensory input in patients with neck pain is compromised by many mechanisms. Firstly, a direct trauma to the cervical area may injure cervical terminals affecting afferent information from this area. Secondly, changes in motor control of cervical muscles may desensitize mechanoreceptors and further influence somatosensory input. Thirdly, inflammatory mediators may activate joint and muscle nerve endings changing the activity of muscle spindles. Fourthly, pain can directly affect mechanoreceptors altering the central modulation of somatosensory inputs. Fifthly, the morphological changes of muscles as a consequence of neck pain may further alter the proprioceptive ability of muscles. Lastly, the sympathetic nervous system may depress the discharge rate of cervical afferents and with its interaction with stress may further change cervical inputs. These multidimensional changes in afferent information may also lead to changes in central nervous system processing.
and after interacting with visual and vestibular system afferents finally lead patients with neck pain to disturbances of their sensorimotor control (Jull et al., 2008a).

The vital role of cervical mechanoreceptors in proprioception and their connections to the vestibular and visual system may justify certain symptoms observed in patients with neck pain during impairment of these mechanoreceptors. Dizziness is one symptom that commonly occurs in patients with neck pain. A usual cause of this dizziness is the cervical vertigo which is associated with disturbed sensory inputs from cervical area due to neck pain, injury or pathology. Cervical vertigo is usually described in terms of a vague unsteadiness and lightheadness. It is episodic and it can persist from minutes to hours. Cervical vertigo is exacerbated by increased pain intensity and neck movements and many times it is accompanied by neck pain, blurred vision and nausea. Although the dizziness in patients with idiopathic neck pain is relatively exclusively cervical vertigo, in whiplash-associated disorders further causes of dizziness such as vertebral artery insufficiency, minor brain injury and vestibular lesions should be also considered. Vertebral artery insufficiency and its consequential disturbance in blood flow may lead to dizziness, but it is a rare cause and when happens may be asymptomatic due to the blood flow compensation from collateral arteries. Minor brain injuries due to the motor vehicle accident may be also a cause of dizziness. Peripheral vestibular lesions due to possible shears of the delicate structures of the peripheral vestibular system may also lead to dizziness. However, vestibular lesions prerequisite a mild head injury and in cases of no brain injury, the dizziness of whiplash patients is mostly of cervical origin (Jull et al., 2008a; Treleaven, 2008).

Joint position sense, postural stability and eye movement control are also affected in patients with neck pain. Joint position sense has been found to be impaired in both idiopathic neck pain and whiplash. This problem is further exacerbated when dizziness is present. However, although impaired joint position shows that there is a mismatched afferent input from abnormal vestibular or cervical origins, it cannot differentiate between them. Postural stability problems are observed both in patients with idiopathic neck pain and whiplash associated disorders although the potential vestibular disturbances in the latter may lead to confused conclusions. Postural stability is further compromised by the existence of dizziness. These postural problems are mainly attributed to a disturbed cervical somatosensory input although
vestibular causes cannot be absolutely excluded. Eye movement control is also disturbed in both idiopathic neck pain and whiplash patients. The smooth-pursuit system (allows stable images of a movement point), the saccadic system (allows change a point of fixation) and the optokinetic system (allows eyes fixation on a target when observer is moving) are all affected in these patients. Diplopia has also been observed in some whiplash patients. The problems of eye control systems suggest disturbances of cervicocollic and cervicoocular reflexes which is mainly attributed to dysfunction in somatosensory input from the cervical spine (Jull et al, 2008a; Treleaven, 2008).

Figure 2.10: Sensorimotor disturbances in neck pain.

Psychological states

Although psychological states in low back pain have been extensively examined, relatively little is known about their existence in neck pain. A causal relationship between psychological states and pain and disability is difficult to be established, as they can be both cause and effect. In patients with neck pain it seems that persistent pain may lead to psychological distress including anxiety, depression and behavioral abnormalities. Kinesiophobia and catastrophizing are also psychological states that are believed to be apparent in patients with neck pain. Although it is not supported by concrete evidence, it is further believed that the psychologic states of neck pain patients might also be related with the transition from acute to chronic neck pain. Based on findings in patients with low back pain, kinesiophobia is believed to play the major role in this transition. However, the evidence in neck pain is limited and its association with this transition has not been found to be so important. The psychological state which is purported to be the most important predictor of poor outcome is an early presence of acute posttraumatic stress. The symptoms presented in posttraumatic stress are intrusive thoughts of the injurious event, avoidance behavior related to the injurious event, panic attacks, hypervigilence and sleep disturbance. However, this is the case only in whiplash associated disorders, whereas idiopathic neck pain is much less explored. Furthermore, the relationships between physical and psychological factors are not well-defined, as the current evidence is sparse and has only shown that psychological states such as anxiety, catastrophizing and posttraumatic stress might play a role in sensory disturbances in whiplash patients. Furthermore, whereas kinesiophobia has been found to play an important role for motor responses in low back pain, its role in neck pain is unclear. The evidence about the relationship of psychological with physical factors in idiopathic neck pain remains much less explored (Jull et al, 2008a).

2.2.7 Management

The simplest, but one of the most important actions during assessment of patients with neck pain is taking a history. This history includes recording of the site
of pain, the pain radiation, illness duration, circumstances of onset, mode of onset, pain quality, pain severity, pain frequency, pain duration, time of onset, precipitating factors, aggravating factors and relieving factors. Associated features such as past history of illness, general health, exposure as well as problems in nervous, cardiovascular, urinary, endocrine, gastrointestinal, musculoskeletal, reproductive, respiratory system and skin should be also recorded not only for more clearly understanding patient’s health, but also for excluding more serious cases of neck pain (Bogduk and McGuirk, 2006).

Besides taking patient’s history, medical screening may also include a number of investigations. Plain radiography, computed tomography, SPECT, magnetic resonance imaging, electrophysiological tests, cervical discography and medial branch blocks are usual medical selections for investigating chronic neck pain (Bogduk and McGuirk, 2006). Physiotherapeutic assessment tend to focus mostly on neck inspection, palpation for trigger points (Bogduk and McGuirk, 2006), posture examination, scapular motor control, muscle strength and endurance, cervical range of movement, sensory disturbances, sensorimotor control, deep neck muscles motor control (Jull et al, 2008a) muscle length and imbalances (Sahrmann, 2002; Kendall et al, 2005), intersegmental motion, vertebral artery insufficiency (Maitland et al, 2005) and neuropathodynamics (Shacklock, 2005). All of these medical and physiotherapeutic investigations can give a better insight into the pathophysiology and origins of neck pain and give rise to a better clinical reasoning for implementing treatment strategies.

Medically, neck pain is usually treated by drugs prescription. However, the only concrete evidence about their effectiveness is in relation to local treatment with anesthetics for chronic and intravenous glucocorticoid for acute neck pain. The results about the effectiveness of oral psychotropic agents and epidural steroids are inconsistent, whereas the evidence about the effectiveness of intramuscular injections of multivitamins is questionable. There is also enough evidence to support that the effects of non-steroidal anti-inflammatory drugs (NSAIDs), melatonin, local treatment with botulinum and subcutaneous injections are not promising (Jensen and Harms-Ringdahl, 2007). Lastly, the results about surgical interventions such as anterior cervical fusion, disc replacement and radiofrequency neurotomy are satisfactory and are commonly used when physical treatments fail (Bogduk and McGuirk, 2006).
Physiotherapists use a great variety of exercises and physical modalities for treating patients with neck pain. The diversity in clinical applications render it difficult for collecting evidence about the effectiveness of physiotherapy on the rehabilitation of neck pain. However, a review by Jensen and Harms-Ringdahl (2007) summarizes the evidence for the effectiveness of different therapeutic modalities for pain reduction in acute and chronic neck pain. In this review, individualized home exercises, laser, pulse electromagnetic treatment, strengthening exercises and proprioceptive exercises are suggested to have sufficient evidence to support their effectiveness on treating chronic neck pain. For acute neck pain individualized home exercises, range of movement exercises, laser and pulsed electromagnetic treatment are suggested as effective. All the other rehabilitative strategies (cold spray, transcutaneous electric nerve stimulation, electrical muscle stimulation, acupuncture, traction, mobilization, manipulation, neck collar) have been found either to be questionable or ineffective or to lack of concrete evidence about their effectiveness. Nevertheless, the evidence about the use of multimodal interventions combining physical agents in parallel with cognitive behavioral therapy are believed to be effective for both acute and chronic neck pain.

Considering all of this information, it becomes apparent that although the current medical and physical treatment seem to improve chronic neck pain, these interventions are only directed towards the neuromusculoskeletal aspects of this complaint. This fact has as a result important clinical manifestations of chronic neck pain such as respiratory dysfunction to be totally ignored. Thus, studies exploring respiratory function in chronic neck pain are needed in order to improve clinical reasoning leading to implementation of more complete interventions.
2.3 Respiratory function

Breathing is unique and one of the most important body functions justifying its characterization as the basic rhythm of life (Hough, 2001). The importance of breathing is also reflected by the fact that it is the essential function before respiration occurs. The lungs are the most important anatomical and physiological structures of the respiratory system for these functions. The understanding of how this system works can give a better insight into the physiological causes of respiratory dysfunctions and diseases as well as implications for clinical practice.

Anatomy of the respiratory system

The major anatomical components of the respiratory system are the upper airway, the lower airways, the sites of gas exchange, the pulmonary vascular system, the lymphatic system, the neural component of the lungs, the lungs, the mediastinum, the pleural, the thorax, the diaphragm and the accessory musculature of ventilation.

The upper airway includes the nose, oral cavity, pharynx and larynx. Beside its participation in speech and smell, the major functions of the upper airway are air conduction to the lower airways, humidification and warming of the inspired air and the protection of the tracheobronchial tree from foreign materials. The lower airways include the tracheobronchial tree. The tracheobronchial tree is comprised of a series of branching airways which become progressively narrower and expand throughout the lungs. The lower airways are separated into the cartilaginous airways (trachea, main stem bronchi, lobar bronchi, segmental bronchi, subsegmental bronchi) which contribute to the air conduction and the non-cartilaginous airways (bronchioles, terminal bronchioles) which are important not only for air conduction, but also for gas exchange. The gaseous exchange occurs in specific anatomical areas distal to the terminal bronchioles. These areas include anatomical structures such as the alveolar epithelium which helps to the decrease of the surface tension of the alveoli fluid, the pores of Kohn which permits gas to move between adjacent alveoli, the alveolar
macrophages for removing bacteria and other foreign particles and the interstitium which is the space where the most gas exchange occurs and its collagen protects alveoli from excessive distension (Jardins, 2008).

The pulmonary vascular system similar to the systemic vascular system includes arteries, arterioles, capillaries, venules and veins. The pulmonary artery serves to transfer deoxygenated blood from the right ventricle of the heart to the lungs. The pulmonary arterioles help to transfer nutrients to the respiratory bronchioles and alveoli and are useful for blood distribution and regulation. These arterioles lead to capillaries which are where gas and fluid exchange occurs. After its transfer through the pulmonary capillaries, the blood enters the venules which finally lead to veins. These veins carry the blood back to the left atrium of the heart. The lymphatic system is composed of lymphatic vessels, lymph nodes and juxta-alveolar lymphatics. The lymphatic vessels are found superficially around the lungs and are important for removing excessive fluid and protein molecules leaking out from the pulmonary capillaries. The vessels end in lymph nodes which produce lymphocytes and monocytes enhancing defense of the respiratory system. Juxta-alveolar lymphatics are peribronchovascular vessels which are found next to alveoli further protect the interstitial space of lung parenchyma. The pulmonary function is also highly influenced by the sympathetic nervous system which increases heart rate, constricts blood vessels, relaxes bronchial smooth muscles, decreases bronchial secretions and increases blood pressure (Jardins, 2008).

The lungs are very important anatomical structures of the respiratory system (Figure 2.11). The right lung is larger and heavier and consists of the upper (apical, posterior, anterior), the middle (lateral, medial) and the lower lobe (superior, medial basal, anterior basal, lateral basal, posterior basal). The left lung is divided in the upper (apical/posterior, anterior, superior lingual, inferior lingual) and lower lobe (superior, anterior medial basal, lateral basal, posterior basal). The mediastinum is a cavity formed by the two lungs, the sternum and the thoracic vertebrae and contains important anatomical structures such as the heart, the trachea, major blood vessels, thymus gland, nerves, lymph nodes and part of the oesophagus. The pleural cavity is split into the visceral pleura which is firmly attached to the lungs and its outer layer - the parietal pleura. The thorax is a bony structure which encloses and protects the respiratory system. The thorax is formed posteriorly by the twelve thoracic vertebrae,
anteriorly the sternum and laterally by the twelve ribs. Finally, the diaphragm which is the most important respiratory muscle is a dome-shaped musculofibrous partition separating the abdominal from the thoracic cavity. Respiration is also assisted by a number of muscles attached to the thoracic structures (Jardins, 2008).

Figure 2.11: Lungs.

This figure presents the lungs and their subdivision into lobes (reproduced from Jardins T.D. (2008). Cardiopulmonary anatomy and physiology: essentials of respiratory care. 5th ed. Canada: Thomson Delmar Learning, with permission).

Respiratory control

Breathing is mostly an unconscious process changing and adjusting to the optimum $\text{PaO}_2$ and $\text{PaCO}_2$ levels. The respiratory center is the medulla and the reticular formation where a minimum number of neurons are contained for controlling the basic sequence of expiration and inspiration. The middle and lower pons includes the apneustic center and when respiration is not controlled by the pneumotaxic center, apneustic breathing occurs. The pneumotaxic center is found on the upper part of the
pons and its action is on the inhibition of the apneustic center or the inspiratory component of the medulla with a consequential balancing of inspiration and expiration maintaining the normal breathing pattern. Breathing is regulated by central and peripheral chemoreceptors. Central chemoreceptors are found on the upper medulla and they are stimulated by an increase in arterial PaCO$_2$ leading to an increase of rate and depth of ventilation. Although less important than central chemoreceptors, peripheral chemoreceptors are found on the carotid bodies and increase ventilation when they are stimulated by an increase of PaCO$_2$. However, their main role is to increase ventilation when they are stimulated by a potential hypoxemia. Finally, breathing can be also voluntary controlled. Voluntary breathing is controlled by the cerebral cortex and is important during activities such as communication, singing, coughing, blowing, sniffing and sucking. However, its importance is much less than the involuntary control of breathing as the latter serves a more vital role (Irwin and Tecklin, 2004; Frownfelter and Dean, 2006).

Mechanics of respiration

Breathing is divided into the inspiratory and expiratory phases. During inspiration, the diaphragm flattens about 5-7 cm generating a negative intrathoracic pressure with a consequential sucking of air into lungs. During the diaphragmatic contraction, the abdominal content is pressed downwards and when the abdominal wall compliance reaches its limit, the outward pressure expands the lower rib cage. The accessory inspiratory muscles stabilize the upper thoracic cage for preventing its downward movement. However, in forced inspiration or in cases of increased inspiratory workload accessory muscles may become major inspiratory muscles.Expiration is mostly passive since elastic recoil provides the appropriate driving pressure for returning pulmonary structures and diaphragm to their pre-inspiratory position. This recoil is caused by the surface tension of the gas-liquid interface of the alveoli and the elasticity of the stretched lung tissue. The higher the lung volume the higher the elastic recoil and if this elastic recoil is not counterbalanced by outward pressure the lungs are pulled inwards. Although expiration is highly passive, the
Accessory expiratory muscles can be highly active during forced expiration. During inspiration, alveolar pressure is negative, whereas it becomes slightly positive during expiration. The pleural pressure is usually negative due to the inward pressure from lung recoil and outward pressure from chest wall recoil. Chest wall recoil assists inspiration, whereas at the end of a quiet exhalation the difference between the outward and inward recoil is neutralized (Hough, 2001).

**Muscle function**

The main respiratory muscle is the diaphragm which has an inspiratory function. This muscle is a dome-shaped muscle between the thoracic and the abdominal cavity (Jardins, 2008). The importance of this muscle is demonstrated by the fact that quiet breathing is mainly based on this muscle. During quiet inspiration the diaphragm contracts and moves firstly downwards pressing the fulcrum of the abdominal contents and secondly outwards against the lower rib cage evoking expansion of the lower chest. Normal expiration is mainly passive and is performed after relaxation of this muscle (Hough, 2001; Jardins, 2008).

Forced inspiration is performed not only by the diaphragm, but also by accessory muscles. There is some controversy about which exactly are the accessory muscles of inspiration. Apart from the diaphragm, the muscles that have been purported to contribute to forced inspiration are the anterior, medial and posterior scalenus, the sternocleidomastoid, the pectoralis major, the trapezius, the external intercostals (Jardins, 2008), the levators costarum and the serratus posterior superior (Palastanga et al, 2002). The main function of these muscles is elevation of the rib cage pulling from either one or more ribs (Jardins, 2008).

Forced expiration includes other accessory muscles and controversy about forced expiration kinematics is apparent. The accessory muscles that are purported to take part in forced expiration are the rectus abdominis, the external abdominis obliquus, the internal abdominis obliquus, the transversus abdominis, the internal intercostals (Jardins, 2008) as well as the transversus thoracic, the subcostals, the serratus posterior inferior and the latissimus dorsi (Palastanga et al, 2002). Abdominal
muscles help expiration as their contraction pushes the diaphragm into the thoracic cage with a consequential decrease of rib cage capacity (Jardins, 2008). The other accessory muscles, although they are attached to different ribs, help expiration by pulling the rib cage downwards decreasing again the rib cage capacity (Palastanga et al, 2002).

These inspiratory and expiratory muscles form a system like a pump called the respiratory pump. The main role of the respiratory pump is to mobilize the chest wall and to control the airway tone in a rhythmic and coordinated manner so that the alveoli are adequately ventilated and arterial blood gases and pH remain at normal level. Like all the skeletal muscles, respiratory muscle force is dependent on velocity and length changes. A pressure-volume loop can provide indirectly the force-length relationships of the respiratory pump, whereas information about its force-velocity relationship can be indirectly provided by pressure-flow loops. Thus, the overall behavior of the respiratory pump can be satisfactorily described through these loops (Irwin and Tecklin, 2004).

**Ventilation**

Ventilation is the movement of gas between the alveoli and the outside of the body and should not be confused with respiration which is a) the gas exchange between tissue cells and environment and b) the regulation of the acid-base balance and metabolic and defense functions of the respiratory system. Ventilation can be divided into 1) alveolar ventilation which is the amount of fresh air entering alveoli and participating in gas exchange and 2) dead space ventilation which is the amount of entering air that does not participate in gas exchange (Hough, 2001).

Throughout the lungs there are regional differences in ventilation. It seems that the lower pulmonary fields can accept the most amount of air, whereas the upper pulmonary fields can be less ventilated. This occurs due to the fact that alveoli in the upper lung fields are initially more inflated having higher resting volumes in relation to the lower lung fields. However, this resting volume is mostly dead space gas which does not participate in gas exchange. In contrast, alveoli in the lower lung fields are less inflated and have less resting volume due to their compression by the upper lung
fields. Thus, being less inflated, they have bigger potential to expand. The inspired air travels firstly to the alveoli of upper lung fields and after quickly filling them it travels to the lower more expandable lung fields. The distribution of ventilation is gravity dependent. This means that the distribution of ventilation is favored in the lower lung fields independently of each position. For example, in side-lying the upper lung is less ventilated, whereas the alveoli of the lower lung, which are more compressed due to the weight of the upper lung and the abdominal content, have higher potential to expand and are finally better ventilated (Hough, 2001; Frownfelter and Dean, 2006).

**Perfusion**

The lungs are served by a low-pressure pulmonary and a high-pressure bronchial circulation. Although the high-pressure circulation services the lung tissue, it is not vital for life (Hough, 2001). Lung perfusion refers to the blood flow of the pulmonary circulation which contributes to gas exchange. Hydrostatic pressure is a significant factor for the perfusion of the lower pulmonary lobes as it reflects the gravity effect on the blood and leads to a better perfusion of the lower pulmonary areas. The non-uniformity of lung perfusion is attributed to the interaction of alveolar, venous and arterial pressures of the lung. In the upper lung fields alveolar pressure approximates to atmospheric pressure overriding the arterial pressure with a consequential closing of the pulmonary capillaries. In contrast to these lung fields, in the lower lung fields the greater capillary hydrostatic pressure overrides the alveolar pressure leading to a better perfusion. Finally, it should be mentioned that low partial pressures of arterial oxygen may constrict pulmonary blood vessels leading to hypoxic vasoconstriction. This mechanism helps to divert the blood from the poorly ventilated or oxygenated lung areas leading to better ventilation and perfusion matching (Frownfelter and Dean, 2006).

An appropriate ventilation to perfusion ratio (V/Q) is critical for suitable tissue oxygenation. The existence of an appropriately ventilated but poorly perfused lung field or of an appropriately perfused but poorly ventilated lung field may lead to inadequate oxygenation of body tissues. In the former case, there would not be sufficient blood to transfer the appropriate quantity of oxygen to the body tissues,
whereas in the latter case a shunt would be created that means that blood would not be adequately oxygenated. The appropriate V/Q ratio for maintaining normal levels of PaCO$_2$ and PaO$_2$ is 0.8. Furthermore, the base receives 18 times more blood and 3.5 times more gas than the upper pulmonary lobes. Thus, it seems that at the base perfusion is in excess of ventilation. In contrast, the upper pulmonary lobes have ventilation in excess of blood. The appropriate matching of perfusion and ventilation occurs in the middle pulmonary areas. Thus, it can be concluded that normal lungs have increased alveolar dead space in the apices and shunts in the bases (Hough, 2001; Frownfelter and Dean, 2006).

**Gas exchange and transport**

After reaching the alveoli, the air should pass the alveolar-capillary membrane (Figure 2.12). This movement occurs through gaseous diffusion which happens in both gaseous and liquid states leading to equilibrium between blood and gas. More specifically, inhaled O$_2$ must cross through a thin tissue barrier composed of the surfactant lining, the alveolus, the alveolar epithelium, the interstitial tissue and the capillary endothelium. Oxygen should also travel through a blood barrier composed of a layer of plasma, the erythrocyte membrane and the intracellular fluid of the erythrocyte until reaching and attaching to a hemoglobin molecule forming oxyhemoglobin. Carbon dioxide has also to overcome these barriers. Thus, CO$_2$ diffuses out of the red blood cell and after crossing the plasma and the tissue barrier it enters to the alveolar air (Hough, 2001; Irwin and Tecklin, 2004; Frownfelter and Dean, 2006).

After its diffusion to the alveolar-capillary membrane, oxygen is transported to body tissues attached to hemoglobin molecules. There, it diffuses out of the tissue capillaries to the cells and contributes to energy production in the form of Adenosine Triphosphate (ATP). The metabolic activity of cells leads to CO$_2$ production which diffuses out of the cells into tissue capillaries and returns to the lungs through the blood (Irwin and Tecklin, 2004). Tissue oxygenation is determined by a balance between oxygen supply and tissue demands. Furthermore, oxygen delivery to the tissues can be influenced by various factors including oxygen content of the blood,
cardiac output, CO distribution, hemoglobin levels and local perfusion. Thus, an appropriate matching of perfusion and ventilation is not enough by itself for appropriate tissue oxygenation and an effective oxygen transport and delivery necessitates the fulfillment of many prerequisites (Hough, 2001).

Figure 2.12: Gas exchange.

This figure represents the gas exchange between alveoli and capillaries (P_{V\text{O}_2}: partial pressure of oxygen in mixed venous blood, P_{V\text{CO}_2}: partial pressure of carbon dioxide in mixed venous blood, P_{A\text{O}_2}: partial pressure of oxygen in alveolar gas, P_{A\text{CO}_2}: partial pressure of carbon dioxide in alveolar gas, P_{\text{aO}_2}: partial pressure of arterial oxygen, P_{\text{aCO}_2}: partial pressure of arterial carbon dioxide) (reproduced from Jardins T.D. (2008). Cardiopulmonary anatomy and physiology, essentials of respiratory care. 5th ed. Canada: Thomson Delmar Learning, with permission).
Blood gases disturbances

The importance of appropriate levels of blood gases is illustrated by the disturbances caused by their potential abnormal values. Hypoxaemia is the condition caused when the arterial oxygen reaches abnormally low levels. Hypoxaemia can be caused by low or high V/Q ratio, hypoventilation, diffusion abnormality and low oxygen content in the atmospheric air. It is a serious life-threatening condition clinically accompanied by cyanosis, tachypnoea, tachycardia, peripheral vasoconstriction, respiratory muscle weakness and restlessness. This condition can also lead to reduced oxygen delivery to body tissues, a condition known as hypoxia. Beside hypoxaemia, hypoxia can be also caused by reduced oxygen capacity of the blood, reduced or disturbed blood flow, reduced CO and reduced ability of tissues to extract oxygen. Hypercapnia is another serious condition which refers to the increased level of CO$_2$ in the blood. CO$_2$ level reflects ventilation ability and hypercapnia is a usual result of hypoventilation. This condition is clinically accompanied by a flapping tremor of hands, tachypnoea, tachycardia, weakness of respiratory muscles, drowsiness, sweating and peripheral vasodilation which may lead to warm hands and headaches. Both hypoxemia and hypercapnia may lead to coma in serious disturbances. Hypoxaemia alone can lead to type I respiratory insufficiency whereas its existence in parallel with hypercapnia may lead to type II respiratory insufficiency (Hough, 2001).

Hypocapnia is another serious disturbance and refers to the reduced level of CO$_2$ in arterial blood. Hypocapnia is usually the result of hyperventilation where the ventilation exceeds the metabolic body requirements. The reduced level of PCO$_2$ leads to alkalosis due to a consequential rise of pH. This results in the constriction of smooth muscles of vessels, gut and bronchi. The oxygenation of tissues may also be affected not only because of the reduced blood flow due to the vasoconstriction, but also because of the reduced release of oxygen and nitric oxide by haemoglobin. The importance of nitric oxide for tissue oxygenation is depicted in its vasodilatory action which inhibits platelets adhesion, activation and aggregation. The consequences of hypocapnia are summarized in Table 2.2 (McLaughlin, 2009).
Table 2.2: Effects of hypocapnia in body systems (McLaughlin, 2009)

<table>
<thead>
<tr>
<th>System</th>
<th>Effects</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cerebral</td>
<td>Headache, impaired intellectual function, confusion, giddiness, visual</td>
</tr>
<tr>
<td></td>
<td>disturbances, lightheadness, syncope, seizures, hallucinations,</td>
</tr>
<tr>
<td></td>
<td>depersonalization, unilateral somatic symptoms</td>
</tr>
<tr>
<td>Muscular</td>
<td>Increased membrane excitability</td>
</tr>
<tr>
<td>Cardiac</td>
<td>Chest pain, coronary artery spasm, electrocardiographic changes</td>
</tr>
<tr>
<td>Respiratory</td>
<td>Bronchospasm, asthma, breathlessness</td>
</tr>
<tr>
<td>Gastrointestinal</td>
<td>Increased tone, increased motility, increased sensitivity</td>
</tr>
</tbody>
</table>

**Critical indices of respiratory function**

Respiratory function tests are commonly used for the assessment of pulmonary function. Hough (2001) summarizes the main reasons for the quantification of lung function deriving from such tests. Pulmonary function tests can be used for the definition of abnormalities, for recording the progress of a disease or its response to treatment and for providing a risk and preoperative assessment. Furthermore, demographic parameters such as gender, ethnic origin and age as well as time of assessment should be always considered as they can potentially alter the results (Buff et al, 1995; Hough, 2001).

Pulmonary capacity can be divided in four lung volumes (Figure 2.13) (Jardins, 2008). Some of the most usual functional tests are the ones conducted for the assessment of these volumes. Tidal Volume ($V_T$) is the volume of air that moves into and out of the lungs during one quiet breath (Jardins, 2008). This index reflects the functions of the respiratory centres, respiratory muscles, the chest wall and lung mechanics as it is the involuntary part of breathing. Its normal value is approximately 300-800 mL (Hough, 2001). Inspiratory Reserve Volume (IRV) is the extra volume of
air that can be voluntarily inhaled after a normal tidal volume inhalation (Jardins, 2008) and can give indications about the inspiratory muscle strength and the inward elastic recoil of the lungs. Its normal value is about 3.1 L (Hough, 2001). Expiratory Reserve Volume (ERV) is the extra volume of air that can be voluntarily exhaled after a normal tidal volume exhalation (Jardins, 2008) and it is found to be decreased with obesity, ascites or after upper abdominal surgery whereas its normal value is about 1.2 L (Hough, 2001). The last of the volumes is the Residual Volume (RV) which is the amount of air remaining in the lungs after maximum exhalation (Jardins, 2008) and its normal value is approximately 1.2 L. The importance of this volume is depicted by the fact that it prevents the lungs from a potential collapse (Hough, 2001).

Figure 2.13: Pulmonary volumes and capacities.

![Pulmonary Volumes and Capacities Diagram](image)


Pulmonary capacities are combinations of pulmonary volumes (Figure 2.13). Inspiratory Capacity (IC) is the volume of air that can be inhaled after a normal
exhalation ($V_T + IRV$). Functional Residual Capacity (FRC) is the volume of air remaining in the lungs after a normal exhalation ($ERV + RV$) (Jardins, 2008). FRC is a useful indicator as it does not depend on effort and it reflects the amount of air in the lungs in the resting position where the inner and outer recoils are balanced (Hough, 2001). Vital Capacity (VC) is the maximum amount of air that can be exhaled after a full inspiration (Jardins, 2008). VC is a useful index as it represents three volumes under volitional control ($IRV + V_T + ERV$) and indicates the ability to breath deeply and cough giving rise to implications about inspiratory and expiratory muscle strength (Hough, 2001). The last combination of volumes is the Total Lung Capacity (TLC) which can be defined as the maximum amount of air that can be accommodated by the lungs ($IRV + V_T + ERV + RV$) (Jardins, 2008). The RV/TLC ratio is an index of hyperinflation (Hough, 2001). Plethysmography, gas dilution, nitrogen washout and spirometry are common techniques for recording these volumes and capacities (Ruppel, 2009).

All of these capacities are dependent on the prerequisite that breathing is performed in a usual, quiet manner. However, sometimes it is more meaningful to examine these volumes using a forced manoeuvre. In this case VC is renamed as Forced Vital Capacity (FVC) and is defined as the maximum amount of air that can be forcefully exhaled after a full inspiration. Normally, FVC is the same as VC, but in obstructive disorders it appears to be less than VC because the manoeuvre causes collapse of airways (Hough, 2001). Another useful index that can be obtained by the forced manoeuvre is the Forced Expiratory Volume in T seconds ($FEV_T$). $FEV_T$ is the maximum volume of gas exhaled in a specific time period (Jardins, 2008). A time period of 1 sec ($FEV_1$) is usually used because this period is the most sensitive to airways resistance. $FEV_1$ normally is the 80% of VC and is an important index of disease severity (Hough, 2001).

These volumes and capacities obtained by the forced manoeuvre (Figure 2.14) can also give the $FEV_1/FVC$ ratio which is a more accurate measure than $FEV_1$ alone (Hough, 2001). This ratio in parallel with the $FEV_1$ is critical for the diagnosis of respiratory diseases as it helps significantly in the differentiation between obstructive and restrictive disorders (Ruppel, 2009). This ratio normally is 0.8. In obstructive diseases it appears to be reduced, whereas in restrictive diseases can be higher than the normal (Hough, 2001).
Apart from the volumes and capacities which are important indicators of pulmonary function, flows are usually measured as they can also give important diagnostic and clinical information. Peak Expiratory Flow (PEF) is the highest flow
achieved during a forced expiration from maximum inspiration (Figure 2.14). PEF reflects the large airways resistance, expiratory muscle strength and effort and depicts the ease with which the lungs are ventilated. Its normal value ranges from 300 to 600 L/min (Hough, 2001). On the other hand, Peak Inspiratory Flow (PIF) is the highest flow achieved during a forced inspiration and is a less useful measure (Figure 2.15) (Ruppel, 2009). PIF is usually not described as the examination of PEF is more meaningful as airways closure happens during expiration. Forced Expiratory Flow (FEF) can be measured in several parts of expiration. The Forced Expiration Flow from the 25% to 75% of expiration (FEF_{25\%-75\%}) and at the 50% of expiration (FEF_{50\%}) are mean forced expiratory flows during the middle half of the forced expiration and are used for measurement of small airways resistance (Hough, 2001).

A flow-volume curve during expiration and inspiration shows that during expiration the highest flow occurs initially, where it is effort dependent and represents the function of the large airways. After a small part of air has been expired, flow is independent of effort due to the greater dynamic compression with higher intrapleural pressures and depends only on small airways resistance and elastic recoil (Levitzky, 1995; Hough, 2001). On the other hand, the inspiration leads to a hill-shaped tracing where the highest flow occurs at the middle of the inspiration (Jardins, 2008).

Maximal Expiratory Pressure (MEP) and Maximal Inspiratory Pressure (MIP) are the highest pressures developed during a forceful expiration and inspiration respectively against a closed airway (Figure 2.15) (Ruppel, 2009). These are other measures of pulmonary function and are directly related to the inspiratory and expiratory muscle strength. In clinical practice, MIP and MEP are very useful measures as they are used for the evaluation of patients’ ability to maintain spontaneous, unassisted mechanical ventilation (Jardins, 2008). The most accurate results of these measures derive when the MIP is measured from either RV or FRC and when the MEP is measured from TLC (Hough, 2001). The mean values for MIP and MEP for men respectively are 125cm H_{2}O and 230cm H_{2}O and for women respectively are 90cm H_{2}O and 150cm H_{2}O. The pressure can be measured using a manometer, an aneroid-type gauge or a pressure transducer (Ruppel, 2009).
Lastly, the Maximal Voluntary Ventilation (MVV) and the minute volume/ventilation are other measures of pulmonary function (Figure 2.16). Although similar, these two measures examine different aspects of lung function. More specifically, the minute volume is the volume of air inhaled or exhaled per minute and derives multiplying $V_T$ to respiratory rate. Its normal value is about 5-7 L/min (Hough 2001). On the other hand, MVV is the air volume inhaled and exhaled with maximum effort over 12 or 15 sec (Hough, 2001; Jardins, 2008; Ruppel, 2009). MVV has a range of normal values between 50 and 200 L/min (Hough, 2001) and is a general test for evaluating performance of respiratory muscle strength, lung and thorax compliance, airway resistance and neural control mechanisms (Jardins, 2008).
Finally, the most vital assessment of respiratory function is the recording of blood gases values. The assessment of arterial blood gases is crucial to recognizing potential acid-basic disturbances and respiratory insufficiency. The most basic information derived from an arterial blood gas analysis is the pH, the partial pressure of oxygen in arterial blood (PaO₂), the partial pressure of carbon dioxide in arterial blood (PaCO₂) and oxygen saturation in arterial blood haemoglobin (SaO₂) (Hough, 2001). The pH has been defined as “the negative logarithm, to the base 10, of the hydrogen ion concentration [H⁺] in moles per liter, or –log H⁺” (Jardins, 2008, p282). The pH has no units and the normal values are between 7.35 and 7.45 (Hough, 2001). Oxygen can be carried in the blood either combined with haemoglobin or dissolved in the plasma. Carbon dioxide is a byproduct of metabolism within the cells and the measurement of its partial pressure reflects adequacy of ventilation (Capovilla et al, 2000). In contrast, the partial pressure of oxygen can be affected not only by ventilation, but also by other causes of hypoxaemia such as ventilation/perfusion (V/Q) mismatch and diffusion abnormality (Hough, 2001). The PaO₂ and the PaCO₂ are expressed in millimeters of mercury (mmHg) and the normal values are 80-100mmHg and 35-45mmHg, respectively (Hough, 2001; Ruppel, 2009). Finally, SaO₂
is an index which shows the oxygen saturation in arterial blood haemoglobin and it is normally between 95% and 98% (Hough, 2001). Disorders that alter for any reason the ventilation, the V/Q ratio or the diffusion may cause a change in arterial blood gases (Hough, 2001; Jardins, 2008).

Factors influencing respiratory function

Normal breathing and respiration can be affected potentially by a number of factors. These factors should be carefully considered in any study examining respiratory parameters in order to minimize their external influence on pulmonary function.

It is well-known that lung function is highly dependent on race and height (Ruppel, 2009). This may be due to potential differences in anatomical size of the respiratory system as such changes may alter the ability of lungs to accommodate air or alter the biomechanics of respiratory system leading to different respiratory ability. Respiratory function is also dependent on weight. Obesity has been defined as a generalized increase in body mass that is the result of excessive fat accumulation and can seriously affect respiratory function due to the extra work of breathing caused by reduced chest wall compliance. The reduction of lung volumes and respiratory muscle dysfunction due to the compression of the thoracic cage, diaphragm and lungs have been also stipulated as causes of increased work of breathing. In addition, the total oxygen consumption and carbon dioxide production can also increase and hypoxemia is sometimes apparent due partially to the early closure of dependent airways (Jubber, 2004).

Smoking is another influential factor on respiratory function. Dyspnoea, asthma, cough and sputum production are commonly observed in smokers (Langhammer et al, 2000) and smoking is the predominant cause of lung cancer and chronic obstructive pulmonary diseases such as chronic bronchitis and pulmonary emphysema (Reid and Chung, 2004). The detrimental effects of smoking on respiratory function can be also depicted by a change in arterial blood gases, increase in airway resistance, negative changes in lung volumes, reduced mucociliary clearance, reduced phagocytic function leading to a higher risk for a pulmonary
infection and reduced performance and physical fitness (Hough, 2001; Reid and Chung, 2004).

Respiratory function is also highly dependent on age. Aging leads to degradation of tissue elastin reducing elastic recoil and increasing dynamic compression with a consequential increase in airway closure. The chest wall becomes less flexible due to an increase of crossed collagen fibres contributing to the chest stiffness. Sometimes calcification of cartilages and kyphoscoliosis are observed. Lung volumes changes are also apparent with an accompanied increase of RV leading to the “senile emphysema” with a consequential decrease of surface area for gas exchange. This in turn may give rise to a ventilation/perfusion mismatch and a disturbance of arterial blood gases. Finally, the strength and endurance of respiratory muscles are also reduced (Hough, 2001; Reid and Chung, 2004).

Gender is another influential factor on respiratory function. The main reason for the differences in lung function between men and women is their different anatomical and physiological characteristics (Harms, 2006). More specifically, the different morphology and structure of the respiratory system is depicted by the reduced lung volumes, smaller respiratory flow rates, reduced diameter of airways, reduced diffusion surface and reduced strength of respiratory muscles in women (Harms, 2006; Ruppel, 2009). Furthermore, the reproductive feminine hormones, progesterone and oestrogen, have been suggested as influencing thermoregulation, metabolism and respiratory function (Bayliss and Millhorn, 1992; da Silva et al, 2006; Harms, 2006). In addition, pregnancy can further compromise pulmonary function mainly due to the increased oxygen consumption to support the foetus and restriction of lung volumes by swelling. Increased weight further compromises respiration and 75% of pregnant women experience breathlessness (Hough, 2001).

The menstrual cycle may also influence respiratory function though existent evidence is controversial. The justification is that respiratory function is influenced by female sexual hormones and especially progesterone leading to an increased respiratory response during the luteal phase. It is also suggested that the parallel action of progesterone and oestradiol may increase ventilation due to their action on receptomediated mechanisms in both the peripheral and central regulation of respiration (Bayliss and Millhorn, 1992; da Silva et al, 2006). However, research evidence in humans suggests that its influence on respiratory function is minimal (da
Nevertheless, the potential influence of different stages of the menstrual cycle in studies examining respiratory parameters should be carefully considered when considering external influences.

Respiratory function is also compromised not only by respiratory diseases (Pryor and Webber, 1998), but also by neuromuscular and neurological diseases. In neuromuscular diseases progressive respiratory failure is interrelated with intercostal, diaphragmatic and accessory respiratory muscle weakness, with a decreased pulmonary compliance, a weak cough and changes in vital capacity. Moreover, disturbances in arterial blood gases and dyspnoea are also apparent (Mier-Jedrzejowicz et al, 1988; Hallum, 2001). Neurological patients may also have a compromised respiratory system with a variable aetiology on the pathology of the disease or secondarily as a result of the sedentary life of the sufferers (Carter and Edwards, 2002; Stokes, 2004). Finally, diseases of the cardiovascular system may also lead to respiratory dysfunction which can be attributed to various causes such as a ventilation/perfusion mismatch, insufficient oxygenated blood supply of the respiratory muscles, generalized muscular atrophy related to cardiac cachexia and the existence of pulmonary congestion and oedema (Ambrosino et al, 1994; Hough, 2001).

Respiratory function may be also affected by disorders resulting in deformities of the chest such as kyphoscoliosis. An increased curvature of the spine may lead to lung compression and particularly the concave side of the curve with a consequential decrease in ventilation. Such abnormalities may also increase the work of breathing and curvatures of more than 70° may lead to respiratory failure (Shannon et al, 1970; Hough, 2001).

Physical activity also affects pulmonary function. Immobility has been found to lead to a reduction in lung volumes, increased work of breathing, decreased levels of arterial oxygen, changes in ventilation delivery, closure of the small airways and increased secretions (Hough, 2001; Reid and Chung, 2004). Cheng et al (2003) found that physically active individuals have increased lung volumes, improved cardiorespiratory fitness and a generally better respiratory function. These facts obviate the beneficial influence of physical activity on respiratory function.

Respiratory function may be also affected by environmental exposures. People who work in farms or mines have an increased possibility of developing fibrosing
alveolitis. Furthermore passive smoking or the exposure to any harmful agent can seriously affect the respiratory system (Hough, 2001). Thus, it seems that the quality of the environmental air is a factor that may compromise normal respiration.

All the previously discussed factors may alter respiratory function. Researchers interested in examining respiratory parameters should be aware of these factors and their potential influence on assessment, in order to control for their external influence on respiration. The elimination of their influence can be performed either by matching techniques or by their exclusion from the study or finally by using appropriate statistical techniques such as Analysis of Covariance (ANCOVA). However, their exclusion or not from future studies is highly dependent on the priority of each piece of research in relation to internal or external validity. Although the exclusion of these factors could lead to more valid results due to the elimination of any undesirable influence, it could also lead to a decreased generalizability of the findings to the general population. Nevertheless, their exclusion could lead to more valid conclusions and a deeper understanding of any cause and effect relationship in respiratory variables.
2.4 Respiratory dysfunction in chronic neck pain

Respiration is a complex function and can be influenced by biomechanical, biochemical and psychological factors being vulnerable to adaptations. The close anatomical and biomechanical connection of the cervical and thoracic spine as well as the neural and musculoskeletal connection they present led Kapreli et al (2008) to develop a model for the potential development of respiratory dysfunction in patients with chronic neck pain (Figure 2.17).

Figure 2.17: Neck pain mechanisms for respiratory dysfunction

According to this model, the deficits accompanying chronic neck pain including reduced strength and endurance of neck muscles, altered cervical proprioception, reduced mobility of the cervical area, psychological states as well as pain by itself may directly influence respiratory muscle function due to the common use of sternocleidomastoid, trapezius and scaleni or indirectly through a change in rib cage mechanics. These changes in parallel with the direct effects of pain on ventilation may finally lead patients with chronic neck pain to respiratory dysfunction. Although all of these changes in respiratory function of patients with chronic neck pain are supported by a scientifically valid rationale, they have not been investigated and their examination remains of high scientific and clinical interest for obtaining a better insight into the impact of neck pain on the quality of life and health of sufferers. The proposed mechanisms for the development of this respiratory dysfunction as well as the existent evidence are described analytically below.

2.4.1 Mechanisms

The existence of each neck pain deficit in patients with chronic idiopathic neck pain and the potential mechanisms for the development of respiratory dysfunction are analytically discussed below.

Pain

According to the model developed by Kapreli et al (2008), pain is one important factor leading patients with chronic neck pain to respiratory dysfunction. Nishino et al (1999) found that experimental pain increases the respiratory rate, the occlusion pressure and the minute ventilation, whereas tidal volume was stable throughout the experiment. Furthermore, PaCO₂ followed a similar change to pain intensity as it was initially decreased and after a small period of time it increased, but without returning to the initial PaCO₂ levels. Another controlled study by Borgbjerg et al (1996) also revealed that experimental pain stimulates ventilation leading to
increased minute ventilation and occlusion pressure as well as to increased tidal volume. In agreement with these results, Kato et al (2001) found that acute experimental pain leads to increase of respiration rate, peak inspiratory/expiratory flows and minute ventilation. However, although sustained pain was found to have similar effects on respiration, with the exception of respiratory rate these effects were not different from the respiratory effects of a placebo condition, suggesting that the respiratory disturbances in sustained pain are attributed mostly to pain expectation rather than pain itself. The authors explained that this difference between acute and sustained pain may be justified by the fact that pain experience leads to an early elicitation of substance P which has stimulatory effects on respiratory centers, whereas in the sustained pain, respiration may be depressed either by decreases in the neurokinin-1 mediated effect or by increased availability of opioids which have depressant effects on respiration.

In contrast to the previous findings by Kato et al (2001) about the respiratory effects of sustained pain, Glynn et al (1981) found that prolonged spinal musculoskeletal pain of more than 1 month may lead to hyperventilation and consequentially decreased partial pressure of arterial carbon dioxide (P$_\text{a}$CO$_2$). The pain-induced hyperventilation found by all researchers might be attributed to many mechanisms although the real mechanism is not clear. Thus, this hyperventilation could be attributed to the stimulatory effects on respiration of substance P an important pain neurotransmitter (Henry and Sessle, 1985). Furthermore, psychological states such as anxiety and phobia have known stimulatory effects on ventilation (Holt and Andrews, 1989). Lastly, considering the analgesic effects of hyperventilation (Chalaye et al, 2009) it could be also considered that hyperventilation could be a patient’s response or habituation in order to reduce the pain intensity.

The hyperventilation-induced analgesia was examined by Chalaye et al (2009). In this study it was found that slow deep breathing can increase both pain threshold and pain tolerance. These findings in parallel with increased heart rate variability led the authors to speculate a potential mechanism for hyperventilation-induced analgesia. According to them, the stretch-sensitive baroreceptors detect the blood pressure increase due to the increased intrathoracic pressure and the consequential increased venous return. Peripheral baroreceptors exert a strong
excitatory influence on the pain inhibitory relays of the nucleus tractus solitarius which is involved in pain modulation and found on the brainstem. Thus, it seems that hyperventilation has an important role in pain inhibition which may be intentionally or unintentionally be adopted by pain sufferers.

Beside the pain-induced hyperventilation, Kapreli et al (2008) also stipulated that respiratory function associated with chronic neck pain may also be affected by analgesic and anti-inflammatory drugs which are commonly prescribed in these patients. Research has shown that analgesics have a depressant effect on respiratory function (Borgbjerg et al, 1996; Moren et al, 1997; Dahan et al, 2005), whereas anti-inflammatory drugs such as ketoprofen do not seem to affect respiratory function and are usually used in parallel with analgesics to reduce respiratory side-effects (Moren et al, 1997). Although the use of drugs should be considered an extraneous factor as their respiratory effects cannot be attributed to neck pain by itself, the opioids released as a result from periaqueductal gray matter stimulation in pain conditions might also exert depressant effects on respiration.

Finally, pain may have indirect effects on respiratory function of neck pain patients. Pain may influence physical characteristics of patients with chronic neck pain including neck muscle strength, endurance, range of movement, proprioception and posture. Neck pain is also stipulated to be an important factor associated with the appearance of psychological states such as anxiety, depression, kinesiophobia and catastrophizing. Each one of these physical and psychological factors may have its own unique contribution to a potential respiratory dysfunction and their mechanisms are discussed in detail in the following subsections.

**Strength**

Muscle strength can be characterized as the ability of a muscle to generate sufficient tension for the purposes of posture and movement (Smidt and Rogers, 1982). Potential impairment of muscle strength can lead to inability to generate normal levels of force defined as muscle weakness (Shumway-Cook and Woollacott, 2007). The strength of neck musculature in patients with chronic idiopathic neck pain
have been examined in a number of studies (Chiu and Lo, 2002; Falla et al, 2004a; Ylinen et al, 2004; Cagnie et al, 2007a; O’Leary et al, 2007; Rezasoltani et al, 2010; Scheuer and Friedrich, 2010; Lindstrom et al, 2011). The findings of these studies including either patients with idiopathic or non-specific chronic neck pain are presented in Table 2.3. In summary, the great majority of these studies agree that patients with chronic idiopathic neck pain have decreased strength in every neck muscle group including cervical flexors, extensors, lateral flexors and rotators. This reduction depicts the muscle strength of global muscles rather than the local muscles who’s role is more important in lower loads (Comerford and Mottram, 2001a). However, local muscles are also important as they contribute to optimal force production due the more stable interface they offer. The same conclusions arise from studies examining the cervical strength in patients with cervicogenic headache (Watson and Trott, 1993; Barton and Hayes, 1996; Dumas et al, 2001). Patients with cervicogenic headache have been found to have much less cervical strength than patients with other types of headaches revealing the disabling nature of chronic neck pain. However, in headache deriving from whiplash injuries the strength of neck extensors is expected to be even more pronounced, something which can be justified by the more disabling nature of this condition (Dumas et al, 2001).

Table 2.3: Neck muscle strength in chronic idiopathic neck pain

<table>
<thead>
<tr>
<th>Study</th>
<th>Sample</th>
<th>Assessment</th>
<th>Results</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cagnie et al, 2007a</td>
<td><strong>Case group</strong> 30 women with chronic neck pain (Age: 32.9 yrs)</td>
<td>Three maximal voluntary contractions of neck flexors and extensors (the mean was accepted). Isometric strength was assessed with an isokinetic dynamometer. Supine position for extension, prone position for flexion.</td>
<td>Patients with chronic neck pain had reduced strength of neck extensors and extension/flexion ratio, but normal strength of neck flexors</td>
</tr>
<tr>
<td></td>
<td><strong>Control group</strong> 48 pain free women (Age: 20-59 yrs)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Authors</td>
<td>Case group</td>
<td>Control group</td>
<td>MVC during flexion, extension, lateral flexions, protraction and retraction. Three trials (average and best were accepted). Isometric neck dynamometer. Sitting position.</td>
</tr>
<tr>
<td>------------------</td>
<td>-------------------------------------------</td>
<td>----------------------------------------------------</td>
<td>---------------------------------------------------------------------------------------------------------------------------------</td>
</tr>
<tr>
<td>Chiu and Lo, 2002</td>
<td>21 patients with mechanical neck pain (12 females, age: 27±9.5 yrs)</td>
<td>25 healthy participants (10 females, age: 22.1±3.9 yrs)</td>
<td>MVC during flexion, extension, lateral flexions, protraction and retraction. Three trials (average and best were accepted). Isometric neck dynamometer. Sitting position.</td>
</tr>
<tr>
<td>Falla et al, 2004a</td>
<td>20 patients with non-neurogenic chronic neck pain&gt;1 year (17 females, age: 29±6.8 yrs, chronicity: 5.2±3.2yrs)</td>
<td>20 asymptomatic individuals (16 females, age:30±7.5 yrs)</td>
<td>Three maximal voluntary contractions of neck flexors (best value was accepted). Isometric cervical flexion dynamometer. Supine position.</td>
</tr>
<tr>
<td>Lindstrom et al, 2011</td>
<td>13 women with chronic non-traumatic neck pain&gt;1 year (Age: 37.7±7.8 yrs, chronicity: 7.1±6.1yrs VAS: 5.1±1.8, NDI: 21.6±8.4)</td>
<td>10 pain-free women (Age: 33.1±9.3 yrs NS)</td>
<td>Two maximal voluntary contractions at each neck movement (cervical flexion, extension, left and right lateral flexions) (the best was accepted). Assessed with a cervical isometric dynamometer. Sitting position.</td>
</tr>
<tr>
<td>O’Leary et al, 2007</td>
<td>46 women with chronic neck pain&gt;3 months (Age: 37±10.1 yrs, NDI: 22.8±5.2)</td>
<td>Five maximal voluntary contractions of craniocervical flexors (the best was accepted).</td>
<td>Patients with chronic neck pain had reduced strength in craniocervical flexors.</td>
</tr>
<tr>
<td>Study</td>
<td>Control group</td>
<td>Case group</td>
<td>Patients with chronic non-specific neck pain had reduced strength in cervical flexors, extensors and increased flexors/extensors strength ratio</td>
</tr>
<tr>
<td>-------------------------------------------</td>
<td>-------------------------------------------------------------------------------</td>
<td>----------------------------------------------------------------------------</td>
<td>--------------------------------------------------------------------------------</td>
</tr>
<tr>
<td>Rezasoltani et al, 2010</td>
<td>47 pain free women (Age: 27.8±7.7 yrs Sig.)</td>
<td>10 women with chronic non-specific neck pain during the last year (Age: 37.2±6 years)</td>
<td>had reduced strength in cervical flexors, extensors and increased flexors/extensors strength ratio</td>
</tr>
<tr>
<td></td>
<td>Assessed with a craniocervical flexion dynamometer. Supine position.</td>
<td>Three maximal voluntary contractions of cervical flexors and extensors (the best was accepted). Assessed with a cervical isometric dynamometer. Sitting position</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Patients with chronic non-specific neck pain had reduced strength in cervical flexors, extensors and increased flexors/extensors strength ratio</td>
<td></td>
</tr>
<tr>
<td>Scheuer and Friedrich, 2010</td>
<td>10 healthy women (Age: 32.6±6.4 NS)</td>
<td>53 patients with chronic neck pain&gt;3 months (73% females, age: 49.7±10.7 yrs)</td>
<td>had reduced strength in cervical flexors, extensors and lateral flexors</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Control group 42 pain-free controls (71% females, age: 48.7±12 yrs)</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Two maximal voluntary contractions at each neck movement (cervical flexion, extension, left and right lateral flexion). An isometric neck dynamometer was used for the assessment. Standing position</td>
<td></td>
</tr>
<tr>
<td>Ylinen et al, 2004</td>
<td>21 pain free women matched in occupation, age, weight and height</td>
<td>21 women with non-specific chronic neck pain&gt;6 months (Age: 44±6 years, VAS: 54±22mm, ODI: 13±8, NDI: 13±5, Chronicity: 9±6 yrs)</td>
<td>Patients with chronic neck pain had reduced strength in cervical flexors, extensors and rotators</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Control group</td>
<td>had reduced strength in cervical flexors, extensors and rotators</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Three or more maximal voluntary contractions of cervical flexors, extensors and right and left rotators (best was accepted). Assessed with an isometric neck dynamometer. Sitting position.</td>
<td></td>
</tr>
</tbody>
</table>
The muscle weakness of patients with chronic neck pain can be attributed to many underlying causes. O’Leary et al (2007) attribute muscle weakness of cervical muscles mainly to muscle plastic changes and to the altered neural drive as a consequence of chronic neck pain. However, psychosocial influences such as effort inhibition due to pain experience and kinesiophobia also seem to be significant contributors to muscle weakness. The alterations in motor control strategies and neural drive and the muscle plastic changes as well as their underlying mechanisms are more analytically described in Section 2.2.6 “Manifestations of neck pain”.

According to the hypothesis developed by Kapreli et al (2008), the reduction in muscle strength of cervical muscles may have a serious impact on respiratory function. This cervical muscle weakness may affect respiratory function in both a direct and indirect way. Trapezius, scaleni and sternocleidomastoid are all global muscles that participate in both neck movement and inspiration and their potential dysfunction may affect both systems. Scaleni are active during quiet inspiration and contribute to breathing even when the pulmonary volumes increase is very small. In contrast, sternocleidomastoids are relaxed during quiet breathing and activate mainly during forced inspiration. Although scaleni are more active and have a greater mechanical advantage, the greater mass of sternocleidomastoid leads both muscles to similar respiratory effects. Furthermore, it should be mentioned that the topographic allocation of neural drive to the external intercostals and parasternal muscles is related to their inspiratory mechanical advantage (Legrand et al, 2003). Thus, when sternocleidomastoid and scaleni do not produce sufficient force for the purposes of inspiration, other respiratory muscles might undergo this extra burden resulting in increased work of breathing. Considering all of these, it becomes obvious that the weakness of these cervico-respiratory muscles as a consequence of chronic neck pain may also lead to respiratory weakness and dysfunction.

Furthermore, the weakness of these muscles in parallel with the other cervical muscles and the associated changes in motor control and their intrinsic properties may lead to a decrease of their passive or active tension, affecting both their dynamic and active support on the joints, with a consequential decreased ability to produce force and stability in the joints they control. A weak muscle has also reduced ability to counteract to the forces applied to the same anatomical area it supports and it is prone to elongation and strain (Sahrmann, 2002). Thus, Kapreli et al (2008) support that the
dysfunction of these muscles may lead to changes in functional length and recruitment with a subsequential over-pull or under-pull during motion altering the length-tension associations. The changes in force-length curves may finally lead to changes in rib cage mechanics and subsequently to dysfunction of respiratory muscles.

**Endurance/Fatigue**

Muscular endurance can be generally defined as “the ability of a muscle group to exert submaximal force for extended periods” (Heyward, 2010, p. 129). Thus, reduced muscle endurance renders the muscles more prone to fatigue leading to reduced function or duration of activity (de Lateur, 1996). The endurance of cervical muscles in chronic idiopathic neck pain has been examined in a number of studies. These studies are summarized in Table 2.4. The great majority of these studies reveal a reduced ability of both cervical extensors and flexors to exert submaximal loads for a prolonged time (Harris et al, 2005; Lee et al, 2005; O’Leary et al, 2007; Peolsson and Kjellman, 2007). This deficit seems to be apparent in both the upper and lower cervical region. Furthermore, electromyographic studies reveal an increased activation of superficial cervical muscles (Falla et al, 2003; Falla et al, 2004a; Falla et al, 2004c; Jull et al, 2004; Kumar et al, 2007; Johnston et al, 2008a; Johnston et al, 2008b, Cheng et al, 2010) suggesting that these muscles become quickly fatigued as they need to be more active to produce the same amount of force. Furthermore, deep cervical flexors seem to be hypoactive (Falla et al, 2004b) leaving cervical vertebrae without support with a consequential instability. The reduced endurance of upper and lower cervical muscles has been also observed in cervicogenic headache (Watson and Trott, 1993; Dumas et al, 2001).
<table>
<thead>
<tr>
<th>Study</th>
<th>Sample</th>
<th>Assessment</th>
<th>Results</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cheng et al, 2010</td>
<td><strong>Case group</strong> 12 patients with non-traumatic chronic neck pain&gt;2 years (6 females, age: 25.4±2.1yrs, chronicity: 4.4±2.2yrs, NRS: 3.7±0.8, NDI: 10.4±5)</td>
<td>EMG of SCM, splenius capitis and semispinalis capitis during return from flexion or extension to NHP. 3 trials. MVC normalized average rectified values. Sitting position.</td>
<td>Patients with chronic neck pain had relatively normal activity of their SCMs and semispinalis capitis, but increased activation of their splenius capitis.</td>
</tr>
<tr>
<td></td>
<td><strong>Control group</strong> 12 asymptomatic age-matched controls (5 females, age:24.9±1.8yrs NS)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Edmondston et al, 2011</td>
<td><strong>Case group</strong> 13 women with postural chronic neck pain&gt;3 months (age:28.9±12.6yrs, chronicity: 51±16 months, usual VAS: 42±16mm, NPAD: 34.6±12.1%)</td>
<td>EMG of SCM and erector spinae during neck extensor and neck flexor endurance test. Both EMG and time-dependent test. Median frequency decline rate after sub-maximal normalization was used. Supine position for neck flexors and prone position for neck extensors.</td>
<td>Patients with chronic neck pain did not have significant myoelectric manifestations of fatigue in their examined muscles. They also did not have time-dependent endurance deficits in both neck flexors and extensors.</td>
</tr>
<tr>
<td></td>
<td><strong>Control group</strong> 12 asymptomatic women (age: 26.1±5.3yrs)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Falla et al, 2003</td>
<td><strong>Case group</strong> 10 patients with non-neurogenic chronic neck pain&gt;1 year (9 females, age:28.7±9.2 yrs, chronicity: 4.7±3.4 yrs, currentVAS:0.5±0.8 cm, usual VAS: 5.6±2cm, NDI: 12.7±2.8)</td>
<td>EMG of SCM and AS during isometric contraction of neck flexors at 25% and 50% of their MVC. Initial values and rate of change of the mean median frequency, average rectified value and conduction velocity normalized with the</td>
<td>Patients with chronic neck pain had increased myoelectric manifestations of muscle fatigue for both SCM and AS in contractions of 25% and 50% of their MVC.</td>
</tr>
</tbody>
</table>

Table 2.4: Neck muscle activity and endurance in chronic idiopathic neck pain.
<table>
<thead>
<tr>
<th>Study (Falla et al., 2004a)</th>
<th>Control group</th>
<th>Case group</th>
<th>Electroencephalography (EEG) and muscle activity</th>
<th>Patients with chronic neck pain had increased activation (reduced neuromuscular efficiency) of their SCM and AS at 25% of maximal load, but relatively normal activity at 50%.</th>
</tr>
</thead>
<tbody>
<tr>
<td>10 asymptomatic individuals (9 females, age: 30.1±7.6 yrs)</td>
<td>20 patients with non-neurogenic chronic neck pain&gt;1 year (17 females) (29±6.8 yrs) (chronicity: 5.2±3.2yrs)</td>
<td>EMG of SCM and AS during flexion. EMG during isometric contractions at 25% and 50% of their MVC. MVC normalized average rectified value was used.</td>
<td>Controls had normal activity at 25% and 50% MVC. Case group had increased activity at 25% MVC and decreased activity at 50% MVC.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>20 asymptomatic individuals (16 females) (30±7.5 yrs)</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Study (Falla et al., 2004b)</th>
<th>Control group</th>
<th>Case group</th>
<th>Electroencephalography (EEG) and muscle activity</th>
<th>Patients with chronic neck pain tend to have increased activity in SCM and AS. They also had reduced activity in their deep neck flexors especially when the task demands increased.</th>
</tr>
</thead>
<tbody>
<tr>
<td>10 asymptomatic individuals (7 female, age: 26.4±5.8 yrs)</td>
<td>10 female patients with non-neurogenic unilateral chronic neck pain&gt;1 year (age:32.3±7.2yrs, chronicity: 5.9±3.7 yrs, VAS: 5±2.1cm, NDI: 11.8±5.1)</td>
<td>Superficial EMG of SCM and AS and invasive EMG of deep neck flexors during the craniocervical flexion test. Internal peak amplitude normalized root mean square was used.</td>
<td>Controls had normal activity at 25% and 50% MVC. Case group had increased activity at 25% MVC and decreased activity at 50% MVC.</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Study (Falla et al., 2004c)</th>
<th>Control group</th>
<th>Case group</th>
<th>Electroencephalography (EEG) and muscle activity</th>
<th>The SCM and AS of the painful side had greater myoelectric manifestations of fatigue in both 25% and 50% MVC contractions.</th>
</tr>
</thead>
<tbody>
<tr>
<td>The non-painful side of the same patients</td>
<td>10 female patients with non-neurogenic unilateral chronic neck pain&gt;1 year (age:32.3±7.2yrs, chronicity: 5.9±3.7 yrs, VAS: 5±2.1cm, NDI: 11.8±5.1)</td>
<td>EMG of SCM and AS during isometric contraction of neck flexors at 25% and 50% of their MVC. Initial values and rate of change of the mean median frequency, average rectified value and conduction velocity normalized with the intercept of the</td>
<td>Controls had normal activity at 25% and 50% MVC. Case group had increased activity at 25% MVC and decreased activity at 50% MVC.</td>
<td></td>
</tr>
<tr>
<td>Study</td>
<td>Case group</td>
<td>Control group</td>
<td>Supine position.</td>
<td></td>
</tr>
<tr>
<td>------------------------</td>
<td>------------------------------------------------------------------------------</td>
<td>--------------------------------------------------------------------------------</td>
<td>--------------------------------------------------------------------------------</td>
<td></td>
</tr>
<tr>
<td>Harris et al, 2005</td>
<td>20 patients with non-traumatic neck pain (38±10 yrs)</td>
<td>20 asymptomatic individuals (33±8 yrs)</td>
<td>Neck flexor muscle endurance test. Time-dependent test. Supine position.</td>
<td></td>
</tr>
<tr>
<td></td>
<td><strong>Harris et al, 2005</strong></td>
<td><strong>Control group</strong></td>
<td>Patients with neck pain had reduced endurance of their neck flexors.</td>
<td></td>
</tr>
<tr>
<td>Johnston et al, 2008a</td>
<td>Three subgroups -14 office workers with moderate neck pain (age: 45.5±10.3yrs, chronicity: 8.2±8.7 yrs, NDI: 33.5±3.6) -38 office workers with mild pain (age: 43.8±9.4yrs, chronicity: 10.7±8.7 yrs, NDI: 19.5±5.9) -33 office workers without neck pain (age: 43.2±10.6yrs)</td>
<td>22 non-office women workers without neck pain (age:37.4±10.5yrs)</td>
<td><strong>Johnston et al, 2008a and 2008b</strong></td>
<td></td>
</tr>
<tr>
<td></td>
<td><strong>Case group</strong></td>
<td><strong>Control group</strong></td>
<td><strong>a)EMG of SCM, AS, UT and cervical extensors (splenius capitis) during typing tasks. Peak amplitude normalized mean square root was used. Sitting position.</strong></td>
<td></td>
</tr>
<tr>
<td></td>
<td><strong>Three subgroups</strong> -14 office workers with moderate neck pain (age: 45.5±10.3yrs, chronicity: 8.2±8.7 yrs, NDI: 33.5±3.6) -38 office workers with mild pain (age: 43.8±9.4yrs, chronicity: 10.7±8.7 yrs, NDI: 19.5±5.9) -33 office workers without neck pain (age: 43.2±10.6yrs)</td>
<td><strong>22 non-office women workers without neck pain (age:37.4±10.5yrs)</strong></td>
<td><strong>b)The same electromyographic procedure for the craniocervical flexion test and a unilateral muscle coordination task</strong></td>
<td></td>
</tr>
<tr>
<td></td>
<td><strong>a)SCM, AS and cervical extensors of all office workers were hyperactive during typing tasks. The three subgroup of office workers did not present sig. differences in their muscles activity, although the moderate pain subgroup tended to be more active than the other two subgroups.</strong></td>
<td><strong>b)Mild and moderate patients had increased activity of both SCM and AS during craniocervical flexion test and this was more obvious as the procedure was becoming more demanding. Greater activation was also observed for SCM, AS, UT and cervical extensors unilateral to coordination task.</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Jull et al, 2004</td>
<td>25 patients with idiopathic neck pain</td>
<td>EMG of SCM during craniocervical flexion test (action)</td>
<td>Both patients with idiopathic neck pain and whiplash had</td>
<td></td>
</tr>
</tbody>
</table>
(80% females, age: 40.3±9.2 yrs, chronicity: 8.5±6 yrs, usual VAS: 6.3±1.5cm)

Control group A
25 patients with whiplash (68% females, age: 36.3±10.2 yrs, chronicity: 1.8±1.1 yrs, usual VAS: 6.2±2.3)

Control group B
25 asymptomatic individuals (60% females, age: 39.3±2.3 yrs)

Kumar et al, 2007
Case group
34 patients with chronic neck pain>3 months
(17 females, age:52 yrs)

Control group
63 asymptomatic individuals (33 females, age: 32 yrs)

Case group
EMG of SCMs, UTs and splenius capitis during maximal isometric (pain tolerance for patients) and 20% of maximal isometric contractions (pain threshold for patients) of neck flexors, extensors, lateral flexors and posterolateral extensors. Peak normalized EMG was mainly used. Sitting position.

Patients with chronic neck pain had increased activation of their muscles during the most maximal and submaximal contractions.

Lee et al, 2005
Case group
17 patients with untreated neck pain
Age: 40.5±15.1 yrs

Control group A
16 pain-free individuals
(40.5±15.1 yrs NS)


Both patients with treated and untreated neck pain had reduced endurance of their neck extensors.
<table>
<thead>
<tr>
<th>Study</th>
<th>Control group B</th>
<th>Case group</th>
<th>EMG of SCM and splenius capitis during isometric contractions of neck flexors and extensors. MVC normalized average rectified value was used. Sitting position.</th>
<th>During flexion, patients with chronic neck pain had increased activity of splenius capitis (reduced neuromuscular efficiency), but not of SCM. During extension both SCM and splenius capitis were hyperactive.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lindstrom et al, 2011</td>
<td>22 individuals with treated neck pain (37.9±12.1 yrs NS)</td>
<td>13 women with chronic non-traumatic neck pain&gt;1 year (37.7±7.8 yrs)</td>
<td>VAS: 5.1±1.8 cm</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Control group</td>
<td>10 pain-free women (33.1±9.3 yrs)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>O’Leary et al, 2007</td>
<td>Case group</td>
<td>46 women with chronic neck pain&gt;3 months (Age: 37±10.1 yrs) (NDI: 22.8±5.2)</td>
<td>Voluntary contraction of craniocervical flexors at 20% and 50% of their isometric MVC. Time dependent test. Supine position.</td>
<td>Patients with chronic neck pain had reduced endurance in their craniocervical flexors at both 20% and 50% of their MVC.</td>
</tr>
<tr>
<td></td>
<td>Control group</td>
<td>47 pain free women (27.8±7.7 yrs Sig.)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Peolsson and Kjellman, 2007</td>
<td>Case group</td>
<td>78 patients with non-whiplash and non-neurogenic neck pain (45±11yrs) (VAS: 35±22mm) (NDI: 32±16)</td>
<td>Upper neck extensor and upper neck flexor endurance tests. Time dependent tests. Prone position for extensors and supine position for flexors.</td>
<td>Patients with neck pain had decreased endurance of their upper neck flexors and extensors.</td>
</tr>
<tr>
<td></td>
<td>Control group</td>
<td>116 gender- matched healthy controls (43±12yrs)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

The findings of the above studies can be explained by the muscle fibers transformation, and the modification of motor unit synchronization. In patients with chronic neck pain a percentage of slow-twitched type I muscle fibers is transformed to fast-twitched type IIb muscle fibers (Uhlig et al, 1995). Considering that type IIb muscle fibers are more prone to fatigue, it becomes obvious that the cervical muscles of patients with chronic neck pain have reduced ability to bear loads effectively for prolonged time (Falla et al, 2004c). The greater activity of superficial muscles with their consequential greater fatigability can be explained as a compensatory mechanism to the reduced electromyographic activity of deep cervical muscles. This compensation results in modification of neural strategies of recruitment of motor neurons for achieving the same functional task. The greater electromyographic activity of superficial muscles can be also explained by the fact that nociceptive input changes the excitability of the motoneuron pool with a consequential increase of the reflex-mediated muscle stiffness. This increase may lead to reduced blood flow and consequential accumulation of metabolites and ions which further stimulate γ-muscle spindle system and lead to a further stimulation of alpha motoneurons (Falla, 2004; Falla et al, 2004a). Lastly, it should be mentioned that the reduced relative resting periods and prolonged muscle activity after voluntary contraction of superficial muscles of chronic neck pain patients are a further explanation for the greater fatigability of their neck muscles (Falla and Farina, 2008).

Kapreli et al (2008) suggested that the increased fatigability of superficial cervical muscles and the decreased ability of deep cervical muscles to bear submaximal loads for a prolonged time may have a serious impact on respiratory function. The reduced endurance of cervical muscles and especially of the sternocleidomastoid, scaleni and trapezius may lead them to quickly lose their ability to produce optimal force and consequentially this may lead to respiratory dysfunction in a manner similar to the reduced muscle strength described in the previous subsection. Furthermore, important role to this respiratory dysfunction seem to play the deficits in local muscles. The local muscle system, acting as a system of “active ligaments”, plays an important role for segmental stability and movement control (Comerford and Mottram, 2001a). The reduced endurance and hypoactivity of these deep cervical muscles may lead to segmental instability not only of the specific area, but also of their related articulations such as the shoulder and thoracic spine (Key et
al, 2008a; Key et al, 2008b). Considering that respiration necessitates a stable spine in order to appropriately be performed, the spinal instability caused by the local muscular system may lead to alteration of rib cage mechanics. This altered thorax biomechanics which is further compromised by the postural alterations and muscle imbalances due to the dysfunction of both the global and local muscle system may lead to dysfunction of other related respiratory muscles such as the diaphragm, intercostals or abdominals leading to a more generalized respiratory dysfunction (Kapreli et al, 2008).

### Range of movement

Range of Movement (ROM) is the range within which a joint is available to move and to a great extent reflects the joint mobility. The mobility of a joint can be examined either through its active or passive ROM. Active ROM is more idiosyncratic and more difficult to interpret, but it offers a better representation of coupled-motion sequences and is more representative of activities of daily life (Strimpakos, 2011a). The active range of cervical movement has been examined in a number of studies (Rix and Bagust, 2001; Chiu and Lo, 2002; Lee et al, 2005; Cagnie et al, 2007b; Grip et al, 2007; Vogt et al, 2007; Grip et al, 2008; Johnston et al, 2008b; Sjolander et al, 2008; Cheng et al, 2010) (Table 2.5). Despite some inconsistencies, a great amount of literature agrees that patients with chronic idiopathic neck pain have reduced ROM in each cervical movement. The same conclusions derive when the population of interest is patients with cervicogenic headache and this mobility is further affected when neck pain is traumatic in origin (Dumas et al, 2001).
Table 2.5: Cervical Range of Movement (ROM) in chronic idiopathic neck pain.

<table>
<thead>
<tr>
<th>Study</th>
<th>Sample</th>
<th>Assessment</th>
<th>Results</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cagnie et al, 2007b</td>
<td>Case group 14 females with chronic idiopathic neck pain&gt;6 months (age: 28.3±5.4yrs)</td>
<td>Active total ROM in sagittal, frontal and transverse plane. Three trials for each movement plane. Ultrasound-based motion analysis system. Sitting position.</td>
<td>Patients with whiplash had reduced ROM in all planes. Patients with chronic idiopathic neck pain had reduced ROM only in transverse plane. Patients with idiopathic neck pain had higher mobility in sagittal and frontal plane in comparison with whiplash patients.</td>
</tr>
<tr>
<td></td>
<td>Control group A 16 females with whiplash&gt;6 months (age: 27.5±4.8yrs)</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Control group B 16 asymptomatic females (age: 20-34 yrs)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cheng et al, 2010</td>
<td>Case group 12 patients with non-traumatic chronic neck pain&gt;2 years (6 females, age: 25.4±2.1yrs, chronicity: 4.4±2.2yrs, NRS: 3.7±0.8, NDI: 10.4±5)</td>
<td>Active ROM of flexion and extension. 3 trials. Electrogoniometer. Sitting position.</td>
<td>Flexion ROM was not affected in patients with chronic neck pain, but extension ROM had a trend to be decreased.</td>
</tr>
<tr>
<td></td>
<td>Control group 12 asymptomatic age-matched controls (5 females, age:24.9±1.8yrs NS)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Chiu and Lo, 2002</td>
<td>Case group 21 patients with mechanical neck pain (12 females, age: 27±9.5 yrs)</td>
<td>Active ROM of flexion, extension, lateral flexions and rotations. 3 trials for each movement (mean and average were used). Potentiometer-</td>
<td>Patients had decreased extension ROM and trends for decreased flexion and right lateral flexion. All the other movements had normal ROM.</td>
</tr>
<tr>
<td></td>
<td>Control group 25 healthy participants (10)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Grip et al, 2007 and 2008

**Case group**
21 patients with chronic idiopathic neck pain >3 months (14 females, age: 49±16yrs, VAS: 49.2±20.8cm, NPAD: 36.2±18.8)

**Control group A**
22 patients with whiplash >3 months (17 females, age: 49±15yrs NS, VAS: 66.1±18.8cm, NPAD: 59.8±17)

**Control group B**
24 asymptomatic individuals (16 females, age: 50±18yrs NS)

Inclinometer.
(position is not mentioned)

5 repetitions.
Sitting position.

(2007) Patient with chronic neck pain had reduced ROM for all their neck movements and for the whiplash patients the neck motion was more affected.

(2008) The same conclusions with their previous study.

Johnston et al, 2008b

**Case group**
Three subgroups
-14 office workers with moderate neck pain (age: 45.4±10.3yrs, chronicity: 8±8.7 yrs, NDI: 33.5±3.6, VAS:1.9±2.4)
-38 office workers with mild pain (age: 43.8±9.4yrs, chronicity: 10.7±8.7 yrs, NDI: 19.5±5.9, VAS: 1.5±1.5)
-33 office workers without neck pain (age: 43.2±10.6yrs)

**Active ROM of flexion, extension, lateral flexions and rotations.
3D electromagnetic motion tracking device.
Sitting position.**

There were no statistical differences in active ROM of each movement. However, there was a trend for ROM reduction for every neck movement as the pain increases.
women workers without neck pain (age: $37.4\pm10.5$ yrs)

Lee et al, 2005

**Case group**
17 patients with untreated neck pain  
Age: $40.5\pm15.1$ yrs

**Control group A**
16 pain-free individuals  
($40.5\pm15.1$ yrs NS)

**Control group B**
22 individuals with treated neck pain  
($37.9\pm12.1$ yrs NS)

Active ROM of flexion, extension, rotations, lateral flexion, protraction, retraction.  
Two trials.  
CROM device.  
Sitting position.

At the first trial only protraction was decreased for the treated neck pain group.  
At the second trial only rotations and extension were reduced for the neck pain groups.  
Flexion had a strong trend to be reduced for the neck pain groups.

Rix and Bagust, 2001

**Case group**
11 patients with chronic non-traumatic neck pain >7 weeks  
(5 females, age: $41.1\pm13.3$ yrs, chronicity: $24\pm18$ months, current NRS: $5.1\pm1.9$)

**Control group**
11 gender- and age-matched asymptomatic controls (5 females, age: $39.3\pm10.3$ yrs)

Active ROM of flexion, extension, rotations and lateral flexions.  
3 trials for each neck movement (mean was accepted).  
CROM device.  
Sitting position.

Cervical ROM was reduced for each neck movement although only a trend was observed for left rotation, extension and right lateral flexion ROM.

Sjolander et al, 2008

**Case group**
9 patients with chronic idiopathic neck pain >6 months  
(9 females, age: $40\pm9$ yrs, chronicity: $97\pm68$ months, usual VAS: $52\pm16$mm, NDI: $37\pm11$)

**Control group A**
7 whiplash

Active ROM of fast right and left rotations.  
8 trials (mean was accepted.  
Electromagnetic motion analysis system.  
Standing position.

Whiplash patients had reduced ROM in comparison to asymptomatic individuals and increased ROM in comparison to patients with chronic idiopathic neck pain although these differences were not significant.
patients >6 months (5 females, age: 45±11 yrs NS, chronicity: 76±84 months NS, usual VAS: 45±19 mm NS, NDI: 44±23 NS)

Control group B
16 asymptomatic individuals (13 females, age: 41±9 yrs NS)

Vogt et al, 2007

<table>
<thead>
<tr>
<th>Case group</th>
<th>Active ROM of flexion, extension, lateral flexions and rotations. 10 trials (mean was accepted). Ultrasound-based motion analysis system. Sitting position.</th>
</tr>
</thead>
<tbody>
<tr>
<td>16 patients with chronic neck pain &gt;1 year (10 females, age: 55.8±2.8 yrs, Current VAS: 37±8 mm)</td>
<td></td>
</tr>
</tbody>
</table>

Control group
18 healthy participants (10 females, age: 56.6±3.5 yrs)

All neck movements had reduced ROM in patients with chronic neck pain, except right lateral flexion which presented only a trend to be reduced.


Although the mechanisms for reduction in range of cervical movement are not absolutely known, several mechanisms have been proposed in the literature. Despite the fact that muscle elasticity is the major contributor to ROM changes, these changes are also dependent on other structures such as tendons, ligaments and bones (Krivickas, 1999). Prolonged immobilization of a muscle in a shortened position leads to a reduction of the number of sarcomeres and reduced maximal length and extensibility. Furthermore, the increased abundance and remodeling of connective tissues due to immobilization also leads to increased elastic stiffness further compromising movement (Gajdosik, 2001). Thus, in patients with chronic neck pain the prolonged maintenance of a bad posture or the avoidance of certain movements for an extended period may lead to such structural changes compromising cervical
ROM. Lee et al (2005) also purport that the reduced ROM of the cervical area may be at least initially a protective mechanism for avoiding stress in the pain-sensitive structures and Jull et al (2008a) that muscle shortening may be protective of nerve tissue mechanosensitivity. Abnormal cervical segmental mobility may further reduce cervical mobility (Dvorak et al, 1988). Finally, despite its questionable influence on idiopathic neck pain, the impact of kinesiophobia on cervical mobility should not be underestimated (Grip et al, 2007).

According to the hypothesis developed by Kapreli et al (2008), the reduced cervical ROM may also contribute to respiratory dysfunction. This assertion seems to be sound when observing reduced cervical mobility as a result of reduced cervical segmental mobility or/and muscle shortening. Reduced segmental mobility in the cervical spine may lead to a compensatory increased mobility of the neighboring thoracic spine (relative stiffness) (Comerford and Mottram, 2001a) altering the stability of the thoracic area. Furthermore, the shortened cervical muscles may change the length-tension relationships as they present reduced ability for force production and appear to be strong only in their shortened position (Gossman et al, 1982; Comerford and Mottram, 2001a). These changes in segmental mobility, length-tension relationships and the consequential muscle imbalances and postural changes might finally affect rib cage mechanics and respiratory function in a way similar to the one which has already been described for the muscle strength and endurance deficits. However, it should be mentioned that the fact that patients with chronic neck pain demonstrate reduced cervical ROM does not mean that muscles should only appear as short. Muscle elongation is also possible (Comerford and Mottram, 2001a) and the way it potentially affects respiratory function has been discussed in the previous subsections.

**Proprioception**

Proprioception has been described in the literature as a variation in the sense of touch including the sense of joint motion known as kinesthesia and the sense of joint position (Reinold et al, 2009). Through the years further dimensions of proprioception such as vibration sense, force magnitude sense, postural sway and
delay of muscle contraction have been recognized and used for its assessment (Callaghan, 2011). Joint position sense is the usual measure used for assessing proprioception of the cervical spine. This measure is obtained either by the repositioning of the head to a predetermined target position (head-to-target) or by the head repositioning to the natural head position (head-to-neutral) (Cheng et al, 2010). The accuracy of the performance of each test may be assessed by the constant error which assesses the deviation from the target taking into consideration any over- or under-estimation of the target and the absolute error which assess the deviation from the target without considering this over- or under-estimation. The consistency of the performance may be assessed by the variable error which assesses how repeatable the estimation was independently from its accuracy. Finally, the total variability or root mean square error is a combination of variable and constant error providing a general estimate of the performance (Schmidt and Lee, 2005).

The findings about the existence of proprioceptive deficits in patients with chronic idiopathic neck pain are variable. Many studies detect this abnormality (Pinsault et al, 2008a; Sjolander et al, 2008; Roren et al, 2009; Cheng et al, 2010), but other studies either fail to detect proprioceptive deficits or suggest this was the general conclusion from a number of proprioceptive tests (Rix and Bagust, 2001; Kristjansson et al, 2003; Edmondston et al, 2007; Grip et al, 2007) (Table 2.6). This inconsistency is further enhanced by findings in patients with cervicogenic headache which show that although they have decreased cervical strength, endurance and ROM, their proprioception was not impaired (Dumas et al, 2001). The responsible mechanisms for reduced proprioception in patients with chronic neck pain have already been described in Section 2.2.6 “Manifestations of neck pain”.

The findings about the existence of proprioceptive deficits in patients with chronic idiopathic neck pain are variable. Many studies detect this abnormality (Pinsault et al, 2008a; Sjolander et al, 2008; Roren et al, 2009; Cheng et al, 2010), but other studies either fail to detect proprioceptive deficits or suggest this was the general conclusion from a number of proprioceptive tests (Rix and Bagust, 2001; Kristjansson et al, 2003; Edmondston et al, 2007; Grip et al, 2007) (Table 2.6). This inconsistency is further enhanced by findings in patients with cervicogenic headache which show that although they have decreased cervical strength, endurance and ROM, their proprioception was not impaired (Dumas et al, 2001). The responsible mechanisms for reduced proprioception in patients with chronic neck pain have already been described in Section 2.2.6 “Manifestations of neck pain”.

Table 2.6: Cervical proprioception in chronic idiopathic neck pain.

<table>
<thead>
<tr>
<th>Study</th>
<th>Sample</th>
<th>Assessment</th>
<th>Results</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cheng et al, 2010</td>
<td><strong>Case group</strong> 12 patients with non-traumatic chronic neck pain&gt;2 years (6 females, age: 25.4±2.1yrs, chronicity:</td>
<td>Head-to-neutral test. (from flexion and extension). Eyes opened. 3 trials. CE, VE and RMSE were calculated.</td>
<td>Patients with chronic neck pain had reduced repositioning accuracy (CE and RMSE) for both extension-to-neutral and flexion-</td>
</tr>
<tr>
<td>Study</td>
<td>Case group</td>
<td>Control group</td>
<td>Comparison</td>
</tr>
<tr>
<td>----------------------------</td>
<td>----------------------------------------------------------------------------</td>
<td>-------------------------------------------------------------------------------</td>
<td>------------</td>
</tr>
<tr>
<td>Edmondston et al, 2007</td>
<td><strong>Case group</strong> 21 patients with postural chronic neck pain&gt;3 months (11 females, age: 29±7.4yrs, chronicity: 5.2±4.3yrs, VAS: 48.3±14.8mm)</td>
<td><strong>Control group</strong> 22 asymptomatic individuals (12 females, age: 25.7±6yrs)</td>
<td>Patients with chronic neck pain had not affected repositioning accuracy for the head protraction and head tilt.</td>
</tr>
<tr>
<td></td>
<td>Relaxed to perceived good posture test. Eyes closed. 6 trials (mean was accepted). The repositioning accuracy of head protraction and head tilt were assessed. 3D optical motion analysis system. Sitting position.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Grip et al, 2007</td>
<td><strong>Case group</strong> 21 patients with chronic idiopathic neck pain&gt;3 months (14 females, age: 49±16yrs, VAS: 49.2±20.8cm, NPAD: 36.2±18.8)</td>
<td><strong>Control group A</strong> 22 patients with whiplash&gt;3 months (17 females, age: 49±15yrs, VAS: 66.1±18.8cm, NPAD: 59.8±17)</td>
<td>There was no difference in repositioning accuracy for the three groups although whiplash patients had slightly inferior scores.</td>
</tr>
<tr>
<td></td>
<td>Head-to-target test (flexion, extension, rotations). 5 trials for each movement. Eyes closed. The mean AE, CE and VE were used. Optical motion analysis system. Sitting position.</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Kristjansson et al 2003

**Case group**
20 patients with chronic idiopathic neck pain >3 months (9 females, age: 30±9.1 yrs, chronicity: 28.6±15.5 months, usual VAS: 3.15±2.11 cm, current VAS: 1.82±2 cm, NPAD: 20.53±11.18).

**Control group A**
22 patients with whiplash >3 months (11 females, age: 33.4±10.6 yrs NS, chronicity: 21.9±12.5 months NS, usual VAS: 4.5±2.7 cm NS, current VAS: 3.4±2.8 cm Sig., NPAD: 40±18 Sig.).

**Control group B**
21 asymptomatic individuals (11 females, age: 26.9±6.4 yrs NS).

---

Pinsault et al, 2008a

**Case group**
7 patients with chronic non-traumatic neck pain >3 months (4 females, age: 56±9 yrs).

**Control group A**
7 bilateral labyrinthine-defective patients (3 females, 67±15 yrs).

**Case group**
5 different proprioception tests (head-to-neutral from rotation, head-to-rotation target, head-to-target with rotated trunk, figure-of-eight relocation and figure-of-eight movement test). Eyes closed. 3 trials (mean was accepted). Absolute error for the first four tests and the accuracy of moving through a target for the fifth test. 3D digital motion analysis system. Sitting position.

**Control group A**
7 bilateral labyrinthine-defective patients (3 females, age: 67±15 yrs).

Head-to-neutral from rotation. Eyes closed. 10 trials from each side of rotation. Laser beam technique (Ravel technique). Recording of horizontal, vertical and global AE and VE. Sitting position.

Patients with chronic neck had increased repositioning AE and VE in horizontal plane. The global AE were also increased in chronic neck pain patients, but global VE were not affected. In vertical plane no difference was found between the groups.
<table>
<thead>
<tr>
<th>Study</th>
<th>Control Group A</th>
<th>Case Group</th>
<th>Kinesthetic Performance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Case Group</td>
<td>Control group B</td>
<td>Head-to-neutral test (from right and left rotation, extension and flexion). Eyes closed. 10 trials from each direction (mean was accepted). Laser-beam technique (Ravel technique). Horizontal, vertical and global AE and CE were calculated. Sitting position.</td>
<td>Normal kinesthetic performance.</td>
</tr>
</tbody>
</table>
months, usual VAS: 52±16mm, NDI:37±11) calculated). Electromagnetic motion analysis system. Standing position. significant VE in comparison to the chronic idiopathic neck pain group.

<table>
<thead>
<tr>
<th>Control group A</th>
<th>7 whiplash patients&gt;6 months (5 females, age: 45±11yrs NS, chronicity:76±84 months NS, usual VAS: 45±19mm NS, NDI: 44±23 NS)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control group B</td>
<td>16 asymptomatic individuals (13 females, age: 41±9 yrs NS)</td>
</tr>
</tbody>
</table>


The model developed by Kapreli et al (2008) also purports that potential deficits in proprioception may play an important role in changes of respiratory function. Based on Kapreli and Athanasopoulos (2006) it has been proposed that the altered afferent somatosensory input with the subsequential reorganization of the central nervous system leads to an altered efferent input to cervical muscles. These altered efferents may lead both to reduced or inhibited spinal reflexes leading to dynamic instability of the cervical area or to inhibition of voluntary movements leading to arthrogenous muscle atrophy. The final outcome of these changes may be a reduced functional ability of the cervical area and changes in motor control patterns. According to Kapreli et al (2008), considering the anatomical connection of cervical area and respiratory system as well as the previously described potential effects of reduced strength and segmental instability on respiratory function, these changes may also lead to changes in rib cage mechanics and a consequential respiratory dysfunction.
Forward head posture

Forward Head Posture (FHP) can be generally defined as the anterior head displacement in relation to the body vertical midline (Kendall et al, 2005). Another definition of FHP is the head protrusion accompanied by an upper cervical extension and lower cervical flexion (Szeto et al, 2002) although Kendall et al (2005) support that radiographic evidence shows not only that there is no flexion in lower cervical spine, but also that there is an extension more pronounced than the one of the upper cervical area. FHP can be assessed through different means. The first method is the measurement of the craniovertebral angle which is found between the line extending from the tragus of the ear to the 7th cervical vertebra (C7) spinous process and the horizontal line through C7. A decreased angle means an increased forward head posture. The second method is the measurement of the angle between the line extending from the C7 spinous process to the mastoid process and the line extending from the mastoid process to the outer canthus of the eye. The rationale of this measurement is the description of head posture in relation to the external environment. Another method is the measurement of head posture as a product of both lower cervical flexion and upper cervical extension. The upper cervical extension (head tilt) is measured as the angle between the line from the forehead to tragus and the Y axis. The lower cervical flexion (neck flexion) is measured as the angle between the line from the C7 to tragus and the Y-axis (Yoo et al, 2005).

Although in clinical practice FHP was usually considered as a clinical sign of chronic neck pain, the evidence about the existence of FHP in these patients is inconsistent. Although some studies support the adoption of this bad posture by patients with chronic neck pain (Yip et al, 2008; Lau et al, 2009; Lau et al, 2010), other studies fail to detect any cervical posture abnormality (Hanten et al, 2000; Szeto et al, 2002; Lee et al, 2005; Edmondston et al, 2007; Kapreli et al, 2009) (Table 2.7). Evidence provided by patients with cervicogenic headache further supports this inconsistency (Watson and Trott, 1993; Placzek et al, 1999; Dumas et al, 2001). Thus, considering all of this evidence it can be concluded that although there are some implications about the existence of FHP in patients with chronic idiopathic neck pain, the actual presentation of this postural abnormality remains questionable.
Table 2.7: Forward Head Posture (FHP) in chronic idiopathic neck pain.

<table>
<thead>
<tr>
<th>Study</th>
<th>Sample</th>
<th>Assessment</th>
<th>Results</th>
</tr>
</thead>
<tbody>
<tr>
<td>Edmondston et al</td>
<td>Case group 21 patients with postural chronic neck pain&gt;3 months (11 females, age: 29±7.4yrs, chronicity: 5.2±4.3yrs, VAS: 48.3±14.8mm)</td>
<td>FHP (C7-tragus-vertical angle), head tilt (eyes-tragus-vertical angle) and perceived good posture. 6 trials (mean was accepted). 3D optical motion analysis system. Sitting position</td>
<td>Patients with chronic neck pain did not have FHP and head tilt. They only had different perception about the optimal head posture.</td>
</tr>
<tr>
<td>2007</td>
<td>Control group 22 asymptomatic individuals (12 females, age: 25.7±6yrs)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hanten et al, 2000</td>
<td>Case group 42 patients with neck pain (29 females, age: 43yrs)</td>
<td>FHP (distance of zygomatic arch from the wall). Tape measure. Sitting and standing position.</td>
<td>Patients with neck pain did not present any difference in head posture either from sitting or from standing position.</td>
</tr>
<tr>
<td></td>
<td>Control group 42 age- and gender-matched asymptomatic individuals</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Kapreli et al, 2009</td>
<td>Case group 12 patients with chronic idiopathic neck pain&gt;6 months (7 females, age: 29.4±3.6yrs, chronicity: 4.8±3.7yrs, NDI: 30.3±9, usual VAS: 4.6±2.3cm, current VAS: 3.7±2.1cm)</td>
<td>FHP (craniovertebral angle). Lateral photograph. Sitting position.</td>
<td>Patients with chronic neck pain did not have FHP.</td>
</tr>
<tr>
<td>Study</td>
<td>Group Details</td>
<td>Methods</td>
<td>Findings</td>
</tr>
<tr>
<td>-----------------------</td>
<td>------------------------------------------------------------------------------</td>
<td>------------------------------------------------------------------------</td>
<td>--------------------------------------------------------------------------</td>
</tr>
<tr>
<td>Lau et al, 2009</td>
<td><strong>Case group</strong> 26 patients with chronic neck pain&gt;3 months (15 females, age: 36.5±9.7yrs)</td>
<td>FHP (craniovertebral angle). Electronic head posture instrument (inclinometer-based). 2 assessorX2 trials (the mean of the totally four trials was accepted).</td>
<td>Patients with chronic neck pain have increased FHP.</td>
</tr>
<tr>
<td></td>
<td><strong>Control group</strong> 27 asymptomatic individuals (15 females, age: 31.9±7.6yrs NS)</td>
<td>Standing position.</td>
<td></td>
</tr>
<tr>
<td>Lau et al, 2010</td>
<td><strong>Case group</strong> 30 patients with neck pain (20 females, age: 36.8±9.8yrs, NRS: 5.9±1.6, NPQ: 34.2±11.6)</td>
<td>FHP (craniovertebral angle). Two assessments by the first therapist and one assessment by the second therapist (3 in total). Lateral photograph. Sitting position.</td>
<td>Patients with neck pain have increased FHP.</td>
</tr>
<tr>
<td></td>
<td><strong>Control group</strong> 30 asymptomatic individuals (13 females NS, age: 34.5±10yrs NS)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lee et al, 2005</td>
<td><strong>Case group</strong> 17 patients with untreated neck pain Age: 40.5±15.1 yrs</td>
<td>FHP (head protraction). CROM device. Comfortable and upright sitting.</td>
<td>Patients with untreated neck pain had similar FHP with pain-free individuals, but increased in comparison with individuals with treated neck pain. This difference was observed only in the comfortable sitting position.</td>
</tr>
<tr>
<td></td>
<td><strong>Control group A</strong> 16 pain-free individuals (40.5±15.1 yrs NS)</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td><strong>Control group B</strong> 22 individuals with treated neck pain (37.9±12.1 yrs NS)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Szeto et al, 2002</td>
<td><strong>Case group</strong> 8 females with neck and shoulder pain (7 females,</td>
<td>Head tilt (C7-tragus- forehead angle) and neck flexion (C7-tragus-</td>
<td>The head tilt and neck flexion of patients with neck and shoulder pain</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Yip et al, 2008

<table>
<thead>
<tr>
<th>Group</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control group</td>
<td>8 female age-matched controls (age: 30.7±6.6yrs)</td>
</tr>
<tr>
<td></td>
<td>vertical angle). 5 trials (mean was accepted). Electronic motion analysis</td>
</tr>
<tr>
<td></td>
<td>system and videotaping. Sitting position.</td>
</tr>
<tr>
<td></td>
<td>was not affected, although a trend to be increased was present.</td>
</tr>
<tr>
<td>Case group</td>
<td>62 patients with idiopathic neck pain (36 females, age: 39.9±10.8yrs,</td>
</tr>
<tr>
<td></td>
<td>chronicity: 2.6±2.6yrs, NPQ: 31.9±15.4, NRS: 3.9±11.8)</td>
</tr>
<tr>
<td></td>
<td>FHP (craniovertebral angle). 3 trials (mean was accepted). Head posture</td>
</tr>
<tr>
<td></td>
<td>spinal curvature instrument. Standing position.</td>
</tr>
<tr>
<td></td>
<td>Patients with neck pain have increased FHP.</td>
</tr>
<tr>
<td>Control group</td>
<td>52 pain-free individuals (36 females, age: 42.3±11.2yrs NS)</td>
</tr>
</tbody>
</table>


Although FHP is frequently associated with chronic neck pain a cause-effect relationship is difficult to establish (Szeto et al, 2002) and current literature tends to describe FHP mainly as a cause of neck pain. It can be summarized that the adoption of FHP during many daily prolonged sitting activities may lead to a permanent adoption of this bad posture due to muscle remodeling changes. The deviation of head from body vertical midline necessitates the development of higher torque in cervical muscles for maintaining static equilibrium. These high and prolonged contractions lead to reduced blood flow, fatigue, tissue damage and finally pain (Yoo et al, 2005). Furthermore, during the acquisition of this posture there is an increase in anterior tensile forces and the anterior cervical structures are stretched. Additionally, there is an increase in posterior compressive forces and shortening of the related muscles and consequentially the posterior muscles shorten. Moreover, the cervical discs are stressed increasing the possibility for early disc degeneration (Lau et al, 2010). These changes of muscle length and activation lead to changes of their length-tension curve.
and consequent muscle imbalances. Finally, ‘creep’ phenomena give FHP a continuously aggravating role (Szeto et al, 2002).

Although it is usually ignored, FHP may be a result of neck pain. Considering the changes in superficial and deep muscle activity, the reduced endurance and strength of cervical muscles, the mobility restrictions and the consequential muscle imbalances presented in patients with chronic neck pain, the FHP might be a postural adaptation in order for the cervical and related muscles to achieve their maximal mechanical advantage. Furthermore, FHP can be justified as a central nervous system misunderstanding for the appropriate head position due to deficits in sensorimotor control (Edmondston et al, 2007).

Although, the cervical postural changes were not initially part of the model for explaining neck pain mechanisms leading to respiratory dysfunction, the developers of this model consider that the contribution of FHP to this dysfunction is important (Kapreli, 2009, personal contact) and its stipulated mechanisms have been recently announced (Dimitriadis et al, 2009). FHP shares similar mechanisms to the other deficits for the development of respiratory dysfunction as it may be both a cause and effect of changes in muscle strength, endurance, activity, range of movement, proprioception and muscle imbalances. However, FHP may also lead to joint overloading and abnormal stresses on the non-contractile elements of the cervical area (Szeto et al, 2002; Yoo et al, 2005; Lau et al, 2010). This excess loading and stress may lead to repetitive micro-trauma to cervical structures. Beside the consequential pain increase with its direct impact on respiration, the excessive stress and microtrauma to ligaments may lead them to lose their functional role with a consequential instability of the area. Furthermore, microtrauma affecting mechanoreceptors may further compromise sensorimotor control leading to further cervical instability (Treleaven, 2008). As it has already been discussed, this segmental instability may lead to a more generalized instability of the spine (Key et al, 2008a; Key et al, 2008b) and finally to respiratory dysfunction due to altered rib cage mechanics (Kapreli et al, 2008).
Psychological states

Psychological states such as anxiety, depression, kinesiophobia and catastrophizing which are commonly met in pain conditions are also apparent in patients with chronic idiopathic neck pain although their role and real existence are not well-explored (Jull et al, 2008a). Anxiety is generally considered as an emotional state of abnormal tension and apprehension paralleled with hyperactivity of the autonomous nervous system (Taylor et al, 2009). Bru et al (1993) found that anxiety is weakly correlated with neck pain intensity, whereas in another study by Luo et al (2004) including mostly idiopathic neck pain patients it was again found that anxiety is weakly correlated with neck pain disability. However, Leino and Magni (1993) found that anxiety could predict the development of neck/shoulder pain 5 years after the initial assessment.

Depression has been described in the literature as an emotional state which is characterized by prolonged and ongoing sadness and life resignation (Madden et al, 2000). Luo et al (2004) found that depression is weakly correlated with neck pain disability and cannot predict it. Additionally, Pool et al (2010) found that the depression levels in neck pain patients cannot predict their recovery. In contrast to these findings, many studies have found some association between depression and neck pain. More specifically, Mantyselka et al (2010) found that the existence of daily neck pain is a significant predictor of depression. In agreement to these findings, Rajala et al (1995) found that neck pain is most frequently observed among depressed individuals, whereas Haythornthwaite et al (1991) was led to the same conclusions by using only patients with chronic neck/shoulder pain although the results were not significant. Furthermore, Leino and Magni (1993) and Rajala et al (1995) found that depression is able to predict the appearance of neck pain, whereas a positive correlation of shoulder/neck pain and depression was also found by Pollock et al (2011).

Kinesiophobia has been described as an excessive, irrational and debilitation phobia of physical movement and activity as a consequence of a feeling for vulnerability to physical injury or re injury (Kori et al, 1990). Based on the literature in low back pain, kinesiophobia could be hypothesized to be a critical factor for the
transition from acute to chronic neck pain (Vlaeyen and Linton, 2000). However, patients with neck pain have been found as less kinesiophobic than low back patients (George et al, 2001). Furthermore, although kinesiophobia seems to be a recognized state among patients with chronic idiopathic neck pain, these patients seem to be less kinesiophobic than whiplash patients (Grip et al, 2007). Evidence suggests that kinesiophobia is related and is able to predict chronic neck pain disability (George et al, 2001; Landers et al, 2008). Additionally, Pool et al (2010) found that kinesiophobia can impede short- and long-term recovery of patients with sub-acute neck pain after rehabilitation. Finally, although the findings in another study by Hill et al (2007) are in contrast with Pool et al (2010), they still found an association of kinesiophobia with recovery after physiotherapy when univariate analysis was used.

Catastrophizing has been described as a negative mental predisposition towards actual or anticipated pain experience (Sullivan et al, 2001). Although catastrophizing is considered a psychological state related to the disability of whiplash patients (Buitenhuis et al, 2008), little is known about its role on idiopathic neck pain. A study by Pool et al (2010), where a combined population of sub-acute whiplash and idiopathic neck pain patients was used, shows that catastrophizing cannot predict patients’ recovery after rehabilitation. In contrast, in another study by Hill et al (2007) in patients with nonspecific neck pain, catastrophizing was found to have an eminent role for the prediction of patients’ recovery after physiotherapy.

Considering the findings of the previous studies, it can be concluded that anxiety, depression and kinesiophobia reveal some association with pain and disability of patients with neck pain, whereas no conclusions can be extrapolated for the role of catastrophizing. Furthermore, it becomes obvious that there is no one single study using only patients with chronic idiopathic neck pain. In all of the previous studies these patients were just a percentage of the sample used. This fact impedes any valid conclusions about this population and whichever conclusion is extrapolated can be only speculative.

Despite this lack of evidence, some speculations about the association of psychological states and chronic idiopathic neck pain can be proposed. The real causality direction between psychological states and neck pain has not been established since they can be both cause and effect. It seems that anxiety, depression, kinesiophobia and catastrophizing may arise from neck pain and especially disabling
neck pain conditions. However, these psychological states may also lead to or exacerbate neck pain in the way described in Section 2.2.3 “Neck Pain Mechanisms”.

According to Kapreli et al (2008) the psychological status of patients with chronic neck pain may also influence their respiratory function. Anxiety can directly influence respiratory function due to release of adrenaline causing hyperventilation and consequentially decrease in PaCO$_2$ (Whelan and Young, 1953). Kinesiophobia as well as catastrophizing through its association with kinesiophobia may also cause adrenaline release potentially leading to similar respiratory changes (Henry, 1986). Kapreli et al (2008) also postulates that depression and kinesiophobia may pose a further barrier for normal movement and physical activity restricting the cervical range of motion and contributing to the changes of thoracic cage mechanics and respiration.

2.4.2 Evidence for respiratory disturbances in chronic neck pain

Evidence about the existence of respiratory dysfunction in chronic neck pain is limited and sparse among the scientific literature. However, after a thorough literature review four studies were recognized providing evidence about the existence of respiratory dysfunction in chronic neck pain (Table 2.8).

The first is an epidemiological study by Makela et al (1991). The aim of this study was the investigation of determinants, prevalence and consequences of chronic neck pain in 8,000 individuals living in Finland. The participants were asked to complete a health questionnaire and they underwent a clinical examination including joint function tests, blood pressure assessment, chest radiograph and spirometric examinations. The study reduced the measures to dichotomous variables and found that chronic neck pain was associated with respiratory function (odds ratio = 1.47, 95%CI = 1.22-1.76) when age and gender were adjusted for. However, when the other variables, such as musculoskeletal dysfunctions, were adjusted for, this association was not found to be significant (odds ratio = 1.12, 95%CI = 0.90-1.39). From these
findings it can be concluded that neck pain is associated with respiratory dysfunction, but this co-morbidity may both derive from another deficit such as non-specific generalized musculoskeletal pain or vice versa. The study could be designed more appropriately to exclude or control the external influence of many factors influencing respiratory function, but this limitation can be justified by the fact that such an approach could deviate from the original aims of the study. Finally, it should be also mentioned that the evidence provided by this study refers to the association of chronic neck pain with respiratory diseases rather than with respiratory function which may not be pathologic.

Evidence about respiratory function of neck pain patients is also provided in a study by Nilsen et al (2007) aimed at investigating activation of the autonomous nervous system and pain after low-grade mental stress in patients with fibromyalgia and shoulder/neck pain. In this study a group of 23 patients with fibromyalgia, a group of 29 patients with idiopathic chronic neck-shoulder pain and a group 35 healthy controls were recruited and performed a mentally-demanding and reaction-time computer task during which the participants were asked to match a brick to a frame given in the computer. Despite the findings from this experiment about the activation of the autonomous nervous system, baseline comparisons between the groups showed that patients with neck-shoulder pain have increased respiratory rate. The fact that they had also increased respiration rate in comparison with the other widespread pain condition reveals that changes in respiratory function of neck-shoulder patients may be attributed to the biomechanical connection of the respiratory system and neck-shoulder region rather than to the pain by itself. However, the respiratory rate alone cannot provide a good understanding of respiratory dysfunction in neck pain patients. Furthermore, the fact that a combined sample of neck and shoulder pain patients was used in parallel with the fact that the chronicity of their condition is not mentioned permits only a partial generalizability of these findings to patients with chronic idiopathic neck pain.

The existence of respiratory disorders in patients suffering from neck pain was also examined in a pilot cross-sectional study by Perri and Halford (2004). Unfortunately, the fact that the selection criteria for the study are not mentioned does not allow for valid conclusions about the generalizability of the findings. The assessment of the 94 participants (68% females, age: 11-80 year old) included a
Visual Analogue Scale (VAS) for assessing pain intensity, whereas the chest wall mechanics was assessed through observation and palpation using self-constructed nominal and ordinal scales. The results showed that among 38.5% of the participants who suffered from neck pain 83.8% had abnormal breathing. This percent was higher for the neck than any other type of musculoskeletal pain including the back, buttocks, arm and leg pain. Although the correlation between neck pain and altered breathing was found to be significant, it was not strong \((r=0.22, \ p<0.05)\). When neck pain was assessed as a total incorporating pain at the moment, on average, at best and at worst the association was found to be stronger and more significant \((r=0.36, \ p<0.01)\). However, the methodology followed in this study has serious limitations. The statistical validity of the findings is questionable due to inappropriate use of Pearson correlation coefficient for ordinal data. Another limitation is that the assessment of respiratory function lacked of objectivity being prone to experimenter bias. Furthermore, the extremely variable population used further compromise the findings of the study, since respiratory mechanics and function between young children and old people may be very different. Moreover, the lack of information about sample characteristics such as pain chronicity and type of pain impede the appropriate generalization of the findings. Finally, the fact that only a non-physiologically relevant variable such as chest mechanics was assessed does not provide any direct evidence about respiratory dysfunction in neck pain patients.

The most important evidence about the existence of respiratory dysfunction in chronic neck pain comes from a pilot study by Kapreli et al (2009) in 12 chronic idiopathic neck pain patients and 12 gender-, age-, height-, weight- and activity level-matched healthy controls. The Baecke questionnaire, a VAS, an electronic spirometer, a digital mouth pressure meter and a digital lateral photograph were used for assessing physical activity level, pain intensity, pulmonary function, respiratory muscle strength and forward head posture respectively. It was found that patients with chronic neck pain had significantly lower maximal voluntary ventilation, maximal inspiratory pressure (MIP) and maximal expiratory pressure (MEP) \((p<0.05)\) than controls. Pulmonary volumes and flows were also reduced in patients with chronic neck pain but the results were non-significant \((p>0.05)\). This lack of significance can be explained potentially by the small sample size which may have led to type II error. Furthermore, forward head posture was found to have a significant negative
correlation with MIP ($R^2=0.75$, $p<0.01$) and MEP ($R^2=0.43$, $p<0.05$). The stronger relationship between forward head posture and MIP can be explained by the function of sternocleidomastoid, scalene and trapezius which contribute both to neck function and forced inspiration. The findings of this study provide evidence about the existence of respiratory dysfunction in patients with chronic neck pain. However, the small sample size did not allow for definitive detection of differences which may potentially exist. Furthermore, although forward head posture is a usual finding in patients with chronic neck pain this study focussed on the examination of total neck biomechanical impairment without discerning differences between strength, range of movement, endurance and proprioception. Thus, the contribution of these impairments to pulmonary dysfunction remains unclear.

Table 2.8: Evidence for respiratory dysfunction in chronic neck pain.

<table>
<thead>
<tr>
<th>Study</th>
<th>Methods</th>
</tr>
</thead>
<tbody>
<tr>
<td>Kapreli et al, 2009</td>
<td><strong>Design:</strong> Case-control</td>
</tr>
<tr>
<td></td>
<td><strong>Sample:</strong> 2 groups were used.</td>
</tr>
<tr>
<td></td>
<td>1&lt;sup&gt;st&lt;/sup&gt; group</td>
</tr>
<tr>
<td></td>
<td>12 patients with chronic idiopathic neck pain &gt; 6 months</td>
</tr>
<tr>
<td></td>
<td>(7 females, age: 29.4±3.6 years, chronicity: 4.8±3.7 years, current VAS: 3.7±2.1mm, usual VAS: 4.6±2.3mm, NDI: 30.3±9)</td>
</tr>
<tr>
<td></td>
<td>2&lt;sup&gt;nd&lt;/sup&gt; group</td>
</tr>
<tr>
<td></td>
<td>12 healthy age-, gender-, height-, weight- and physical activity matched controls (age: 29.1±3 years).</td>
</tr>
<tr>
<td></td>
<td>Participants with cervical spine, abdominal and chest surgeries, with neurological, pulmonary, cardiovascular and neuromuscular diseases, with malignancies, smokers, obese as well as participants with any environmental or industrial exposures and patients undergoing physiotherapy were excluded from the study.</td>
</tr>
</tbody>
</table>
Assessment: Spirometry was used for recording pulmonary volumes (3 trials), flows and MVV (3 trials), a portable mouth pressure meter for recording MIP and MEP (best of five trials was accepted) and lateral photographs for FHP. The measurements were performed from a sitting position.

Results: Respiratory strength and MVV were reduced in patients with chronic neck pain. Pulmonary volumes and flows were not affected. FHP was negatively correlated with MIP and MEP.

Makela et al, 1991

Design: Cross-sectional

Sample: 7217 Finish ≥ 30 year-old (3895 females)

Assessment: Individuals were considered to have chronic neck pain (>3 months duration) if they had a previous diagnosis of neck pain, a history of severe longstanding pain with positive finding during clinical examination or mild/moderate pain with detectable physical signs during palpation and joint function tests. Respiratory system was assessed by using chest radiographs and spirometry.

Results: The appearance of chronic neck pain was associated with the development of respiratory diseases. However, when all the other musculoskeletal disorders were adjusted for, this association was vanished.

Nilsen et al, 2007

Design: Quasi-experimental

Sample: 3 groups were used

1st group: 29 females with chronic idiopathic neck-shoulder pain (48.3 years, range: 32-63 years)
2nd group: 23 females with fibromyalgia (age: 39.7 years, range: 21-61 years)
3rd group: 35 healthy females (age: 41.1 years, range: 19-59 years)

Patients with hypertension, infectious, metabolic, neuromuscular, neurological, cardiovascular and pulmonary diseases, history of injury, tendinitis or capsular affection of the shoulder, connective tissue disorders, serious headaches and medication related to neural, vascular or muscular function were excluded from the study.
### Perri and Halford, 2004

| Assessment: | Respiratory rate was assessed by using a thermistor. |
| Results: | Respiration rate of patients with neck-shoulder pain is increased in comparison to the other two groups, whereas fibromyalgia patients had the same respiratory rate with the healthy controls. |
| Design: | Cross-sectional |
| Sample: | 94 participants (68% females, age: 11-80 years) |
| Assessment: | Observation and palpation of chest mechanics from a standing position. Nominal and ordinal scales were used for assessing the magnitude of faulty breathing. Neck pain intensity was assessed by using visual analogue scales. |
| Results: | The 83.8% of neck pain patients had faulty breathing. Neck pain intensity was moderately correlated with faulty breathing |

### Abbreviations

This review indicates that patients with neck pain may present with respiratory problems. However, the evidence provided is limited and many methodologies described are inappropriate for providing such evidence. Although the last study (Kapreli et al, 2009) provides the best evidence about the existence of respiratory problems in patients with chronic neck pain the findings are preliminary and many questions remain unanswered such as “Is there any blood chemistry disturbance in patients with chronic neck pain?”, “Are the pulmonary volumes and flows really unaffected?”, “Can the findings about the reduced respiratory strength be replicated?”, “Do the chronic neck pain biomechanical and psychological states contribute to this potential respiratory dysfunction?” and “If yes, how strong is their contribution?”. However, although all of these questions are critical for understanding the respiratory dysfunction underlying chronic neck pain, their investigation necessitates the existence of valid and reliable measurement tools for avoiding potential misconclusions.
2.5 Measurement of chronic neck pain impairments

This section presents evidence about the validity and reliability of measurement tools for the assessment of musculoskeletal deficits including strength, endurance, range of movement, proprioception and forward head posture, for the assessment of psychological states including anxiety, depression, kinesiophobia and catastrophizing as well as for the assessment of pain and disability. All of these parameters may act as predictors of respiratory dysfunction in chronic neck pain.

2.5.1 Musculoskeletal assessment

The validity and reliability of assessment tools for the strength, endurance, Range of Movement (ROM) and proprioception of the cervical area have been extensively examined and described in reviews and studies by Strimpakos et al (2004, 2005a, 2005b, 2006). In parallel with these findings and conclusions a systematic review was performed for detecting new findings and suggestions for neck assessment. Databases searched included AMED, CINAHL, EMBASE (1996-2008), Ovid MEDLINE (1950-2008), Health and psychosocial instruments and all EBM reviews. The search was conducted for the period 2002- July 2008. The inclusion criteria were a) existence of neck pain, b) validity or reliability study, c) examination of strength, fatigue, ROM or proprioception. The exclusion criteria were a) studies in children, b) studies which examined only rotation, c) neck pain due to malignancy. The search strategy included the following:
Proprioception OR Kinesthesia OR Zebris OR strength OR endurance OR fatigue OR “range of movement” OR “range of motion” OR ROM

AND

Reliability OR validity OR responsiveness

AND

“neck pain” OR “cervical pain” OR “whiplash” OR “cervical syndrome” OR “cervicogenic headache” OR “cervicobrachial pain”

After the exclusion of any duplicates and irrelevant studies, 18 articles were selected as on the basis that they may contribute to the body of knowledge in relation to validity and reliability of the selected measures. These studies are summarized in Table 2.9.

Table 2.9: Reliability and validity of assessment tools for neck musculoskeletal impairments.

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Chiu and Lo, 2002</td>
<td>Cagnie et al, 2007a</td>
<td></td>
</tr>
</tbody>
</table>

|-----------|-------------------|-------------------|-------------------|------------------|

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Piva et al, 2006</td>
<td></td>
<td>Cagnie et al, 2007b</td>
</tr>
</tbody>
</table>

|----------------|--------------------------|------------------|------------------|
Muscle strength is an abstract concept rendering difficult the examination of its criterion validity as no measurement tool has been established as a gold standard (Portney and Watkins, 2009). A number of measurement tools have been developed and examined for the assessment of muscle strength. Manual testing is frequently used in clinical settings for assessment of muscle strength, but it is not suitable for research due to its clinical nature and the fact that it does not provide numerical data. Sphygmomanometers, hand held dynamometers, strain gauges and isokinetic dynamometers are some other measurement tools that have been used to quantify muscle strength and their reliability (Agre et al, 1987; Vernon et al, 1992; Ylinen et al, 1999) and validity (Agre et al, 1987; Vernon et al, 1992; Chiu and Lo, 2002; Cagnie et al, 2007a; Jull et al, 2007) has been established.

The most detailed protocol and analysis for the assessment of neck muscle strength is provided by Strimpakos et al (2004). In this study, the muscle strength of 33 healthy participants for all the neck movements (flexion, extension, lateral flexion, rotation) from two different positions (standing, sitting) was examined. Three or more repetitions were performed for each muscle group at each position and the maximum of these contractions was used as the Maximum Voluntary Contraction (MVC). This experiment showed that the isometric neck dynamometer constructed by the researchers has excellent intra-rater reliability for all the muscle groups in both positions (ICC in sitting=0.84-0.90, ICC in standing=0.89-0.96) and inter-rater reliability for all the muscle groups in the standing position (ICC=0.88-0.94). The standard error of measurement and the smallest detectable difference were also found to be very good. The results for the standing position are presented in Table 2.10. The inter-rater reliability in the sitting position was not examined as the standing position in terms of intra-rater reliability was found to be more reliable. Furthermore, its validity was established by measuring load cell accuracy against known weights (r=1, p<0.001). It was also examined using the known groups method confirming the actual differences of neck muscle strength between men and women (p<0.05) for every neck movement and position.
Table 2.10: Intra- and inter-rater reliability of neck isometric dynamometry. The reliability was examined from a standing position in healthy people as provided by Strimpakos et al (2004).

<table>
<thead>
<tr>
<th></th>
<th>Intra-rater reliability</th>
<th>Inter-rater reliability</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>ICC</td>
<td>SEM</td>
</tr>
<tr>
<td>Flexion</td>
<td>0.96</td>
<td>12.6</td>
</tr>
<tr>
<td>Extension</td>
<td>0.95</td>
<td>16.3</td>
</tr>
<tr>
<td>R. Flexion</td>
<td>0.93</td>
<td>14.9</td>
</tr>
<tr>
<td>L. Flexion</td>
<td>0.94</td>
<td>13.1</td>
</tr>
<tr>
<td>R. Rotation</td>
<td>0.92</td>
<td>1.2</td>
</tr>
<tr>
<td>L. Rotation</td>
<td>0.89</td>
<td>1.3</td>
</tr>
</tbody>
</table>


In addition to the study by Strimpakos et al (2004), which was performed in healthy volunteers, the reliability and validity of neck isometric dynamometry has been also established in patients with chronic neck pain. More specifically, Chiu and Lo (2002) found that isometric dynamometry has high test-retest reliability for both healthy people (ICC=0.94-0.98) and patients with mechanical neck pain (ICC=0.92-0.99). Isometric dynamometry was also found to be able to discriminate healthy people from patients with neck pain. Furthermore, in another study by Cagnie et al (2007a) it was also found that an isokinetic dynamometer can differentiate the isometric muscle strength of neck extensors between healthy people and patients with chronic neck pain. Thus, considering all of this evidence it seems that neck isometric dynamometry can be used with confidence for the assessment of strength in patients with chronic neck pain.
Endurance/fatigue assessment

Neck muscle endurance can be assessed by a number of methods including time-dependent tests, electromyography-based methods or subjective scales (Strimpakos et al, 2005a). Electromyography is considered the most objective method for the measurement of neck muscle fatigue. However, the current literature reveals questionable reliability of electromyographic measurements. Gogia and Sabbahi (1990; 1991) found that the Initial Median Frequency (IMF) can be used as a reliable index of muscle fatigue at different contraction levels from both a sitting and prone position. Falla et al (2002) found that when examining initial values of EMG signal the reliability is variable, but for Mean Frequency (MNF) and Conduction Velocity (CV) slopes the reliability is poor. Thuresson et al (2005) found very variable reliability in myoelectric fatigue indices, but in some occasions it was acceptable for the normalized MF slope. Finally, Strimpakos et al (2005a) examining a number of myoelectric fatigue indices concluded that the only reliable estimate of muscle fatigue is the IMF. However, the normalized MF and RMS slopes, that are considered to be more representative of endurance and fatigue as they depict the change in these variables over time, had totally unacceptable reliability (ICC=0.31-0.63). The variable findings from these studies in parallel with the fact that EMG measurement is a long procedure with obvious testing effects does not suggest its use especially in studies including a number of other procedures for assessing other deficits.

An alternative method is the use of subjective scales such as the Borg scale of perceived exertion. However, the fact that different subjects may have different perception of effort does not allow for extrapolation of valid conclusions. Furthermore, this scale present a very poor concurrent validity with EMG methods (r=0.01-0.39) (Strimpakos et al, 2005a). Another method for the assessment of neck muscles endurance is the use of time-dependant methods. Although these methods are dependent on psychology, emotion and motivation of subjects to perform or maintain maximal effort until exhaustion they are affordable and time-sufficient procedures (Strimpakos et al, 2005a) with established validity and reliability (Harris et al, 2005; Kumbhare et al, 2005; Cleland et al, 2006; Edmondston et al, 2008).
A systematic review by de Koning et al (2008) shows that the only one of clinical tests with established reliability for non-specific neck pain is the test for the examination of endurance of short neck flexors. According to this clinical test participants are instructed to “tuck in their chins” performing craniocervical flexion while keeping their heads raised. The endurance index is the time the participants are able to maintain this position until their chin begins thrusting. Although, this test has been initially described by Grimmer (1994), several modifications of this test have been used. Harris et al (2005) examined this test checking the maintenance of the craniocervical flexion by observing the separation of the formed skinfolds posterior to the mandible and the loss of the head position above the table by putting the left hand under the participant’s head. The findings of this study revealed that this test is reliable for the healthy participants (intra-rater: ICC=0.82-0.91, inter-rater: ICC=0.67-0.78) and moderately reliable for patients with neck pain (inter-rater: ICC=0.67). However, Edmondston et al (2008) found that this test is also highly reliable for patients with postural neck pain (ICC=0.93).

Finally, beside the fact that the previous test has been proposed by de Koning et al (2008) as the most suitable clinical test for assessing neck muscles endurance, the craniocervical flexion test proposed by Jull et al (2008a) should be also considered during patients assessment. Although de Koning et al (2008) describe that this test has inadequate evidence regarding its reliability, it seems that it has better face validity for assessing the endurance of deep neck flexors. However, the clinical nature of these assessment tools necessitates the examination of their reliability before the implementation of any research.

Range of movement assessment

Visual estimation (Van Suijlekom et al, 2000), typical goniometers (Chaves et al, 2008), gravity inclinometers (Cleland et al, 2006), gravity goniometers (Piva et al, 2006), tape measures (Alaranta et al, 1994; Day and Fox, 2009) and cervical range of movement devices (CROM) (Tousignant et al, 2002; de Hertogh et al, 2007) are frequently used for ROM assessment, but they are more useful for clinical practice
rather than research. Research necessitates the existence of more accurate measurement tools such as electronic inclinometers (Hoving et al, 2005), electrogoniometers (Alund and Larsson, 1990) ultrasound-based systems (Strimpakos et al, 2005b; Cagnie et al, 2007b), electromagnetic devices (Sterling et al, 2002; Jull et al, 2007) and optoelectronic kinematic analysis (Antonaci et al, 2002) which have been extensively used in research for cervical ROM assessment. Finally, although radiographs are considered the gold standard for ROM measurement, the radiation exposure as well as opinions that x-rays cannot be considered the gold standard since they are not sufficiently reliable for measuring global cervical range of movement (Chen et al, 1999) do not render them the first choice in clinical practice and research.

Three-dimensional ultrasound-based motion analysis systems are a usual choice for accurate measurement of cervical ROM. In a study by Strimpakos et al (2005b) it was found that this system provides a valid and reliable tool for cervical ROM assessment. More specifically its criterion validity when it was compared with cervical radiographs was very high for both cervical extension (ICC=0.95) and flexion (ICC=0.88). The ultrasound-based system was also found to have very high intra-rater reliability for both passive and active ROM and for both sitting and standing positions. The standard error of measurement and smallest detectable difference (SDD) were also found to be quite good. The results of the study regarding the intra-rater reliability of the system for assessing active ROM from the standing position are presented in Table 2.11. However, the inter-rater reliability was not promising restraining researchers from using more than one raters in one study. In contrast to this last finding, another study by Cagnie et al (2007b) revealed that the same motion analysis system not only has good intra-rater reliability (ICC=0.62-0.87), but also very good inter-rater reliability (ICC=0.79-0.94). The same study also established the discriminant validity of the system since it could discriminate between healthy people and patients with neck pain. These findings suggest that ultrasound-based motion analysis for assessing cervical ROM can provide valid and reliable estimates leading to valid conclusions.
Proprioception assessment

The exact measurement of proprioception is not possible as it is an abstract concept allowing measurement only of some of its aspects. Joint position sense is the aspect of proprioception which is measured almost exclusively in patients with neck pain. Thus, proprioception is usually recorded in degrees and an appropriate tool for ROM measurement should be used. Although there is a number of valid and reliable tools for measuring cervical ROM such as ultrasound based motion analysis systems, the selection of an appropriate test for measuring proprioception remains a challenge.

Although a number of proprioceptive tests have been developed, cervical proprioceptive ability is usually recorded through the ability to relocate to the natural head posture and the relocation of the head to a predetermined angle or point (Armstrong et al, 2008). Although the relocation to the natural head posture is frequently used, it does not seem to be the most representative of proprioception. This is because the relocation to the natural position may be mainly dependent on elastic elements of the region which push or pull the cervix towards the natural position (Shumway-Cook and Woollacott, 2007).

The “fly test” is a recently developed test for measuring proprioception. This test records the cervical movement of patients which is triggered by a moving cursor on a monitor (Kristjansson et al, 2004). This test eliminates the limitations of the

Table 2.11: Intra-rater reliability of ultrasound-based motion analysis system. The measurements have been received from a standing position (Strimpakos et al, 2005b).

<table>
<thead>
<tr>
<th>Movement</th>
<th>ICC</th>
<th>SEM</th>
<th>SDD (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sagittal plane</td>
<td>0.86</td>
<td>6.5</td>
<td>12.1</td>
</tr>
<tr>
<td>Transverse plane</td>
<td>0.73</td>
<td>8.5</td>
<td>13.8</td>
</tr>
<tr>
<td>Frontal plane</td>
<td>0.83</td>
<td>6.8</td>
<td>17.4</td>
</tr>
</tbody>
</table>

previous test as it does not use the natural head posture for assessment of proprioception. It was found that this test has the ability to discriminate patients with whiplash-related disorders from healthy people and that it has good test-retest reliability. In contrast, a study by Swait et al (2007) showed that this test is poorly correlated with joint position error after head repositioning and that it needs at least 5 trials in order for reliability to be achieved. However, the most serious limitation of this test seems to be the fact that it is dependent on a visual feedback which influences proprioception (Lovelace, 1989).

The relocation of the head to a specific angle with closed eyes seems to have better face validity than the relocation to the natural position and the “fly” test as it eliminates the limitations of the previously discussed tests. These problems can be overcome by the procedure followed by Loudon et al (1997) who examined proprioception through relocation of the head to a predetermined angle giving a kinesthetic instruction. In this study, the participants had to reproduce head rotation both at 30° and 50° and lateral rotation at 20° and CROM was used for recording degrees. It was found that this test has high intra- (ICC=0.98-0.99) and inter-rater reliability (ICC=0.97) as well as the ability to discriminate between healthy subjects and whiplash patients. However, proprioception for flexion and extension as well as Standard Error of Measurement (SEM) and Smallest Detectable Difference (SDD) were not examined.

These limitations led Strimpakos et al (2006) to investigate the most appropriate protocol for examining proprioception. Strimpakos et al (2006) examined the reliability of an ultrasound-based motion analysis system for measuring neck movement reproduction both in the sitting and standing position. Five target angles were examined and 3 repetitions were performed at each of them. It was found that this test has unacceptable intra-rater (ICC=0.01-0.5), inter-rater reliability (ICC=0.15-0.64) and smallest detectable differences for all the angles. Although it has been recently suggested that the poor reliability found in this study was potentially due to the insufficient number of trials (Pinsault et al, 2008b), other researchers (Lee et al, 2006) following an assessment protocol similar to the one by Strimpakos et al (2006) have found that the Zebris is quite reliable still when three trials are performed. However, it was found to be moderately reliable only for the flexion (ICC=0.65-0.71)
and left rotation (ICC=0.54-0.83), whereas the assessment of extension was highly unreliable (ICC=0.03-0.38).

Considering all of these observations, it seems that the measurement of proprioception remains a challenge not only regarding the appropriate test, but also regarding the appropriate measurement tool. Thus, the reliability of tests of proprioception should be carefully considered before the implementation of any study and if possible the raters’ reliability to be re-examined in order to avoid possible misconclusions.

### 2.5.2 Head posture assessment

Plumb lines (Kendall et al, 2005), goniometers (Nilsson and Soderlund, 2005), radiography (Morningstar, 2002), Cervical Range of Motion (CROM) instruments (Lee et al, 2005), head posture spinal curvature instruments (Yip et al, 2008), electronic motion analysis systems (Edmondston et al, 2007) and video cameras (Yoo et al, 2005) are measurement tools that have been occasionally used for assessing the Forward Head Posture (FHP). One of the most usual methods is the assessment of FHP through lateral photographs (Kapreli et al, 2009). The preference towards this method of measurement may be explained by its accuracy as well as by its quick, inexpensive, and convenient nature. However, for understanding the validity and reliability of a method for assessing FHP is not only important to examine the measurement tool used, but also the anatomical angle which is considered representative of forward head posture.

Yoo et al (2005) performed a study in order to examine the reliability of the different methods of FHP measurement when different anatomical angles are assessed (craniovertebral, occulocervical and mixed head tilt and neck flexion). The findings of this study show that all these measurements of head posture have very high inter-rater and intra-rater reliability. The findings about the assessment of craniovertebral angle through a video-camera were highly promising (intra-rater ICC=0.96, inter-rater ICC=0.99). In agreement with these findings, Brunton et al (2003) also found that the assessment of craniovertebral angle by using lateral photographs provide reliable estimates of FHP both from standing and sitting position. More specifically, this
procedure has excellent intra-rater reliability for both positions (ICC=0.98), whereas excellent was also its test-retest reliability from both standing (ICC=0.92-0.94) and sitting position (ICC=0.95). Thus, the use of lateral photographs for assessing FHP through craniocervical angle can be used with high confidence in research and clinical practice.

2.5.3 Psychological assessment

A number of instruments have been developed for the assessment of psychological states in patients with neck pain. The Hospital Anxiety and Depression Scale (HADS) is one of the most frequently used instruments for assessing psychological states and has been translated and validated into Greek language (Georgoudis and Oldham, 2001). HADS has the ability to assess both anxiety and depression which seem to be two of the most important psychological states in patients with chronic neck pain. The HADS is a 14-item questionnaire. The 7 of these items examine anxiety whereas the other 7 items examine depression. Each question has 4 potential answers. Each question can be scored from 0 to 3 depending on the answer. The score of each subscale (depression, anxiety) can be totally scored from 0 to 21. Scores between 0 and 7 mean that the individual has normal anxiety or depression. Scores between 8 and 10 mean that the individual has borderline abnormal anxiety or depression. Lastly, scores between 11 and 21 mean that the individual has abnormal anxiety or depression (Zigmond and Snaith, 1983).

Although the HADS has been validated into Greek language (Georgoudis and Oldham, 2001), the fact that it was designed initially for severely ill patients may compromise its content validity in relation to musculoskeletal patients. However, it can be also used in this population as Harter et al (2001) found that the HADS has very good predictive value in a sample of patients with musculoskeletal diseases including neck pain sufferers. Similar were the findings in a later study (Harter et al, 2006) in patients with cancer, cardiovascular, but also musculoskeletal disorders. Another advantage of HADS is that it excludes questions assessing somatic symptoms of psychological distress. This is important in a study examining patients with chronic
neck pain because this chronic pain may give rise to high scores on the most measures of depression by endorsing questions relative to reduced activity or fatigue (Harter et al, 2001).

Kinesiophobia which seems to be another psychological state in patients with chronic neck pain is usually examined by using either the Tampa Scale for Kinesiophobia (TSK) (Kori et al, 1990) or the Fear-Avoidance Beliefs Questionnaire (FABQ) (Waddell et al, 1993). Both of these questionnaires have been translated and validated into Greek language (Georgoudis et al, 2005; Georgoudis et al, 2007). However, the fact that the FABQ includes items that have been developed specifically for patients with low back pain seriously affects its face and content validity. This fact in parallel with the fact that TSK is used more frequently than FABQ for assessing kinesiophobia in patients with neck pain leads to a preference towards it. The TSK is a 17-item questionnaire and each item uses an ordinal scale and can be rated from 1 (strongly disagree) to 4 (strongly agree). The total score is the sum of all the item scores with a score range from 17 to 68. The TSK has also been investigated for its reliability, validity and internal consistency with acceptable results in patients suffering from neck pain (Cleland et al, 2008b).

Catastrophizing which is also believed to be apparent in patients with chronic neck pain is usually examined with the Pain Catastrophizing Scale (PCS). PCS is a 13-item instrument developed by Sullivan et al (1995). PCS reflects three different aspects of catastrophizing. The first is “rumination” (4 items), the second is “magnification” (3 items) and the third is “helplessness” (6 items). Each item assesses through an ordinal scale that can be rated from 0 (not at all) to 4 (all the time). The total score of the questionnaire can be ranged from 0 to 52. The PCS has been examined for its validity and reliability (Sullivan et al, 1995; Lame et al, 2008) and has been also validated in patients with neck pain (Miro et al, 2008). The PCS has been also translated and validated into Greek language by Chatzidimitriou et al (2006).
2.5.4 Pain and disability assessment

The majority of studies tend to use scales for quantifying pain experience. However, some researchers have also tried to avoid questionnaires by using specific equipment for pain assessment such as algometers (Keele, 1954) and pain matchers (Lundeberg et al, 2001). Although both of them are suitable for neck pain assessment (Ylinen et al, 2007; Bunketorp et al, 2008), algometry seems to be appropriate only for assessing pain threshold. Pain matcher is a modern device able to assess not only pain threshold, but also pain intensity. This can be achieved by asking patient to match neck pain intensity with pain intensity electrically induced in another body part. However, the fact that the pain experienced by electrical stimulation in another body part may be perceived differently than the neck pain in parallel with the fact that pain matcher is an unpleasant tool lead to a reconsideration of its appropriateness. Finally, it should be noted that similarly to subjective scales these two devices cannot provide objective measurement of pain intensity as its recording is highly dependent on patients’ perception of pain.

Pain is most usually assessed through pain scales. Visual Analogue Scale (VAS) (Price et al, 1983) and 11-point Numerical Rating Scale (NRS) (Cleland et al, 2008a) are two of the most popular pain scales. Despite their similarity, their main difference is that VAS is presented graphically as a 10cm line and the participant is asked to mark the point which represent his/her pain intensity, whereas NRS is presented verbally and the patient is asked to rate his/her pain from 0 to 10 or 100. The start of each of these scales represents a “no pain” situation, whereas their end represents the “worst imaginable pain”. Furthermore, the fact that VAS has ratio properties (Price et al, 1983) renders it more appropriate for research due to the availability of more rigorous statistical tests. In contrast to this, the NRS can be used only as ordinal scale due to a lack of evidence about its ratio properties (Williamson and Hoggard, 2005). Pain-o-meter is one of the gauges which have been devised as alternatives for pain assessment (Gaston-Johansson, 1996). It is a hard, plastic and self-administered measurement tool allowing assessment of both pain intensity and pain quality. However, the pain assessment is performed with a similar scale to VAS (Bunketorp et al, 2008). Thus, pain-o-meter does not seem to offer a better approach for pain assessment than the more time-effective and cost-effective VAS.
The VAS scale has been found to have good reliability and validity (Carlsson, 1983; Wewers and Lowe, 1990; Hagino et al, 1996) and to present ratio properties (Price et al, 1983). Unfortunately, there is no known evidence for its psychometric properties translated into Greek language (where the current study was undertaken), potentially because it is used as a reference standard for validating other measurement tools. However, the fact that this scale is presented graphically in parallel with the fact that the numeric and reading system in Greece is the same with the ones at which VAS was originally developed render less prominent the need for its cross-cultural validation. Nevertheless, the frequency of its use and its use as a reference standard have indirectly validated VAS into Greek.

Questionnaires are also frequently used for pain assessment. Some of these questionnaires such as the McGill Pain Questionnaire (MPQ) (Wilkie et al, 1990) assess pain as a multidimensional experience focusing mostly on pain quality. Other questionnaires such as the Copenhagen Neck Functional Disability Scale (CNFDS) (Jordan et al, 1998), the Northwick Park Neck Pain Questionnaire (NPQ) (Leak et al, 1994), the Neck Pain and Disability Scale (NPDS) (Wheeler et al, 1999), the Neck Bournemouth Questionnaire (NBQ) (Gay et al, 2007) and the Neck Disability Index (NDI) (Vernon and Mior, 1991) are disease-specific and assess pain-related disability. All of these questionnaires have been occasionally used in studies examining several aspects of chronic neck pain, but NDI seems to be the main preference of researchers not only in observational and experimental studies, but also as a reference tool for the validation of the other questionnaires.

The NDI has been developed by Vernon and Mior (1991) and is a 10-item questionnaire. It has been developed and validated for assessing pain-related disability in patients with neck pain and it has been found to have good test-retest reliability and internal consistency (Vernon and Mior, 1991; Cleland et al, 2008a). It has also been translated and validated into Greek language by Trouli et al (2008). Its items assess pain intensity, personal care, lifting restriction due to pain, pain-related reading problems, headaches, concentration, work restrictions due to pain, pain-related driving problems, sleeping disturbance and restriction of recreation activities due to pain. Each item is an ordinal scale and the participants’ responses are rated from 0 to 5. The total score may range from 0-50 and can be multiplied by 2 in order to present the disability as a percentage.
2.6 Assessment of respiratory parameters

This section provides evidence about the validity and reliability of tools that are usually used for the assessment of respiratory function including spirometry and assessment of respiratory muscle strength and blood gases.

2.6.1 Spirometry

Spirometry is an invaluable pulmonary test for assessing respiratory health including vital elements of pulmonary function such as pulmonary volumes, flows and Maximal Voluntary Ventilation (MVV). The first spirometers were introduced around 1844 and initially they were water-sealed volume-displacement spirometers. Today, these spirometers have been substituted by more modern electronic flow-sensing spirometers that are able to integrate flow signals in order to estimate lung volumes by a variety of methods (Ruppel, 2009). The validity and reliability of electronic spirometers for assessing pulmonary volumes, flows and MVV have been established by many researchers (Cox et al, 1973; Shanks and Morris, 1976; Wiltshire and Kendrick, 1994; Fonseca et al, 2005). However, despite the fact that spirometry is a valid and reliable procedure for recognizing pulmonary disturbances there was a world-wide inconsistency in the way it was performed often leading to misconclusions. Nowadays, after the understanding of this problem by the two most important respiratory societies (American Thoracic Society and European Respiratory Society), spirometry has been converted to a well-standardized procedure able to provide accurate estimates of respiratory function (Miller et al, 2005).

2.6.2 Respiratory muscle strength assessment

Respiratory muscle strength can be assessed either with invasive or non-invasive techniques (Polkey et al, 1995). Despite the fact that invasive techniques such as the placement of oesophageal balloons, gastric and transdiaphragmatic
pressure are considered to be more valid because of their more direct nature, the fact that they are difficult, long and unpleasant procedures leads to a preference towards non-invasive procedures such as the recording of nasal or mouth pressures (Syabbalo, 1998). Although, these non-invasive procedures are volitional and consequentially provide more biased estimates of respiratory function in comparison with the non-volitional methods, their assessment procedure is easy and are widely accepted and applied (Polkey et al, 1995; Syabbalo, 1998).

The Maximal Inspiratory Pressure (MIP) and Maximal Expiratory Pressure (MEP) are the usual indices of respiratory muscle strength and reflect the ability of respiratory muscles to generate force during a short quasi-static contraction (Larson et al, 1993). The capture of these indices can be performed by using mouth pressure meters. The validity and reliability of these devices have been established by many researchers (Larson et al, 1993; Hamnegard et al, 1994; Maillard et al, 1998; McConnell and Copestake, 1999; Romer and McConnell, 2004). In agreement with these studies, in a recent study by Dimitriadis et al (2011) it was found that portable mouth pressure meters can provide highly reliable estimates of respiratory muscle strength since MIP and MEP were found to have very good test-retest reliability (ICC=0.81-0.90) with acceptable standard error of measurement and smallest detectable difference. The test-retest reliability of MIP and MEP from a standing position is presented in Table 2.12. It was also found that if there is a sufficient number of familiarization trials, the performance of additional 2 trials is enough for obtaining excellent intra-rater reliability (ICC>0.9). Thus, the capture of MIP and MEP through a mouth pressure meter is a valid and reliable way to assess respiratory strength.

<table>
<thead>
<tr>
<th></th>
<th>ICC</th>
<th>SEM</th>
<th>SDD (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>MIP (cmH₂O)</td>
<td>0.81</td>
<td>11.5</td>
<td>22.7</td>
</tr>
<tr>
<td>MEP (cmH₂O)</td>
<td>0.83</td>
<td>13.7</td>
<td>25.1</td>
</tr>
</tbody>
</table>

Table 2.12: Test-retest reliability of mouth pressure meter. This table presents the reliability of Maximal Inspiratory Pressure (MIP) and Maximal Expiratory Pressure (MEP) from a standing position and by accepting the best of 18 trials (Dimitriadis et al, 2011).

ICC: Intraclass Correlation Coefficient, SEM: Standard Error of Measurement, SDD%: Smallest Detectable Difference expressed as a percentage of grand mean
2.6.3 Blood gases recording

The “gold standard” of the assessment of blood gases is considered an analytic method which requires intermittent blood sampling (Shapiro and Cane, 1989). However, the invasive nature of blood sampling as well as the fact that it is intermittent, relatively expensive and there is a time delay to obtain the results has rendered the non-invasive blood gas monitoring as the standard care in the clinical setting (Capovilla et al, 2000; Bolliger et al, 2007). The fact that non-invasive blood gases measurement has improved patient care and comfort also leads to this direction (Capovilla et al, 2000).

Pulse oximetry, capnography and transcutaneous measurement are the most usual non-invasive methods for assessing arterial blood gases (Shapiro and Cane, 1989; Ruppel, 2009). Oxygen saturation detected by using pulse oximetry (SpO\textsubscript{2}) helps to the estimation of SaO\textsubscript{2} by analyzing the light absorbed which passes through a capillary bed by reflectance or transmission (Ruppel, 2009). However, it does not provide any estimate for PaO\textsubscript{2} or PaCO\textsubscript{2}. The latter can be recorded by capnographic techniques which assess PaCO\textsubscript{2} by indirectly detecting expired CO\textsubscript{2} level (PETCO\textsubscript{2}) (Capovilla et al, 2000). Nevertheless, capnography fails to provide any estimates of PaO\textsubscript{2}. In contrast to capnography, transcutaneous measurement of blood gases is a less biased method (Hinkelbein et al, 2008) and provides estimates of both PaO\textsubscript{2} (PtcO\textsubscript{2}) and PaCO\textsubscript{2} (PtcCO\textsubscript{2}) by recording the passage of O\textsubscript{2} and CO\textsubscript{2} across a fleshy well-perfused area of the skin (Shapiro and Cane, 1989).

The convenience and the non-invasive character of transcutaneous measurement of blood gases has increased its popularity in both clinical practice and research. Most researchers have been led to the conclusion that transcutaneous measurements generally comprise a valid, reliable and accurate way to measure arterial blood gases (Cuvelier et al, 2005; Domingo et al, 2006; Rodriguez et al, 2006; Vivien et al, 2006; Storre et al, 2007; Maniscalco et al, 2008), although some researchers have been led to different conclusions (Weaver et al, 2004; Bolliger et al, 2007). Transcutaneous measurement has been also found to be accurate and valid in obese people (Maniscalco et al, 2008) overcoming concerns about the variation of skin thickness as a diffusion barrier (Ganter and Zollinger, 2003). However, the
concerns about its inappropriateness in patients with cardiac problems and perfusion disorders should be always taken into consideration (Ganter and Zollinger, 2003; Baulig et al, 2007).

The TCM40© (Radiometer, Copenhagen, Analis, Belgium) is a tool for transcutaneous measurement of arterial blood gases. This measurement tool allows the measurement of PtcO₂, PtcCO₂ and SpO₂. This tool has been found to be accurate for recording PaCO₂ (bias: -0.6 mmHg, precision: ± 7.5 mmHg) when it was compared with in-hospital reference blood gas analyzer. Bias by transcutaneous assessment was much better than the ones obtained by capnography which was the other non-invasive technique used (bias: -5.3 mmHg) (Hinkelbein et al, 2008). Additionally, Boulouffe et al (2006) provide promising results about its validity as it was found to be significantly correlated with gazometric values for the PaCO₂ (r=0.87, p<0.001), although the validity for the recording of PaO₂ was poorer (r=0.45, p<0.01). Thus, it can be concluded that although blood sampling and analysis is the gold standard for assessing arterial blood gases, their transcutaneous assessment is a valid and reliable alternative which can be used safely still in healthy people where the direct blood sampling might not be possible for ethical reasons.

In conclusion, the literature review shows that neck muscle strength, range of movement, pain intensity and disability can be validly and reliably assessed by using neck isometric dynamometry, an ultrasound-based motion analysis system, a visual analogue scale and Neck Disability Index respectively. Psychological states can be also validly and reliably assessed by using the Hospital Anxiety and Depression Scale, the Tampa Scale for Kinesiophobia and the Pain Catastrophizing scale which have been also translated and validated into Greek language. Finally, respiratory muscle strength and partial pressure of arterial carbon dioxide can be validly and reliably assessed by using a mouth pressure meter and transcutaneous blood gas monitoring, whereas spirometry can provide valid and reliable estimates of pulmonary volumes, flows and maximal voluntary ventilation. However, because there was a lack of reliable measurement for proprioception and muscle endurance, these were not chosen for this study. Nevertheless, their theoretical importance for the development of respiratory dysfunction in patients with chronic neck pain led to pilot their reliability before the implementation of the main study.
3. Aims
3. AIMS

The literature review reveals that there is a close anatomical and functional association between cervical region and respiratory system. Considering, this association, it can be stipulated that patients with chronic neck pain may also accompanied by respiratory dysfunction. However, the literature does not provide concrete evidence about the existence of respiratory problems in patients with chronic neck pain. Changes in respiratory muscle strength and maximal voluntary ventilation are supported only by piloting findings, whereas changes in other critical respiratory parameters such as partial pressure of carbon dioxide, pulmonary volumes and respiratory flows remain largely unexplored and are supported by no evidence. Moreover, it is largely unknown which musculoskeletal deficits and psychological states in patients with chronic neck pain are related with this potential respiratory dysfunction and until now they are only connected by theoretical assumptions. The largely unexplored respiratory function in these patients reveal a strong need for a study exploring the existence of respiratory dysfunction and its potential origins in patients with chronic neck pain. The findings of this study could have a significant impact in the usual clinical reasoning in patients with chronic neck pain as the usually ignored respiratory system would obtain a more eminent role.

Considering all of these unanswered questions, this study was initially aimed at exploring whether patients with chronic neck pain have affected any of the previously mentioned respiratory parameters. Then, another important aim of this study was to examine which of the known neck pain deficits (neck muscle strength, endurance, range of movement, forward head posture, pain and psychological states) of patients with chronic neck pain are correlated with these respiratory function parameters. Ultimately, this study was also aimed at putting for the first time all the neck pain deficits together for the prediction of this respiratory dysfunction.
4. Hypotheses
4. HYPOTHESES

The aims of the study lead to some hypotheses which need statistical testing. Thus, the initial aim of the study which was to understand whether patients with chronic neck pain present respiratory dysfunction consequentially led to the following hypothesis:

\( H_0: \) Patients with chronic neck pain do not have different Maximal Inspiratory (MIP) and Expiratory Pressures (MEP), Maximal Voluntary Ventilation (MVV), partial pressure of arterial carbon dioxide (P_{\text{a}}CO_2), pulmonary volumes and flows than healthy people.

Furthermore, the need for examination of which chronic neck pain deficits are associated with this respiratory dysfunction gave rise to the following hypothesis:

\( H_0: \) Neck muscle strength, endurance, Range of Movement (ROM), forward head posture, pain and psychological states in patients with chronic neck pain are not correlated with MIP, MEP, MVV, P_{\text{a}}CO_2, pulmonary volumes or flows.

Finally, although it was not an original aim of the study, the need for understanding which of the known neck pain deficits were apparent in the chronic neck pain patients used in the study led to the following hypothesis:

\( H_0: \) Patients with chronic neck pain do not have different neck muscle strength, endurance, ROM, forward head posture, anxiety and depression than healthy people.
5. Methods
5. METHODS

5.1 Design

This study was a case-control observational study, as this design allowed for identifying differences between people with neck pain and those without (Clancy, 2002). Furthermore, case-control studies can provide estimates of causality, but only when combined with other evidence. Although, similarly to cross-sectional studies, subjects were assessed at one point in time, the term “case-control” was selected in order to highlight the fact that groups of individuals were selected on the basis of whether or not they had the disorder of interest. The selection of a group of subjects before recognizing whether they are cases or controls would lead to a proportion of cases and controls similar to the population, but their selection as cases or controls allows for equal sample sizes, an appropriate individual matching and better control of extraneous variables. The selection of a prospective design could be also possible as it would additionally provide information about changes in the magnitude of respiratory dysfunction over time. However, the facts that a) a prospective study would be more prone to testing and historical effects and b) the compliance of participants could not be ensured (high risk for drop-outs) rendered difficult the selection of such a design (Portney and Watkins, 2009).

This study involved collection of data from people with chronic neck pain and healthy gender-, age-, height- and weight- matched controls. Additionally, a third group of patients with musculoskeletal non-spinal pain was used in order to partially exclude the psychosocial and biochemical influences of neck pain on respiratory function. However, the third group was used only for descriptive statistics for future reference.
5.2 Subjects

In this study, 45 patients with chronic idiopathic neck pain (M/F: 13/32, age: 35.9±14.5 years), 45 healthy gender-, age-, height- and weight-matched controls (M/F: 13/32, age: 35.4±14 years) and 10 patients with musculoskeletal non-spinal pain (M/F: 6/4, age: 26.2±3.36 years) were recruited. The sample size estimation is described in the Section 5.3. Gender, age, height and weight were selected for matching in order to eliminate their known influence on respiratory function avoiding misconclusions about potential differences between patients with neck pain and healthy controls (see Section 2.3 Respiratory function – Factors influencing respiratory function). The non-spinal pain group was small and was not matched as it was used only for future reference. The participants’ demographics are described in detail in Table 6.1 of the Results section. The participants of the study were recruited from every available area in Lamia or other areas in Greece. The sample was conveniently collected after advertising the study verbally or with posters (Appendix I).

The inclusion criteria for the neck pain group were a) at least 6-month history of neck pain which was associated with cervical joint dysfunction and pain complaints at least once a week, b) aged between 18 and 65 years old, c) Greek nationality with sufficient verbal and writing skills in order to appropriately cooperate, complete the questionnaires and sign an informed consent and d) a sufficient mental state in order to cooperate and sign an informed consent. The exclusion criteria of the study were a) spinal or chest surgery, b) smoking history, c) whiplash injuries, d) acute or chronic neuromusculoskeletal pain in any other body area e) serious obesity (Body Mass Index>40), f) clinical abnormalities of the thoracic cage or vertebral column, g) occupational industrial exposures, h) serious cardiac, pulmonary, neuromuscular, neurological, mental and metabolic disorders, i) diabetes mellitus, j) malignancies. All of these patient categories were excluded as these conditions may seriously affect respiratory function.

The inclusion criteria for healthy participants were a) existence of a patient with chronic neck pain of the same gender and of about the same age (±5 years), height (±10 cm) and weight (±10%) in order for the healthy participant to be
individually matched with this patient, b) Greek nationality with sufficient verbal and writing skills in order to appropriately cooperate, complete the questionnaires and sign an informed consent, c) a sufficient mental state in order to cooperate and sign an informed consent. The exclusion criteria were the same with the ones defined for the chronic neck pain group.

The inclusion criteria for the musculoskeletal non-spinal pain group were a) at least 6-month history of musculoskeletal pain in any body region except the spine, which was associated with dysfunction of the relative area and pain complaints at least once a week, b) an age between 18 and 65 year old, c) Greek nationality with sufficient verbal and writing skills in order to appropriately cooperate, complete the questionnaires and sign an informed consent, d) a sufficient mental state in order to cooperate and sign an informed consent. The exclusion criteria were the same with the ones defined for the other two groups.

5.3 Sample size calculation

The sample size calculation was performed with the help of a biomedical statistician. The sample size calculation was conducted using data from the pilot study by Kapreli et al (2009) who examined the effects of chronic neck pain on respiratory function including strength of respiratory muscles. The comparison between the two groups was performed by using t-tests and the effect size was calculated using the Pearson correlation coefficient. Although Pearson’s r is suitable and potentially preferable to Cohen’s d for interpreting the effect size (Field, 2005), sample size calculation can be performed using the latter index (Portney and Watkins, 2009). The effect size in parallel with the significance level, the power and the direction of the hypothesis can reveal the appropriate sample size. The literature review led to a two-tailed hypothesis as there is not enough evidence to predict the direction of the hypothesis. The study can be protected from type I error defining the significance level equal to 0.05. A power of 80% was also selected in order to protect the results from type II error (Bowling and Ebrahim, 2005). The effect size expressed as d is unknown and was calculated by the following data for the Maximal Inspiratory Pressure (MIP) found in the pilot study by Kapreli et al (2009):
**Existence data for MIP:**

Mean MIP for chronic neck pain patients = 88.42 cmH₂O

Standard Error of MIP for chronic neck pain patients \( (SE_{\text{neck pain}}) \) = 7.4 cmH₂O

Mean MIP for healthy controls = 112.58 cmH₂O

Standard Error of MIP for healthy controls \( (SE_{\text{control}}) \) = 11.5 cmH₂O

Sample size of neck pain group \( (n_1) \) = 12

Sample size of control group \( (n_2) \) = 12

The standard deviations for the neck pain \( (s_{\text{neck pain}}) \) and control group \( (s_{\text{control}}) \) were calculated as follows:

**Calculation of standard deviations**

\[
s_{\text{neck pain}} = SE_{\text{neck pain}} \times \sqrt{n_1} = 7.4 \times \sqrt{12} = 25.634
\]

\[
s_{\text{control}} = SE_{\text{control}} \times \sqrt{n_2} = 11.5 \times \sqrt{12} = 39.837
\]

In order to calculate the \( d \), the calculation of the common standard deviation should be initially performed. As common standard deviation \( (s) \) it was considered the square root of the pooled variance \( (\sqrt{s_p}^2) \):

**Calculation of the common standard deviation**

\[
s = \sqrt{\frac{[(n_1 - 1) \ s_{\text{neck pain}}^2 + (n_2 - 1) \ s_{\text{control}}^2]}{[n_1 + n_2 - 2]}}
\]

\[
s = \sqrt{\frac{[(12 - 1) \ 25.634^2 + (12 - 1) \ 39.837^2]}{[12 + 12 - 2]}}
\]

\[
s = \sqrt{\frac{(7228.122 + 17456.852)}{22}}
\]

\[
s = 33.497
\]
After calculating the common standard deviation, the effect size can be found:

**Calculation of effect size**

\[ d = \frac{\text{Mean MIP}_{\text{neck pain}} - \text{Mean MIP}_{\text{control}}}{s} \]

\[ d = \frac{88.42 - 112.58}{33.497} \]

\[ d = 0.72 \]

Considering that an independent t-test could be performed for examining differences between the groups, this effect size required a sample size of 32 in each of the two groups for a power of 80% (\(\alpha=0.05\), two-tailed hypothesis) (Cohen, 1988).

For the correlations that would be examined the effect size was stipulated to be 0.5 as there was no existent data for obtaining the real effect sizes. For a power of 80% the appropriate sample size was found to be 28 participants (\(\alpha=0.05\), two tailed hypotheses) (Cohen, 1988).

The requirement for further regression analysis necessitated its own sample size calculation. Considering that neck strength, range of movement, endurance and forward head posture were to be used as predictors of respiratory function (\(k=4\)) and choosing a trial residual degrees of freedom of 120 (\(d_{\text{res}}=120\)), as it is stipulated that the values of lambda do not vary in great extent among the 3 choices for \(d_{\text{res}}\), lambda was found to be equal to 12.3 (\(\lambda=12.3\)) for a power of 80% (Portney and Watkins, 2009). Considering these findings and stipulating a large effect size \((r=0.5 \Leftrightarrow R^2=0.25)\) (Field, 2005) as there was no existent data for such a regression model the appropriate sample size according to Cohen (1988) is:

\[ N = \frac{\lambda (1 - R^2)}{R^2} = \frac{12.3 (1 - 0.25)}{0.25} = 36.9 \approx 37 \]
Knowing the sample size, there was no need to stipulate the residual degrees of freedom as they could be calculated:

\[ \text{df}_{\text{res}} = N - k - 1 = 37 - 4 - 1 = 32 \]

Having had a new \( \text{df}_{\text{res}} \), a new value of \( \lambda \) was needed. Looking at the appropriate tables constructed by Cohen (1988), the stricter \( \lambda \) value is 15 for a power of 80%. Performing the same equation with previously and adopting the new \( \lambda \) value, \( N \) was found to be:

\[ N = \left[ \lambda \frac{(1 - R^2)}{R^2} \right] = \left[ 15 \frac{(1 - 0.25)}{0.25} \right] = 45 \]

Thus, the sample size calculation for a regression model of 4 predictors suggests the use of a sample of 45 participants.

It could be concluded that this study should include 32 healthy participants for the examination of differences and correlations whereas the group with the chronic neck pain patients could include 45 subjects because a regression model would be additionally constructed for them. However, 45 patients with chronic neck pain and 45 healthy controls were finally recruited as many differences of unknown effect size would be examined and this sample size would increase the statistical power of the study. Finally, no sample size calculation was performed for the non-spinal pain group as it was included only for indicative purposes and no statistical comparison would be performed with this. Thus, 10 patients with chronic non-spinal musculoskeletal pain were also recruited.
5.4 Location of the study/Access arrangements

The measurements of all the participants of the study were performed in the Cardiorespiratory Laboratory, Department of Physiotherapy, Technological Education Institute (TEI) of Lamia, Greece.

The dates of the measurements were arranged according to the individual needs of the participants and the availability of the Cardiorespiratory laboratory. The participants had to arrive to the laboratory just once, but by their own means.

5.5 Ethical Considerations

The study did not include any intervention which could be potentially harmful for the participants. The study included only measurements and the respiratory equipment used was the one used routinely in clinical practice. Furthermore, the measures of neck function had been previously developed and tested with no noted side effects. The study was approved by the Ethics Committee of the Department of Physiotherapy, School of Health and Caring Professions, TEI Lamia, Greece (Appendix II) and the University of Manchester Ethics Committee (Appendix III).

Data was pseudonymised and stored electronically on hard disk in a secure location known only to the researcher. A data back-up was kept in a secure place. The participants were informed that any information leaving the TEI of Lamia would have their names and personal details deleted. They were also informed that their names would not be announced at any future scientific conference or publication. The participants, signed a consent form agreed to give permission only to responsible individuals from the University of Manchester and TEI of Lamia to have access to the records.

The volunteers of the study were provided with an information sheet about the study (Appendix IV). They had one-week to read the information sheet and decide whether they would like to participate in the study. Participation was voluntary and the participants were able to withdraw at anytime without giving any reason. Each
person taking the decision to participate in the study should have firstly signed a consent form (Appendix V).

5.6 Outcome measures

Gender, age, height and weight were recorded for matching patients with chronic neck pain with healthy controls. Physical activity level was assessed for checking similarity between the groups. Pain-induced disability, pain frequency and pain chronicity were assessed for describing and understanding the patients’ characteristics.

Beside these outcome measures, the main outcome measures of the study are separated into two categories. The first category includes the outcome measures of the non-pulmonary deficits of chronic neck pain. These outcome measures help to understand the condition of patients used in the study and were used in order to examine which of the musculoskeletal deficits and psychological states of patients with chronic neck pain correlate with respiratory dysfunction. They were also used as predictors of respiratory dysfunction in the regression models. These outcome measures were a) neck muscle strength (strength of flexors, extensors and their ratio), b) endurance of deep neck flexors, c) neck range of movement for both isolated movements (flexion, extension, lateral flexions and rotations) and total movement in sagittal (flexion and extension), frontal (left and right lateral flexion) and transverse plane (left and right rotation), d) forward head posture, e) pain intensity, f) anxiety, g) depression, h) kinesiophobia and i) catastrophizing.

The second category includes outcome measures that were used for the assessment of respiratory dysfunction of patients with chronic neck pain. These outcome measures were a) quiet breathing pulmonary volumes (vital capacity, inspiratory capacity, expiratory reserve volume, tidal volume), b) forced pulmonary volumes [Forced Expiratory Volume in one second (FEV₁), Forced Expiratory Volume (FEV), FEV₁/FVC], c) respiratory flows (peak expiratory flow, peak inspiratory flow, forced expiratory flow in 25% of forced expiration, forced expiratory flow in 50% of forced expiration, forced expiratory flow in 75% of forced
expiration, forced expiratory flow from the 25% to 75% of forced expiration), d) maximal voluntary ventilation, e) maximal respiratory pressures (maximal inspiratory pressure, maximal expiratory pressure) and f) partial pressure of arterial carbon dioxide.

5.7 Apparatus and materials

The examiner completed a General Health Questionnaire for recording demographics and establishing eligibility criteria through interview with the participants (Appendix VI). A stadiometer (Seca, Birmingham, United Kingdom) and a weight scale (Tanita, Illinois, United States of America) were used for the measurement of participants’ height and weight respectively (Figure 5.1 and 5.2). A Symptoms and Pain History Questionnaire including body charts, symptomatology questions and Visual Analogue scales was also allocated to the patients (Appendix VII). The Visual Analogue Scales (VAS) were mainly used for recording the usual intensity of neck pain and the neck pain at the moment of the measurements (Price et al, 1983). VAS is a 10 cm line where the participants are asked to mark the point on the line which best represents their pain intensity, always considering that the start of the line means no pain and the end of the line means the worst pain that someone can experience. According to VAS scores neck pain can be described as mild (0-30mm), moderate (30-60mm), moderately severe (60-80mm) and severe (80-100mm) (Collins et al, 1997; Konstantinovic et al, 2010).

Participants’ physical activity was assessed with the Baecke Questionnaire of Habitual Physical Activity (BQHPA) (Baecke et al, 1982). The BQHPA comprises of three parts. The first part assesses work-related physical activity (8 items), the second sports-related physical activity (4 items) and the third leisure time-related physical activity (4 items). Each question can be answered in an ordinal scale scoring from 1-5. Each subscale score is equal to the sum of the items scores divided by the number of items of the subscale. Thus, each subscale score may range from 1-5. The total score of the questionnaire is equal to the sum score of the subscales ranging from 3 to 15. However, although the procedure for calculating the final score is quite complicated,
the questionnaire is self-explanatory about the scoring procedure. The questionnaire is presented in Appendix VIII.

Pain-related disability was assessed by using the Neck Disability Index (NDI) (Vernon and Mior, 1991). NDI is a 10-item questionnaire where each item has 6 potential answers scoring from 0 to 5. The final score of the questionnaire is the sum of the scores of the 10 items and can range from 0 to 50. Based on NDI scores, the disability of patients can be classified as “no disability” (0-4), “mild disability” (5-14), “moderate disability” (15-24), “severe disability” (25-34) and “complete disability” (35-50) (Vernon and Mior, 1991; Vos et al, 2006) (Appendix IX).

Anxiety and Depression were assessed by using the Hospital Anxiety and Depression Scale (HADS) (Zigmond and Snaith, 1983). This is a 14-item questionnaire with 7 questions for depression and 7 for anxiety. Each item scores from 0 to 3 and the total score for each of the two subscales can range from 0 to 21 classifying the participant as normal (0-7), borderline abnormal (8-10) or abnormal (11-21) (Appendix X). Kinesiophobia and catastrophizing were assessed by using the Tampa Scale for Kinesiophobia (TSK) (Kori et al, 1990) and the Pain Catastrophizing...
Scale (PCS) (Sullivan et al, 1995) respectively. The TSK is a 17-item questionnaire. Each item scores from 1 to 4 and the final score of the questionnaire can range from 17 to 68 (Appendix XI). The PCS is a 13-item instrument. It has three subscales. The first examines rumination (4 items), the second examines magnification (3 items) and the third examines helplessness (6 items). Each item scores from 0 to 4. The total score is the sum of all items and can range from 0 to 52 (Appendix XII). Cut-off scores for the TSK (41) and PCS (19) have been also recently published (Hill et al, 2010).

Forward Head Posture (FHP) was measured by lateral photographs obtained by a digital colour camera (HDR-SR11E, Sony, Belgium). An adjustable tripod was used for the placement of the camera in the appropriate height. The 7th cervical vertebra was marked with a skin marker. Double-face stick tapes were used for the attachment of a plastic marker to the 7th cervical vertebra in order to be observable when processing the lateral photograph. The craniovertebral angle was assessed by using a 3-D drawing software (Auto-CAD 2010, Autodesk Inc., San Raphael, CA, U.S.A.) (Kapreli et al, 2009).

Respiratory assessments

The TCM40© (Radiometer, Copenhagen, Analis, Belgium) was used for recording PtcCO2. The TCM40 is a portable, light-weight transcutaneous blood gases measurement tool with a colour touch screen. The values of arterial blood gases and the corresponding waveforms are visually displayed in its monitor. The TCM40 has also an electrode for a combined measurement of PtcO2 and PtcCO2. An additional finger sensor also provides estimation of SpO2. These sensors provide continuous monitoring of blood gases values as well as the ability to assess separately each parameter. The TCM40 is displayed in Figure 5.3.
Spirometry was performed by using the Spirolab II (SDI Diagnostics Inc, USA) (Figure 5.4). This tool is a small, light and portable spirometer and consists of two parts. The first is the peripheral part which the participants are asked to breathe into. This part comprises of a removable filter as well as a single-use carton cylindrical mouthpiece. The second is the main part which is connected to the mouthpiece through a wire. This part comprises of a keyboard, a high resolution colour monitor and an external printer. Spirolab II works through a digital turbine flow sensor and does not require any calibration. This spirometer allows the performance of three pulmonary function tests. The first is the Forced Expiratory Technique (FET), the second is the Vital Capacity (VC) technique and the third is the Maximal Voluntary Ventilation (MVV) technique. Important functional respiratory parameters that can be provided with this spirometer is the Forced Vital Capacity (FVC), the Forced Expiratory Volume in one second (FEV₁), the Forced Expiratory Ratio (FEV₁/ FVC), the Tidal Volume (V₇), the Vital Capacity (VC), the Peak
Expiratory Flow (PEF), the Peak Inspiratory Flow (PIF), the Forced Expiratory Flows (FEF25–75%, FEF25%, FEF50%, FEF75%), the Expiratory Reserve Volume (ERV), the inspiratory Capacity (IC) and the Maximal Voluntary Ventilation (MVV) (see Section 2.3 “Respiratory function - Critical indices of respiratory function”). This spirometer was connected to a lab computer and the parameters were visually displayed and processed in the monitor of the computer by using the appropriate software (WinSpiroPRO, Medical International Research, Rome, Italy) (Figure 5.5).

Figure 5.4: Spirolab II (SDI Diagnostics Inc, USA).

Figure 5.5: WinSpiroPRO (Medical International Research, Rome, Italy)
Maximal mouth pressures were measured by using the microRPM (Micro Medical Limited, Rochester, Kent, England) (Figure 5.6). The microRPM is a small, potable and light mouth pressure meter. It can be used for non-invasive measurement of Maximal Inspiratory Pressure (MIP) and Maximal Expiratory Pressure (MEP). It consists of a plastic device which is attached to a removable valve which can permit either inspiration (expiratory valve) or expiration (inspiratory valve) without resistance. This valve is placed on a single-use filter and this filter finally ends to a removable plastic flanged mouthpiece. The plastic device of this mouth pressure meter has a small monitor for visually displaying the measurement results. The results are digitally displayed in cmH₂O using a piezo resistive pressure sensing technology. MicroRPM was connected to a lab computer and the recording was performed with the use of the accompanying PUMA PC software (Figure 5.7).

Figure 5.6: MicroRPM (Micro Medical Limited, Rochester, Kent, England).
Cervical function assessment

The Zebris CMS20 ultrasound-based motion analysis system (Zebris Medizchnic GmbH, Isny, Germany) (Figure 5.8) was used in order to assess Range of Movement (ROM). This tool, after its connection to the participant, allows unrestricted 3-Dimensional motion of head. The system’s headgear was fixed to the head of each subject. This headgear is able to be adjusted in order to adapt to the head size of each participant. A series of three miniature ultrasound transmitters is attached to this headgear. The cervical spine movements are isolated from the rest of spine by a thoracic harness which consists of a plastic shoulder cap and a series of three transmitters. This thoracic harness serves also as a reference. The measurement is based on the determination of the spatial coordinates of the transmitters positioned relative to a three microphone fixed system found on a stand close by. The measurement is derived from the time delay between ultrasound pulses measured at a 20 Hz sampling rate, using triangulation. The dedicated software of the system (WinSpine recording software) was used for the calculation of the spatial position of the head which was displayed graphically in real time (Strimpakos et al, 2005b) (Figure 5.9).
The microphone fixed system (A), the headgear with the attached ultrasound transmitters (B), the shoulder cap (C) and the stabilization system (D) are easily distinguishable. The accompanying software (E) is also observable on the right monitor.

Figure 5.8: The Zebris CMS20 ultrasound-based motion analysis system (Zebris Medizchnic GmbH, Isny, Germany).

The blue line records movements on the sagittal plane (flexion, extension), the red line records movements on the transverse plane (rotations) and the green line records movements on the frontal plane (lateral flexions). The skull moves simultaneously with the participant and allows a visual 3 dimensional analysis.

Figure 5.9: WinSpine recording software (Zebris Medizchnic GmbH, Isny, Germany).
Neck muscle strength was measured using an isometric neck dynamometer (National Instruments, Manchester, UK) (Strimpakos et al, 2004) (Figure 5.10). This tool consists of a 50-kg load cell and a 2 frame stabilization system. The first of these frames is found at the level of the chest and the other one at the lumbar spine. The load cell forms part of a fixed-length strut or tie which is always stationary. The produced forces are always axial in relation to the transducer. The adjustable parts (transducer, seat, frames) are labeled in centimeters for reliability on subsequent measuring occasions. The data was captured by using the accompanying software program (LabVIEW version 5.1) (Figure 5.11).

Figure 5.10 (left): Isometric neck dynamometer (National Instruments, Manchester, UK). The load cell (A) and the two-frame stabilization system are easily observable (B).

Figure 5.11 (below): Isometric neck dynamometer accompanying software (National Instruments, LabVIEW version 5.1, Manchester, UK).
A plinth was used for positioning the participants in the supine position during the examination of endurance. Endurance of deep neck flexors was assessed performing the craniocervical flexion test with the use of a towel for correcting forward head posture and a portable pressure biofeedback device (Stabilizer, Chattanooga, USA). This device comprises of an air filled chamber which is placed under the participants’ neck (Figure 5.15) and a pressure sensor connected through a line to the chamber. Below the pressure sensor there is also attached an air pump for inflating the chamber and a button for deflating it. The pressure biofeedback device is presented in Figure 5.12.

Figure 5.12: Pressure biofeedback device (Stabilizer, Chattanooga, USA).

The blue air filled chamber (A) and the pressure sensor (B) with the attached black air pump (C) are easily observable. On the upper right corner of the figure the pressure sensor interface (D) is more clearly demonstrated.
5.8 Pilot study-familiarization

Before proceeding to the main study, the questionable reliability for the measurement tools of some parameters necessitated the piloting of some equipment. According to the literature, the examination of neck muscles endurance and proprioception was either problematic or inadequate as only a part of the reliability of the various tests was usually presented (see Section 2.5 “Measurement of chronic neck pain impairments”). Thus, some pilot studies were performed aimed at determining reliable measurement tools for the assessment of neck muscles endurance and proprioception. Firstly, a protocol was developed for assessing neck proprioception according to the best evidence provided by the literature and was tested alongside a clinical test for assessing endurance of neck flexors. Secondly, the failure of the first stage to provide a reliable measurement tool either for proprioception or for endurance led to the assessment of another clinical test for assessing endurance of deep neck flexors. Finally, the last stage was the piloting of the main study in order for the assessor to be familiarized with the procedure and for potential problems to be corrected or excluded from the main study. A summary of the three pilot studies is following:

1st pilot study

The first pilot study was aimed at examining the reliability of the Zebris ultrasound motion analysis system for the assessment of neck proprioception and of a clinical test for the assessment of neck flexors endurance.

20 healthy volunteers (M/F: 9/11, Age: 22.2±1.7 years, Height: 170.3±8.3cm, Weight: 67.9±11Kg, BMI: 23.2±2.7) were conveniently recruited. The participants were included in the pilot if they had an appropriate mental state to read the information sheet and sign the consent form. Volunteers with any serious neuromusculoskeletal, cardiovascular, pulmonary, neurological and psychiatric problem were excluded from the study. The measurements were performed at the Cardiorespiratory laboratory, Physiotherapy Department, School of Health and Caring Professions, TEI Lamia, Greece.
Proprioception was assessed by using the Zebris ultrasound-based motion analysis system. The participants were positioned in a standing position looking straight ahead. Their trunk was appropriately stabilized with the Zebris stabilization system. The head triple markers were adjusted to the head of volunteers ensuring their parallel placement with the sagittal plane of head movement. The participants were also fitted with a shoulder cap which functions as a reference point isolating neck spinal movement. During the procedure the participants faced away from the apparatus. The Zebris calibration for determining the Natural Head Position (NHP) was performed by asking the participant to look straight ahead to a fixed point at their head level and maintaining their head at its neutral position (Figure 5.8). After the calibration, the participants were asked to perform three maximal neck flexions and three maximal neck extensions. The best of these movements were considered as the maximal flexion and extension respectively.

After determining the neck ROM, the measurement of proprioception followed. The proprioception assessment was based on the protocol developed by Lee et al (2006). The measurement was performed from the same position and with the same equipment as previously. The first stage for its measurement was the determination of the NHP and the Target Position (TP) in the sagittal plane. The NHP was determined by asking the participant to keep the head in the neutral position while standing comfortably and looking straight ahead at a stable point found at his/her eye level. The Zebris system was calibrated so that the NHP to be defined as equal to 0°. The participant was instructed to memorize this position as his/her NHP. The TP was defined as equal to the 65 % of the maximum ROM in order for the muscles to be put in a slightly lengthened position, but not to excessively stretch the neck soft tissues. The examiner moved the participant’s head at a speed of no more than 35°/sec until reaching the target head position determined by the previous calculation, in order to avoid any excessive vestibular stimulation. The participants were then asked to focus on this position for 2-3 seconds recognizing it as the TP. After the recognition of the NHP and TP the participants performed the head-to-NHP and head-to-target repositioning tests. The participants were firstly asked to reposition their head to the NHP and after maintaining this position for 3 sec to relocate their head to the target position and maintain this position for 3 sec. During the procedure, the eyes of the participants were closed to eliminate any visual influence. 10 repeats
were performed in two directions including both neck flexion and extension with a 1 minute interval between the two different directions. After the completion of this first session, a second session followed after 1 ½ hours after asking the participant to restrain from any action that could influence the results of the second session (for example restraining from smoking, coffee, food and physical exercise). The second session followed exact same protocol as the first. The time frame was kept within the same day to reduce travel commitments for the participants and reduce external variable influence. The proprioception indices used for the analysis were the Constant Error (CE) and the Absolute Error (AE) of the trials for both the head-to-target and the head-to-NHP repositioning tests.

Ten minutes after the completion of the second session, the endurance of the neck muscle flexors was assessed. Their endurance was assessed with a clinical test (Harris et al, 2005) which mostly assesses deep neck flexors. All the participants were positioned on a plinth at a supine position having their legs flexed and their arms relaxed on their trunk. The participants were asked to tuck their chin in order to achieve craniocervical flexion and to raise their head by 2.5 cm. A ruler was used for checking this distance. A line was then drawn at the skin folds behind the mandible. The examiner’s left hand was placed under the occipital bone of the participant without being in contact with it (Figure 5.13). The participant was asked to keep this position for as long as possible. The procedure stopped when the lines at the skin folds separated or when the participant’s head touched the examiner’s hand for more than 1 sec. The time the participant maintained the testing position was recorded with a stopwatch. The test was repeated three times with an interval of 5 min between the trials. During these intervals the participant continued to be in a supine position without raising the head, but turning it left and right at least three times.

The reliability analysis for proprioception was performed by using Intraclass Correlation Coefficient (ICC$_{3,1}$, two way mixed model, single measures, consistency type), Standard Error of Measurement (SEM) and Smallest Detectable Difference (SDD) of the measures between first and second session. The same analysis was performed for examining the reliability of the endurance test. The results about the reliability of Zebris ultrasound-based motion analysis system and about the clinical test for the assessment of neck flexors endurance are analytically presented in Appendix XIII and XIV respectively. The results show that although both the CE and
AE for most of the examined conditions have satisfactory ICCs, the SEM and the SDD values were unacceptable. Similarly, although the findings from the clinical test for assessing neck muscle endurance were more promising than the findings about proprioception, the SEM and SDD were still unacceptable.

Figure 5.13: Endurance test for the neck flexors (1st pilot study).

The hand of the clinician 1 cm below the participants’ head. The head 2.5 cm raised. The line (blue) at the skinfolds behind the mandible is easily observable. If it is separated the test terminates.

Thus, the results of the first pilot study suggested not to examine neck proprioception and endurance since a reliable measurement tool for both the problems had not been provided. However, as far as the endurance was concerned the literature also suggested another clinical test which could potentially provide reliable estimates of neck flexors endurance. This test is called craniocervical flexion test and its reliability was therefore tested in the second pilot study.

2nd pilot study

The aim of the second pilot study was the examination of the reliability of the craniocervical flexion test (Jull et al, 2008b).
20 healthy volunteers (M/F: 8/12, Age: 34.1±12.3 years, Height: 172.5±9cm, Weight: 74±15.9Kg, BMI: 24.7±4) were conveniently recruited. The participants were included in the study if they had an appropriate mental state for understanding the procedure and signing a consent form. Participants with any serious neurological, cardiovascular, pulmonary or psychiatric problem were excluded from the study. The measurements were performed at the Cardiorespiratory laboratory, Physiotherapy Department, School of Health and Caring Professions, TEI Lamia, Greece.

The procedure was performed according to the instructions provided by Jull et al (2008b). Before commencing the test, the participants’ range of craniocervical motion was assessed in order to gain an appreciation of the participant’s range of craniocervical flexion and to familiarize the participant with the test movement. All the participants were positioned on a plinth, a supine crook lying with the participant’s head in natural head position without any pillow. Their arms were positioned relaxed on their trunk. Towels were used when head was found in slight extension. When applied, the towel was aligned with the base of the occiput in order to maintain the upper cervical area free for positioning the pressure biofeedback device. After having achieved the NHP, the air chamber of the pressure biofeedback device was placed uninflated behind participant’s neck in order to detect any change from the cervical curve during craniocervical flexion (Figure 5.14). After this, the air chamber was inflated to a baseline pressure of 20 mmHg. Before commencing the test the pressure was stabilized, since it was sensitive to changes from any body part movement due to consequential biomechanical changes in the cervical area. The pressure sensor was held by the assessor about 30 cm above the participants’ chin, facedown with a small inclination towards the participants’ head. After the participants were told that the test is mostly related to precision and control rather than strength, they were asked to perform the examined movement (Figure 5.15). This movement was visually demonstrated and it was described to them as a head-nodding action, like saying “yes”. They were also advised to perform the movement gently and slowly feeling the sliding of their head up the bed. Finally, they were instructed to avoid raising their head or pushing backwards.

The craniocervical test was performed in two stages. During the first stage, the participants were asked to perform the movement described earlier elevating the target pressure from 20 mmHg to 22 mmHg and to maintain this position for 3
seconds. After this period they were asked to relax and return to the starting position. This process was repeated for each 2 mmHg increment of the test to 30 mmHg. If an apical breath pattern was observed during the procedure, the participants were instructed to nod during expiration. The assessor continuously palpated the sternocleidomastoid and anterior scalene to detect any undesired participation of larger flexor muscles. The deep cervical flexor muscles were considered to have an abnormal or poor activation if a) there was head retraction instead of craniocervical flexion during pressure increments, b) there was a head lifting in order to reach the target pressures, c) there was undesired activity of the large neck flexor or hyoid muscles in the first three increments of the test d) the test was performed with speed and e) the pressure dial read a pressure of more than 20 mmHg after relaxation. The first stage of craniocervical test provided the quantification of performance which is the increment of the pressure increase that the subject can hold for 3 seconds with an appropriate craniocervical flexion action without any palpable activity of large neck flexors. This stage can also help the participants to be familiarized with the correct craniocervical action and also provide the upper value for the second stage of the test.

![Figure 5.14: Positioning for craniocervical flexion test.](image)

The patient is found in a supine crook lying position whereas towels correct head hyperextension due to forward head posture. The pressure biofeedback is placed behind participant’s head.
The second stage of the test was the one which provided quantification of the endurance of the deep cervical neck flexors. The examiner and participant position were exactly as they were during the first stage. During the second stage of the test the participant performed the head nod action to the first pressure level (22 mmHg). The participant was asked to hold the position for 10 seconds and then to relax and return his/her head to the starting position. If the participant could perform 3 repetitions of 10-second holds without any substitution strategy, the test could be progressed to the next pressure level at 2 mmHg increments. The test has a total of five pressure levels for testing deep flexors endurance (22 mmHg, 24 mmHg, 26 mmHg, 28 mmHg and 30 mmHg). Reduced endurance at each pressure level is observed by a) pressure decrease at the pressure sensor, b) apparent activation of the superficial neck flexors and c) a jerky action during holding of the pressure level, suggesting that the participant seeks for an alternative muscle for holding the pressure. The endurance level for each participant was defined as the maximal...
pressure that the participant could hold steady for three 10-second holds without undesired activation of superficial neck flexors or any other substitution strategy. After the completion of the craniocervical flexion test, the participants were asked to return for a second assessment two days after the first one.

The reliability analysis was performed by using the ICC\(_{3,1}\) (two-way mixed model, single measures, consistency type), SEM and SDD. The results about the test-retest reliability of the craniocervical flexion test were very satisfactory as it was presented with very good ICC, SEM and SDD values (ICC=0.81, SEM=0.97, SDD\(\%=11.34\%\)). These results are analytically presented at Appendix XV. Thus, the craniocervical flexion test was selected in the main study for the assessment of the endurance of deep neck flexors.

\textit{3\textsuperscript{rd} pilot study - Familiarization}

Finally, before the main procedure of the study, a pilot study was performed in three healthy subjects and two patients with chronic neck pain in order for the assessor to be familiarized with the tools and the procedure of the study. This pilot study also gave a chance to the researcher to check the procedure for potential problems. The participants of this pilot study were excluded from the main study in order to avoid a potential contamination of the results as these subjects would have experience of the procedure. After, the completion of this stage and the correction of some minor problems the study was ready to commence.
5.9 Main study

After the completion of the pilot studies the main study for investigating the effects of chronic neck pain on respiratory function was ready to commence. The main study complied 5 phases which will be discussed in turn and are summarized for ease of understanding in Figure 5.16.

The main parameters that were measured were isometric neck muscle strength, neck ROM, endurance of deep neck flexors, forward head posture, neck pain, neck pain related disability, anxiety, depression, kinesiophobia, catastrophizing, MIP, MEP, FEV₁, FVC, FEV₁/FVC, forced expiratory flows, PEF, PIF, VC, V_{T}, IC, ERV, MVV and P_{tc}CO₂. The measurement of these variables was performed in a specific order to reduce as much as possible the effects of one test on another. Thus, the participants firstly completed the questionnaires, then the passive measurements followed and finally the participants performed the more strenuous measurements. Furthermore, pulmonary testing was performed before the assessment of biomechanics of the cervical. The process of the study was separated into five phases for the patients with chronic neck pain: a) the meeting and approval phase b) the interview and questionnaire phase, c) the photograph phase, d) the respiratory assessment phase and e) the cervical biomechanics assessment phase.

1st phase: Meeting and approval

After the patients arrived at the research laboratory they were informed once again about the study. They had the chance to read the information sheet again and to discuss any of their concerns and queries about the study with the researcher. Then, they were asked to voluntarily sign the consent form provided in order to commence the measurements. This phase of the study lasted about 5-10 minutes.
Figure 5.16: Phases of the study. This figure presents the five different phases of the study (total duration: 2 - 2 ½ hours)

<table>
<thead>
<tr>
<th>Phase</th>
<th>Description</th>
</tr>
</thead>
</table>
| **Phase 1: Meeting and approval (5-10 minutes)** | - Meeting the participant  
- Experiment description, discussion about the study and question answering  
- Signing of a consent form |
| **Phase 2: Interview and questionnaires (20-25 minutes)** | - General Health Questionnaire (eligibility criteria, demographics)  
- Symptoms and Pain History Questionnaire (body chart, symptoms, VAS)  
- BQHPA  
- NDI  
- HADS, TSK, PCS in randomized order  
- Height and weight |
| **Phase 3: Photograph (5 minutes)** | - Lateral photograph of head posture |
| **Phase 4: Respiratory assessment (55-70 minutes)** | - PtcCO₂ assessment (30 minutes)  
- Spirometry  
  ✓ VC manoeuvre (5-10 minutes)  
  ✓ FET manoeuvre (5-10 minutes)  
  ✓ MVV manoeuvre (5 minutes)  
- MIP and MEP in a randomized order (10-15 minutes) |
| **Phase 5: Cervical biomechanics assessment (30 minutes)** | - Cervical ROM (flexion, extension, right rotation, left rotation, right lateral flexion, left lateral flexion) (10 minutes)  
- Muscle strength of neck flexors and extensors in random order (10 minutes)  
- Endurance of deep neck flexors (10 minutes) |

2\textsuperscript{nd} phase: Interview and questionnaires

After signing the consent form, the assessor completed the General Health Questionnaire after an interview with the participants. This questionnaire gave the chance to confirm that the patient was eligible for participation in the study as well as to record the patient demographics. After completing this questionnaire, the patients were provided with a Symptoms and Pain History Questionnaire for recording their symptomatology. The completion of the VAS scale for pain intensity was also included in the Symptoms and Pain History questionnaire. Recording the patient symptomatology and confirming that the patients were eligible for participation in the study, the BQHPA was allocated for recording their physical activity level. The next questionnaire provided was the NDI for assessing pain related disability. Then, the HADS, the TSK and the PCS were allocated in a randomized order for recording the psychosocial influences of neck pain. The reason for the randomization is the avoidance of bias deriving in an instrument by the completion of the previous questionnaire especially considering that the items of these different questionnaires many times are interrelated. The examiner gave instructions for each questionnaire in a standard manner before their completion and explanations in relation to the structure and completion and not about the content. After the completion of these questionnaires the height and weight of the participants were measured. This part of the study lasted about 20-25 minutes.

3\textsuperscript{rd} phase: Photograph

The FHP was assessed by calculating the craniovertebral angle through lateral photographs. This phase could be also incorporated in the phase of the assessment of neck biomechanics. However, the initial study rationale about the order of the assessments suggested that the measurement of FHP should be placed before any other procedure since it has no known testing effect. For the assessment of FHP, the patient was initially placed in a sitting position and his/her head and neck were passively flexed and extended in order for the seventh cervical vertebra (C7) to be detected accurately. Through the head extension the assessor had his hand on the most prominent area of the cervical spine in order to detect which vertebra disappeared during extension and which one was still palpable. The vertebra that was still palpable
was considered as the C7 (Muscolino, 2009). Then, the assessor marked the C7 with a skin-marker and a small plastic marker was attached to the C7 through a double-face sticky tape so as to be distinguishable from a lateral photograph. If the participant had long hair that covered either the placed marker or the tragus of the ear, the patient’s hair was tied with a hairclip. After the participants had removed their shoes in order not to affect head posture, they were asked to stand as usual in a predetermined position with their feet close to each other and their arms hung relaxed. The participants were then asked to focus their vision on a fixed reference point, at the height of their eyes, directly ahead on the room wall.

Figure 5.17: Craniovertebral angle.

The craniovertebral angle is the angle between the line extending from the tragus of the ear to the 7th cervical vertebra (C7) spinous process and the horizontal line through C7.

After confirming the visual focal point, a lateral photograph of patient’s head was taken. After the first photograph, the patient was asked to slightly flex his/her neck and body and then to return to his/her usual position as previously. A second photograph was then taken and the procedure was repeated until a third photograph had been taken. The base of the camera had been previously calibrated from all planes.
in order not to have any undesired inclination. The lens of camera had been also placed at the height of the subject’s neck focusing on the marked anatomical points and at a 2 ½ meter distance from the participant. The FHP was determined by calculating the craniovertebral angle which is the angle between the line extending from the tragus of the ear to the C7 spinous process and the horizontal line through C7 (Figure 5.17). The calculation of this angle was performed by using a 3-D drawing software (Auto-CAD 2000, Autodesk Inc., San Raphael, CA). The FHP of the patient was considered the mean of the three obtained craniovertebral angles. The duration of this measurement phase was about 5 minutes.

4th phase: Respiratory assessment

Respiratory assessment was performed before the biomechanical assessment because with this testing order respiratory parameters would be more protected from testing effects. The first respiratory parameter assessed was the partial pressure of arterial carbon dioxide (PtcCO₂) as it was the most passive procedure with the less testing effects in comparison with any other respiratory assessments that took place.

Figure 5.18: Electrode placement for recording PtcCO₂.

After the area of interest shaved (not needed in the figure) and cleaned with alcohol, a fixation ring was positioned about 5cm below the middle of the left clavicle. The electrode was attached to this fixation ring after electrolyte solution was placed in the fixation ring cavity.
The TCM40 was firstly calibrated according to the manual instructions, through a removable calibration gas cylinder for about 5 minutes. The calibration was performed for each participant separately. After confirming that the calibration was performed correctly, the participants removed any upper body clothes to allow access to the upper chest. Before the electrodes placement, the placement area was shaved where necessary and the skin was cleaned with alcohol. After cleaning the area, a fixation ring was applied 5 cm below the middle of the left clavicle. The PtcCO\textsubscript{2} electrode was then attached to the fixation ring after a special electrolyte solution was placed on the fixation ring cavity between the PtcCO\textsubscript{2} sensor and the skin for better conductivity (Figure 5.18). The membranes of the sensors were replaced each time a normal calibration could not be achieved. The electrode was heated to 43°C in order to induce vasodilation and reduce stabilization time. Further temperature increase was avoided, in order to avoid any skin thermal injury (Kagawa et al, 2004; Zuur et al, 2007). During the recording, the participants were asked to breath as normal from a comfortable sitting position without speaking (Figure 5.19). The value of PaCO\textsubscript{2} was recorded after a 20min stabilization period as PaCO\textsubscript{2} initially presents high values due to an initial CO\textsubscript{2} overshoot. Values were recorded by calculating the mean PtcCO\textsubscript{2}
over the last 5-min time frame in order to reduce the effects of noise. It should be mentioned that the measurement of the arterial blood gases were performed from a sitting position because a standing position for a long time may have tired the participants and blood gases have been found not to change between sitting and standing positions (Marti and Ulmer, 1982). The duration of PtcCO₂ assessment was about 30 minutes.

After the recording of the arterial blood gases, spirometry was performed. Spirometry included three different pulmonary tests. The first pulmonary test was the VC, the second was the Forced Expiratory Technique (FET) and the third was the MVV manoeuvre. The testing effects determined the criterion for their order. For example, the VC manoeuvre may slightly increase the respiratory volumes as it is similar to a breathing expansion exercise, the FET manoeuvre may induce fatigue and the MVV manoeuvre being a more strenuous test, may induce more tiredness and volume historical effects than the other two tests. The tests were based on the official agreement between the American Thoracic Society and European Respiratory Society about the Standardization of Spirometry (Miller et al, 2005) as well as on the manual accompanying the spirometer. The acceptability criteria for these tests have been also analytically described by Ruppel (2009).

After a short warm up period of breathing exercises the participants performed the VC test. The VC manoeuvre permitted the recording of the VC, V₆, IC and ERV. The patients were placed on a standing position and asked to have their mouth sealed around the cylindrical carton mouthpiece in such a way that their teeth and tongue did not hamper the air flow from the spirometer. Furthermore, a noseclip was placed on their nose to avoid any potential air leak (Figure 5.20). After a short demonstration of the technique, the participants were asked to breathe as usual into the mouthpiece. Then, after a short period of 5-25 seconds the spirometer gave a sound signal to the participant to inhale as much as he/she could to the TLC and then to exhale as much as he/she could to the Residual Volume (RV) in a relaxed manner. The time period between the start of the test and the sound signal was dependent on the time needed for the participant to achieve a consistent breathing pattern. During the procedure, the examiner verbally encouraged the participants to fully inhale or exhale keeping a relatively constant flow. The VC manoeuvre was repeated 3 times with a 30-second interval between the trials. The criteria for acceptability were a) a less than 100ml
variance of the end expiratory volume for the three preceding breaths, b) an existent breathing plateau at maximal inspiration and expiration and c) at least two acceptable VC manoeuvres with volumes that fell within 150 ml each other. VC was reported as the maximum of the three trials whereas VT, IC and ERV were reported as the mean of the three trials. The duration of the test was about 5-10 minutes.

The next pulmonary test the patients performed was the FET. This manoeuvre allows the measurement of FEV1, FVC, FEV1/FVC, PIF, PEF, FEF25%, FEF50%, FEF75% and FEF25%-75%. This test began after a 2-minute break from the previous test. After a short demonstration of the procedure, the participants were placed in a standing position and asked to use the mouthpiece and nose clip in a similar way to the VC manoeuvre (Figure 5.20). Then, after 3 cycles of quiet breathing the patients were asked to inspire as much air as possible and then to expire as forcefully and rapidly as possible all the amount of air and to keep exhaling until they felt that there was no remaining air in the lungs. After completion of the forced expiration, a forced inspiration followed without hesitation. The participants were verbally encouraged throughout the test to perform the test correctly and to expire as much and forcefully as possible. If the participants felt lightheadness, the procedure was immediately stopped. The test was repeated 3 times or more (8 trials maximum) until the measurements fell within 10% from each other with a 30-sec interval period. The selection of the 10% limit was selected in order to ensure that the measurements were representative whilst not inducing obvious learning or tiredness effects. The criteria for FVC manoeuvre acceptability were a) no cough or glottic closure during the first second, b) good start of test, c) complete expiration of the air, d) at least 3 acceptable loops had been obtained. FEV1, FVC, PEF and PIF were reported as the maximum of the trials. FEV1/FVC was calculated from these values. FEF25%, FEF50%, FEF75% and FEF25%-75% were reported from the values of the best loop which was defined as the one with the highest sum of FEV1 and FVC. The duration of this technique was about 5-10 minutes.
The last spirometric test was the MVV manoeuvre. The MVV test was performed after a 2-minute break from the previous test. In contrary to the two previous spirometric tests the subjects were positioned in sitting. The reason for this change was because hyperventilation caused from the procedure may lead to hypocapnia with a consequential transient dizziness (McLaughlin, 2009). After a short
demonstration of the test, the participant was asked to sit without supporting his/her back on the chair and to use the spirometer and nose clip similarly to the previous spirometric tests (Figure 5.20). From this position the participant was instructed to inhale and exhale deeply and rapidly at a rate of 90-110 breaths/min for 12 seconds. The volume breathed should have been more than their $V_T$, but less that their VC. The participant was verbally encouraged through the whole procedure for maximal performance. The test was repeated 3 times with 1-minute intervals between the trials. Acceptability criteria were a) a continuous rhythmic effort for 12 seconds, b) the volume of breaths to be higher than the normal (50% VC) and the rate to be about 90-110 breaths/min and c) at least two acceptable manoeuvres with MVV values within 20%. MVV was reported as the largest of the three trials. The duration of the test was about 5 minutes.

After spirometry, the participants were assessed for their maximal inspiratory and expiratory pressures. This was placed as the last respiratory test due to its effort-dependent nature thereby reducing testing effects. The participants were examined from a standing position (Figure 5.21). MIP and MEP were examined in a randomized order, as the inspiratory and expiratory valves were randomly drawn from a bag. After a short demonstration of the procedure, the volunteers were asked to perform 5 maximal inspiratory and 5 maximal expiratory efforts with an interval of 30 seconds between the trials. Between the MIP and MEP measurement there was a 3-minute interval for substituting the inspiratory with the expiratory valve or vice versa. During the measurement of maximal mouth pressures the participants were asked to close firmly their mouth around the flanged mouthpiece. A noseclip was fitted to avoid any air leak. A small piece of tape was placed on the mouth pressure meter monitor in order for the participants to be blind to their performance. The MEP was assessed after asking the participants to inhale as much as possible and then to exhale maximally against the resistance of the gauge for at least 1 second. The MIP was recorded similarly after asking the participants to expire as much as possible and then to inhale maximally against the resistance of the gauge for at least 1 second. The participants were verbally encouraged throughout the procedure. The acceptability criteria for the MIP and MEP were a) 1-3 second of sustained effort, b) pressure plateau for 1-3 seconds and c) the largest MIP/MEP value should have been varied less than 20% from the second best. The best of the 5 inspiratory and the best of the 5
5th phase: Cervical biomechanics assessment

The first neck assessment that was performed after the pulmonary testing was the measurement of cervical Range of Movement (ROM). ROM was the first neck parameter assessed as its measurement is the least strenuous with the less known testing effects. The ROM assessment was based on recommendations provided by Strimpakos et al (2005b). The patients were placed in a standing position looking straight ahead and the shoulder cap fitted. Participant’s upper and lower back were appropriately supported by the modulated fixation system of the Zebris. Trunk and abdomen were appropriately stabilized by using the Zebris straps. The head triple markers were then adjusted to the participants’ head ensuring that they were parallel.
with the sagittal plane of head movement. During all the cervical movements the participants faced away from the apparatus (Figure 5.22).

Figure 5.22: Cervical Range of Movement assessment.

The participant performed 3 repetitions of all the neck movements (flexion extension, rotations, lateral flexions) from a standing position. The testing position is presented from a) a frontal and b) a lateral view.

After a short warm up period of three repetitions of each movement and a short demonstration of the procedure the main measurements followed. All the neck movements started from the neutral position. This position was achieved by instructing the participants to adopt their usual head posture and gaze at a target point in front of them. The Zebris system was calibrated so that the NHP was defined as equal to 0°. The movements that were performed were subsequently neck flexion, extension, right rotation, left rotation, right lateral flexion and left lateral flexion. Three repetitions of active ROM were slowly performed for each neck movement with the participants having their eyes open. During flexion the participants were asked to move their chin towards their chest and during extension they were asked to look at the ceiling in order to ensure that both the lower and upper cervical spine
contributed to the movement. During rotations they were asked to look behind their shoulder, whereas lateral flexions were described as moving their ears to their respective shoulder. The largest value of the three repetitions was considered as the ROM of each cervical movement. The resting period between the trials was the time needed for recording and saving the data and was about 5-10 sec. The measurement of the neck ROM was about 10 minutes.

Neck flexor and extensor strength was assessed immediately after cervical ROM assessment. The neck muscle strength was examined before neck muscle endurance as its examination was considered less tiring than the endurance examination. The procedure for the muscle strength measurement was based on the findings and suggestions by Strimpakos et al (2004). After a short warm-up period, the strength of neck flexors and extensors was assessed from a standing position in a randomized order. The muscle strength of each of the two examined neck muscle groups was isometrically examined from the NHP. During the assessment of neck flexion the participants faced toward the instrument, whereas during the assessment of neck extension they faced away it. The head and trunk were adjusted to the upright neutral position in order to ensure that the line between the nasion and opisthion was horizontal. The stabilization of the participant’s body was performed in the same manner as during the ROM assessment. The participants were examined having their arms hung at their side. During the examination of neck extensors the participants were asked to push isometrically the load cell which had been placed against their occiput (Figure 5.23), whereas during examination of muscle strength of neck flexors the participants were asked to perform isometric contraction against the load cell which had been placed on the middle of the inner canthus of the eyes (Figure 5.24). Before the main measurement, 3 practice isometric contractions of 5 seconds at different force levels were performed by the subjects. These force levels were set at 25%, 50% and 75% of their maximal force. After this period, three or more Maximal Voluntary Isometric Contractions (MVIC) of 5 sec duration with 1 min intervals were performed until the two best measurements were within 10% from each other for reducing learning or tiredness effects. Participants were verbally encouraged to perform maximal contractions without deviating from standard commands. The best value during extension and the best value during flexion assessment were considered as the maximal strength of neck extensors and flexors respectively. A 3 min resting
period existed between the measurement of neck flexors and extensors muscle strength. The duration of the neck muscle strength assessment was about 10 minutes.

Figure 5.23: Neck extensor strength assessment.

During the examination of neck extensors the participant pushed isometrically for 5 seconds the load cell which had been previously placed against her occiput.

Figure 5.24: Neck flexor strength assessment.

During the examination of neck flexors the participant pushed isometrically for 5 seconds the load cell which had been previously placed on the middle of the inner canthus of the eyes.
The last test of the whole experiment was the assessment of the endurance of deep neck flexors. The craniocervical flexion test was incorporated in the study as its examination during the pilot studies showed that it is a highly reliable clinical test. This test was placed last as it was believed and agreed to have the most likelihood of testing effects among the other biomechanical tests of the neck area. This clinical test was performed with exactly the same manner as during its piloting. The procedure is analytically described at the second pilot study of “5.7 Pilot studies-Familiarization” Section. The duration of the craniocervical flexion test was about 10 minutes.

After the completion of the experiment the participants were thanked for their participation and provided with the researcher’s phone number and e-mail for any information needed. The total duration of the experiment was about 2 – 2½ hours.

The procedure of the experiment was the same for the control group and the musculoskeletal non-spinal pain group. The only difference for the control group was that the neck pain symptomatology, the VAS, the NDI, the TSK and the PCS questionnaires were not completed as these are pain related outcome measures. Finally, the only difference for the musculoskeletal non-spinal pain group was that FHP, cervical ROM, neck muscle strength and endurance of deep neck flexors were not assessed as there are no sound reasons to purport that they had any cervical dysfunction. The duration of the procedure was about 1¾ - 2¼ hours for the control group and 1½ - 1¾ hours for the musculoskeletal non-spinal pain group.

5.10 Statistical analysis

Data was analysed with the help of an experienced academic biomedical statistician. Descriptive statistics were used for presenting anthropometric characteristics of the groups. Tests of normality were not performed because after a thorough discussion with the statistician it was decided that these parameters are theoretically normally distributed and this is the way these parameters are usually handled in the literature. Thus, parametric statistics were used. However, non-parametric statistics were additionally used for ease of understanding that non-
parametric statistics versus parametric did not influence the results. Nevertheless, when there was a disagreement about the group differences between parametric and non-parametric statistics, an additional Kolmogorov-Smirnov test was performed.

Differences in musculoskeletal, psychological and respiratory variables between the chronic neck pain and control group were examined by using paired t-tests. Paired t-tests were preferred to unpaired t-tests due to the predetermined and strict matching of the individuals of the two groups. Wilcoxon signed ranked test was additionally performed as the non-parametric equivalent of paired t-test.

The correlations between neck pain deficits (neck muscle strength, endurance, range of movement, forward head posture, pain, psychological states) and respiratory parameters (pulmonary volumes, flows, maximal voluntary ventilation, strength of respiratory muscles, partial pressure of arterial carbon dioxide) were analyzed by using Pearson correlation coefficients. The Spearman correlation coefficient was additionally used as the non-parametric equivalent of Pearson correlation coefficient. The significance level for examining both differences and correlations was defined equal to 0.05

The third group of the study (patients with chronic non-spinal musculoskeletal pain) was examined only by using descriptive statistics and no inferential statistics was applied to it due to its small sample size and the lack of matching with the other groups. The data from this group is provided only for future reference.

After the performance of these tests, a principal component analysis for the chronic neck pain group was performed aimed at exploring the data and examining whether any data reduction would be possible for the regression analysis. For the principal component analysis the Kaiser criterion was used for accepting factors, whereas the maximum iterations for convergence (the times an optimal solution is searched by the software) was conventionally selected to be 25. Furthermore, for improving the loading of variables onto factors a direct oblimin oblique rotation was performed because there were valid theoretical grounds to believe that the two extracted factors were correlated with each other and the available data set was not very large.

Regression models were constructed for the chronic neck pain group aimed at generating equations able to predict the respiratory dysfunction of patients with
chronic neck pain as well as to describe the relative contribution of each neck pain deficit to the respiratory dysfunction. A stepwise method of regression analysis was used as there was no existent evidence to support an hierarchical regression analysis. The stepwise regression method selected was the backward method (entry=0.05, removal=0.1) in order to avoid any potential suppressor effect which may derive from the forward method leading to type II error. For the examination of the accurate fit of the model to the observed data, the outliers were recognized by using the standardized residuals. If there were more than 5% of standardized residuals with a value of more than 2 or more than 1% of standardized individuals with a value of more than 3, they were considered outliers and their influence was examined. Influential outliers were examined with the Cook’s distance. If Cook’s distance for an outlier had a value of more than 1, then this value was considered a problem and its removal was seriously considered. The generalizability of the regression models was examined by checking the assumptions of regression models and by cross-validating the model by calculating the adjusted $R^2$.

Information about the rationale for the selection of this statistical approach is provided by Hicks (1999), Norman and Streiner (2000), Field (2005) and Portney and Watkins (2009).

Statistical Package for Social Sciences (SPSS, Version 17) was used for all data analysis.
6. Results
6. RESULTS

This section presents the statistical findings of the study which were obtained with the help of an experienced academic biomedical statistician. Initially, the demographics of the groups are presented. After providing demographic details, the differences between the two groups (chronic neck pain, healthy controls) in neck muscle strength, endurance of deep neck flexors, cervical range of movement, forward head posture, anxiety and depression are presented. After the examination about the existence of these deficits, the differences in respiratory function between the two groups are described. The respiratory function of the third group (patients with chronic non-spinal musculoskeletal pain) is then provided by applying only descriptive statistics. After describing these differences between the two groups, the correlations between neck pain deficits (neck pain intensity, pain-induced disability, neck muscle strength, endurance of deep neck flexors, cervical range of movement, forward head posture, anxiety, depression, kinesiophobia and catastrophizing) and respiratory function indices for the chronic neck pain group are presented. Then, the principal component analysis for the chronic neck pain group is described. Finally, the regression models constructed for the patients with chronic neck pain are provided.

6.1 Demographics

Demographic information of the two groups is presented in Table 6.1. Paired t-tests revealed that there are no statistically significant differences between the groups (chronic neck pain group, control group) in age, height, weight, Body Mass Index (BMI) and physical activity level (p>0.05).
6.2 Pain and disability characteristics

The pain intensity and disability characteristics for the Chronic Neck Pain (CNP) and Chronic Non-Spinal Musculoskeletal Pain (CNSMP) group are presented in Table 6.2. Based on Visual Analogue Scale (VAS) scores, 13 patients with chronic neck pain reported that they usually experienced mild neck pain (VAS: 0-30mm), 23 moderate neck pain (VAS: 30-60mm), 8 moderately severe neck pain (VAS: 60-80mm) and 1 severe neck pain (VAS: 80-100mm). Finally, based on Neck Disability Index (NDI) scores, 4 patients with chronic neck pain reported no disability (NDI: 0-4), 30 patients reported mild disability (NDI: 5-14) and 11 patients reported moderate disability (NDI: 15-24) (Table 6.3).

Table 6.2: Pain and disability. The table presents the pain and disability characteristics in patients with Chronic Neck Pain (CNP) and patients with Chronic Non-Spinal Musculoskeletal pain (CNSMP).

<table>
<thead>
<tr>
<th>Pain-related variable</th>
<th>CNP group M (SD)</th>
<th>CNSMP group M (SD)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Current pain (mm)</td>
<td>19.3 (±19.1)</td>
<td>7.6 (±8.8)</td>
</tr>
<tr>
<td>Usual pain (mm)</td>
<td>45.5 (±18.8)</td>
<td>36 (±20.4)</td>
</tr>
<tr>
<td>Pain at best (mm)</td>
<td>15.6 (±12.5)</td>
<td>8.2 (±6.1)</td>
</tr>
<tr>
<td>Pain at worst (mm)</td>
<td>76.8 (±18.5)</td>
<td>67.7 (±18.7)</td>
</tr>
<tr>
<td>Pain duration (months)</td>
<td>69.6 (±57.6)</td>
<td>34.9 (±26.7)</td>
</tr>
<tr>
<td>Pain frequency (days/week)</td>
<td>3.6 (±2.3)</td>
<td>2.9 (±2.4)</td>
</tr>
<tr>
<td>Disability (NDI)</td>
<td>10.6 (±5.2)</td>
<td>-</td>
</tr>
</tbody>
</table>

M: Mean, SD: Standard Deviation, NDI: Neck Disability Index
Table 6.3: Classification of participants. This table presents the classification of patients with chronic neck pain and healthy controls according to known cut-off scores.

<table>
<thead>
<tr>
<th>Variables</th>
<th>Categories</th>
<th>Neck pain</th>
<th>Healthy</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>N (%)</td>
<td>N (%)</td>
</tr>
<tr>
<td>Usual pain</td>
<td>Mild (VAS: 0-30 mm)</td>
<td>13 (29%)</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>Moderate (VAS: 30-60 mm)</td>
<td>23 (51%)</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>Moderately severe (VAS: 60-80 mm)</td>
<td>8 (18%)</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>Severe (VAS: 80-100 mm)</td>
<td>1 (2%)</td>
<td>-</td>
</tr>
<tr>
<td>Disability</td>
<td>No disability (NDI: 0-4)</td>
<td>4 (9%)</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>Mild (NDI: 5-14)</td>
<td>30 (67%)</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>Moderate (NDI: 15-24)</td>
<td>11 (24%)</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>Severe (NDI: 25-34)</td>
<td>0 (0%)</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>Complete (NDI: 35-45)</td>
<td>0 (0%)</td>
<td>-</td>
</tr>
<tr>
<td>Anxiety</td>
<td>No anxiety (HADS: 0-7)</td>
<td>20 (44%)</td>
<td>22 (49%)</td>
</tr>
<tr>
<td></td>
<td>Borderline anxiety (HADS: 8-10)</td>
<td>10 (22%)</td>
<td>17 (38%)</td>
</tr>
<tr>
<td></td>
<td>Anxiety (HADS: 11-21)</td>
<td>15 (33%)</td>
<td>6 (13%)</td>
</tr>
<tr>
<td>Depression</td>
<td>No depression (HADS: 0-7)</td>
<td>36 (80%)</td>
<td>37 (82%)</td>
</tr>
<tr>
<td></td>
<td>Borderline depression (HADS: 8-10)</td>
<td>6 (13%)</td>
<td>6 (13%)</td>
</tr>
<tr>
<td></td>
<td>Depression (HADS: 11-21)</td>
<td>3 (7%)</td>
<td>2 (4%)</td>
</tr>
<tr>
<td>Kinesiophobia</td>
<td>Non-kinesiophobic (TSK: 17-41)</td>
<td>40 (89%)</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>Kinesiophobic (TSK: 42-68)</td>
<td>5 (11%)</td>
<td>-</td>
</tr>
<tr>
<td>Catastrophizing</td>
<td>Non-catastrophizers (PCS: 0-19)</td>
<td>19 (42%)</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>Catastrophizers (PCS: 20-52)</td>
<td>26 (58%)</td>
<td>-</td>
</tr>
<tr>
<td>P&lt;sub&gt;t&lt;/sub&gt;CO&lt;sub&gt;2&lt;/sub&gt;</td>
<td>Hypocapnia (&lt;35mmHg)</td>
<td>19 (42%)</td>
<td>9 (21%)</td>
</tr>
<tr>
<td></td>
<td>Normocapnia (35-45 mmHg)</td>
<td>26 (58%)</td>
<td>33 (77%)</td>
</tr>
<tr>
<td></td>
<td>Hypercapnia (&gt;45mmHg)</td>
<td>0 (0%)</td>
<td>1 (2%)</td>
</tr>
</tbody>
</table>

N (%): Number of participants (percentage), VAS: Visual Analogue Scale, NDI: Neck Disability Index, HADS: Hospital Anxiety and Depression Scale, TSK: Tampa Scale for Kinesiophobia, PCS: Pain Catastrophizing Scale, P<sub>t</sub>CO<sub>2</sub>: partial pressure of arterial carbon dioxide.
6.3 Neck muscle strength

The differences in muscle strength of neck flexors and extensors as well as the neck flexors/neck extensors muscle strength ratio were examined by using paired t-tests. The results are presented in Table 6.4. The analysis showed that patients with chronic neck pain do not seem to differ in muscle strength of neck flexors from healthy controls (p>0.05). The same conclusion was also derived for the flexors/extensors muscle strength ratio (p>0.05). However, the muscle strength of neck extensors was significantly reduced in patients with chronic neck pain in comparison with the healthy controls (p<0.05). The same findings were also derived from the use of the non-parametric Wilcoxon signed rank test (Appendix XVI). The differences are visually presented in Figure 6.1. Although box plots are normally associated with non-parametric data, following statistical advice these plots were deemed more explanatory and provided information about outliers so were adopted for the purpose of this thesis.

Table 6.4: Neck muscle strength. The table presents the differences in neck flexors and extensors muscle strength and their ratio between the patients with chronic neck pain and healthy controls.

<table>
<thead>
<tr>
<th>Strength variables</th>
<th>$M_{\text{neck pain}}$(SD)</th>
<th>$M_{\text{control}}$(SD)</th>
<th>M. Diff. (95%CI)</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td>Flexors (kg)</td>
<td>10.1 (±5.8)</td>
<td>11.3 (±5.8)</td>
<td>-1.2 (-2.6, 0.2)</td>
<td>0.08</td>
</tr>
<tr>
<td>Extensors (kg)</td>
<td>15.4 (±8.6)</td>
<td>18.4 (±7)</td>
<td>-3 (-5.2, -0.7)</td>
<td>0.01*</td>
</tr>
<tr>
<td>Flexors/Extensors</td>
<td>0.67 (±0.15)</td>
<td>0.62 (±0.16)</td>
<td>0.05 (-0.01, 0.12)</td>
<td>0.15</td>
</tr>
</tbody>
</table>

*p<0.05, M: Mean, SD: Standard Deviation, M. Diff.: Mean Difference, 95%CI: 95% Confidence Intervals, p: probability
6.4 Cervical range of movement

The differences in Range of Movement (ROM) between the chronic neck pain and the control group were examined by using paired t-tests. Data were not recorded for the left rotation and left lateral flexion for one patient with chronic neck pain due to software problems. This patient and her matched control were excluded from the analysis of differences in left rotation, left lateral flexion, total transverse and total frontal range of movement. The results are presented in Table 6.5. The results show that the extension, right rotation, left rotation, right lateral flexion and left lateral flexion ROM are significantly reduced in patients with chronic neck pain in comparison with the healthy controls (p<0.05). However, no significant difference was observed in neck flexion ROM between the two groups (p>0.05). Nevertheless, the total ROM was found to be significantly reduced in all the planes (sagittal,
transverse, frontal) \( (p<0.05) \). The results deriving from the use of the Wilcoxon signed rank test are the same and are presented in Appendix XVI. The differences in the total range of movement for each movement plane are graphically presented in Figure 6.2.

Table 6.5: Cervical range of movement. The table presents the differences in Range of Movement (ROM) between patients with chronic neck pain and healthy controls.

<table>
<thead>
<tr>
<th>ROM variables</th>
<th>M_{neckpain}(SD)</th>
<th>M_{control}(SD)</th>
<th>M. Diff. (95% CI)</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>Flexion (°)</td>
<td>67 (±12)</td>
<td>69.9 (±8.2)</td>
<td>-2.9 (-6.9, 1.1)</td>
<td>0.16</td>
</tr>
<tr>
<td>Extension (°)</td>
<td>61.1 (±13.2)</td>
<td>70.2 (±15.1)</td>
<td>-9.1 (-14.5, -3.6)</td>
<td><strong>0.002</strong></td>
</tr>
<tr>
<td>Sagittal (°)</td>
<td>128.1 (±17.9)</td>
<td>140.3 (±19.5)</td>
<td>-12.1 (-19.1, -5.2)</td>
<td><strong>0.001</strong></td>
</tr>
<tr>
<td>Right Rotation (°)</td>
<td>68.7 (±9.3)</td>
<td>76.9 (±8)</td>
<td>-8.2 (-11.6, -4.9)</td>
<td><strong>&lt;0.001</strong>*</td>
</tr>
<tr>
<td>Left Rotation (°)</td>
<td>73.6 (±9.1)</td>
<td>78.2 (±7.8)</td>
<td>-4.7 (-8.2, -1.1)</td>
<td><strong>0.01</strong>*</td>
</tr>
<tr>
<td>Transverse (°)</td>
<td>142 (±16.4)</td>
<td>155.6 (±13.7)</td>
<td>-13.6 (-19.6, -7.6)</td>
<td><strong>&lt;0.001</strong>*</td>
</tr>
<tr>
<td>Right Lateral Flexion (°)</td>
<td>44.1 (±8.9)</td>
<td>48.8 (±8.2)</td>
<td>-4.7 (-8.1, -1.3)</td>
<td><strong>0.008</strong></td>
</tr>
<tr>
<td>Left Lateral Flexion (°)</td>
<td>41.9 (±8.7)</td>
<td>47.7 (±9.1)</td>
<td>-5.8 (-9.8, -1.8)</td>
<td><strong>0.006</strong></td>
</tr>
<tr>
<td>Frontal (°)</td>
<td>86 (±16.1)</td>
<td>96.7 (±16.6)</td>
<td>-10.7 (-17.6, -3.8)</td>
<td><strong>0.003</strong></td>
</tr>
</tbody>
</table>

*p<0.05, **p<0.01, ***p<0.001, M: Mean, SD: Standard Deviation, M. Diff.: Mean Difference, 95%CI: 95% Confidence Intervals, p: probability
The difference in endurance between the chronic neck pain and control group was examined by using a paired t-test. One patient could not perform the test because he had forgotten his glasses and could not read the pressure values of the biofeedback device. This patient and his matched control were excluded from the analysis. The findings are presented in Table 6.6. The analysis shows that the patients with chronic neck pain have significantly reduced endurance of their deep neck flexors in comparison with their matched controls (p<0.01). The same conclusion derived by running the analysis with the non-parametric Wilcoxon signed rank test (Appendix XVI). The difference between the two groups in the endurance of their deep neck flexors is visually demonstrated in Figure 6.3.

6.5 Endurance of deep neck flexors

The difference in endurance between the chronic neck pain and control group was examined by using a paired t-test. One patient could not perform the test because he had forgotten his glasses and could not read the pressure values of the biofeedback device. This patient and his matched control were excluded from the analysis. The findings are presented in Table 6.6. The analysis shows that the patients with chronic neck pain have significantly reduced endurance of their deep neck flexors in comparison with their matched controls (p<0.01). The same conclusion derived by running the analysis with the non-parametric Wilcoxon signed rank test (Appendix XVI). The difference between the two groups in the endurance of their deep neck flexors is visually demonstrated in Figure 6.3.
Table 6.6: Endurance of deep neck flexors. The table presents the difference in deep neck flexors endurance between patients with chronic neck pain and healthy controls.

<table>
<thead>
<tr>
<th>Variables</th>
<th>Mean neck pain (SD)</th>
<th>Mean control (SD)</th>
<th>Mean Difference (95% CI)</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td>Endurance (mmHg)</td>
<td>22.6 (±2.3)</td>
<td>24.1 (±2.2)</td>
<td>-1.6 (-2.5, -0.6)</td>
<td>0.001**</td>
</tr>
</tbody>
</table>

**p<0.01, M: Mean, SD: Standard Deviation, M. Diff.: Mean Difference, 95%CI: 95% Confidence Intervals, p: probability

Figure 6.3: Endurance of deep neck flexors. The figure presents graphically the reduced endurance of deep neck flexors in patients with chronic neck pain in comparison with healthy controls.
6.6 Forward head posture

The difference in forward head posture between the chronic neck pain and the control group was examined by using a paired t-test. Data from a healthy control was not obtained as the hairclip broke and it was not possible to free the cervical area and the tragus of the area from hair surrounding them. Thus, this participant and her matched patient with chronic neck pain were excluded from the analysis. The results are presented in Table 6.7. The analysis shows that patients with chronic neck pain and healthy controls have no statistical significant difference in craniocervical angle ($p>0.05$). The same findings were observed when the non-parametric Wilcoxon signed rank test was applied (Appendix XVI). The difference in forward head posture between the groups is graphically presented in Figure 6.4.

<table>
<thead>
<tr>
<th>Variable</th>
<th>$M_{\text{neckpain}}$ $(\text{SD})$</th>
<th>$M_{\text{control}}$ $(\text{SD})$</th>
<th>$M. \text{Diff. (95% CI)}$</th>
<th>$p$</th>
</tr>
</thead>
<tbody>
<tr>
<td>CCA ($^\circ$)</td>
<td>48.9 $(\pm5.5)$</td>
<td>50.4 $(\pm6.7)$</td>
<td>-1.5 $(\pm3.6, 0.6)$</td>
<td>0.16</td>
</tr>
</tbody>
</table>

Table 6.7: Forward head posture. The table presents the difference in Craniocervical Angle (CCA) between patients with chronic neck pain and healthy controls.

M: Mean, SD: Standard Deviation, M. Diff.: Mean Difference, 95%CI: 95% Confidence Intervals, $p$: probability
Psychological states

Table 6.8 presents descriptive statistics for the three groups for each psychological parameter assessed. The differences in anxiety and depression between patients with chronic neck pain and healthy controls were examined by using paired t-tests. Three-way comparisons were not performed as the group of patients with chronic non-spinal musculoskeletal pain was used only for exploratory purposes. The results are presented in Table 6.9. The results show that patients with chronic neck pain and healthy controls do not significantly differ in anxiety and depression level (p>0.05). The same conclusion derives from the use of the non-parametric Wilcoxon signed rank test (Appendix XVI). The differences in anxiety and depression level between the chronic neck pain and the control group are graphically presented in Figure 6.5.

Figure 6.4: Forward head posture. The figure presents the difference in craniocervical angle (CCA) between patients with chronic neck pain and healthy controls.
Based on HADS values (anxiety subscale), 20 patients with chronic neck pain reported “no anxiety” (HADS: 0-7), 10 patients reported “borderline anxiety” (HADS: 8-10) and 15 patients reported “anxiety” (HADS: 11-21). On the other hand, 22 healthy controls reported “no anxiety”, 17 reported “borderline anxiety” and 6 reported “anxiety”. Based on the scores of the depression subscale of HADS, 36 patients with chronic neck pain reported “no depression” (HADS: 0-7), 6 reported “borderline depression” (HADS: 8-10) and 3 reported “depression” (HADS: 11-21). In terms of the healthy control group, 37 participants reported “no depression”, 6 participants reported “borderline depression” and 2 participants reported “depression” (Table 6.3).

Based on Pain Catastrophizing Scale (PCS) cut-off scores (Hill et al, 2010), 26 patients with chronic neck pain were classified as catastrophizers (PCS: 20-52), whereas 19 patients were classified as non-catastrophizers (PCS: 0-19). Finally, based on Tampa Scale for Kinesiophobia (TSK) cut-off scores (Hill et al, 2010), 5 patients with chronic neck pain were classified as kinesiophobic (TSK: 42-68) and 40 patients as non-kinesiophobic (TSK: 17-41) (Table 6.3).

Table 6.8: Descriptives of psychological states. The table presents the descriptives about each psychological condition for the Chronic Neck Pain (CNP), the control and the Chronic Non-Spinal Musculoskeletal Pain (CNSMP) group.

<table>
<thead>
<tr>
<th>Psychosocial Variable</th>
<th>CNP group</th>
<th>Control group</th>
<th>CNSMP group</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean(SD)</td>
<td>Mdn(Range)</td>
<td>Mean(SD)</td>
</tr>
<tr>
<td>Anxiety</td>
<td>8.7 (±4.5)</td>
<td>8 (18)</td>
<td>7.4 (±3.5)</td>
</tr>
<tr>
<td>Depression</td>
<td>5 (±3.8)</td>
<td>4 (17)</td>
<td>4 (±3.4)</td>
</tr>
<tr>
<td>Depression Class.</td>
<td>-</td>
<td>Normal</td>
<td>-</td>
</tr>
<tr>
<td>Catastrophizing</td>
<td>21.4 (±12)</td>
<td>22 (45)</td>
<td>-</td>
</tr>
<tr>
<td>Rumination</td>
<td>8.4 (±4.6)</td>
<td>8 (16)</td>
<td>-</td>
</tr>
<tr>
<td>Magnification</td>
<td>3.8 (±2.6)</td>
<td>3 (9)</td>
<td>-</td>
</tr>
<tr>
<td>Helplessness</td>
<td>9.3 (±5.8)</td>
<td>9 (23)</td>
<td>-</td>
</tr>
<tr>
<td>Kinesiophobia</td>
<td>33.9 (±6.9)</td>
<td>33 (27)</td>
<td>-</td>
</tr>
</tbody>
</table>

Class.: Classification, SD: Standard Deviation Mdn: Median, Bord. Abn.: Borderline Abnormal
Table 6.9: Anxiety and Depression. The table presents the difference in anxiety and depression levels between patients with chronic neck pain and healthy controls.

<table>
<thead>
<tr>
<th>Variables</th>
<th>$M_{neckpain(SD)}$</th>
<th>$M_{control(SD)}$</th>
<th>M. Diff. (95% CI)</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td>Anxiety</td>
<td>8.7 (±4.5)</td>
<td>7.4 (±3.5)</td>
<td>1.3 (-0.4, 3)</td>
<td>0.12</td>
</tr>
<tr>
<td>Depression</td>
<td>5 (±3.8)</td>
<td>4 (±3.4)</td>
<td>0.9 (-0.6, 2.4)</td>
<td>0.23</td>
</tr>
</tbody>
</table>

Class.: Classification, Bord. Abn.: Borderline Abnormal, M: Mean, SD: Standard Deviation, M. Diff.: Mean Difference, 95%CI: 95% Confidence Intervals

Figure 6.5: Anxiety and Depression. The table presents the differences in anxiety and depression between the patients with chronic neck pain and healthy controls.

HADS: Hospital Anxiety and Depression scale.
6.8 Quiet breathing pulmonary volumes

The differences in quiet breathing pulmonary volumes between the patients with chronic neck pain and healthy controls were examined by using paired t-tests. The results are presented in Table 6.10. The results show that patients with chronic neck pain have significantly reduced vital capacity, Inspiratory Capacity (IC) and expiratory reserve volume (p<0.05). However, tidal volume was not found to be significant different between the groups (p>0.05). The results deriving from the use of the non-parametric Wilcoxon signed rank test reveal the same significant differences with the exception of IC which was not found to be significant different between the groups (Appendix XVII). A Kolmogorov-Smirnov test showed that the differences in IC between the groups were normally distributed (p>0.05). This fact suggests the acceptance of the parametric finding for the IC differences. The differences in quiet pulmonary volumes between the chronic neck pain and the control group are graphically demonstrated in Figure 6.6. The normal values for VC (3.04-5.44 lt) are presented in comparison with its measured values and the measurement error of the equipment used in Table 6.11 (Hankinson et al, 1999; Ruppel, 2009).

Table 6.10: Quiet breathing pulmonary volumes. This table presents the differences in quiet pulmonary volumes between the patients with chronic neck pain and healthy controls.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Mneckpain(SD)</th>
<th>Mcontrol(SD)</th>
<th>M. Diff. (95% CI)</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td>VC (lt)</td>
<td>3.61 (±1)</td>
<td>3.98 (±0.93)</td>
<td>-0.36 (-0.59, -0.13)</td>
<td><strong>0.003</strong></td>
</tr>
<tr>
<td>IC (lt)</td>
<td>2.42 (±0.67)</td>
<td>2.6 (±0.65)</td>
<td>-0.18 (-0.34, -0.02)</td>
<td>0.03*</td>
</tr>
<tr>
<td>ERV (lt)</td>
<td>1.07 (±0.5)</td>
<td>1.24 (±0.46)</td>
<td>-0.17 (-0.33, -0.01)</td>
<td>0.04*</td>
</tr>
<tr>
<td>VT (lt)</td>
<td>0.89 (±0.45)</td>
<td>0.93 (±0.41)</td>
<td>-0.04 (-0.24, 0.15)</td>
<td>0.65</td>
</tr>
</tbody>
</table>

*p<0.05, **p<0.01, M: Mean, SD: Standard Deviation, M. Diff.: Mean Difference, 95% CI: 95% Confidence Intervals, p: probability, VC: Vital Capacity, IC: Inspiratory Capacity, ERV: Expiratory Reserve Volume, VT: Tidal Volume.
Figure 6.6: Quiet breathing pulmonary volumes. This figure presents the differences in quiet pulmonary volumes for the chronic neck pain and the control group.

Table 6.11: Normative values and measurements error. This table presents the normal and the obtained values for the most important respiratory parameters as well as the measurement error of the equipment used.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Normal Values</th>
<th>M_{neckpain}(SD)</th>
<th>M_{control}(SD)</th>
<th>Meas. Error</th>
</tr>
</thead>
<tbody>
<tr>
<td>VC (lt)</td>
<td>3.04-5.44</td>
<td>3.61 ±0.91</td>
<td>3.98 ±0.93</td>
<td>± 3%</td>
</tr>
<tr>
<td>FEV₁ (lt)</td>
<td>2.59-5.38</td>
<td>3.27 ±0.76</td>
<td>3.46 ±0.79</td>
<td>± 3%</td>
</tr>
<tr>
<td>FVC (lt)</td>
<td>3.04-5.44</td>
<td>3.85 ±0.91</td>
<td>4.18 ±0.91</td>
<td>± 3%</td>
</tr>
<tr>
<td>FEV₁/FVC (%)</td>
<td>74.64-87</td>
<td>84.5 ±5.4</td>
<td>82.9 ±5.8</td>
<td>± 3%</td>
</tr>
<tr>
<td>PEF (lt/sec)</td>
<td>5.83-11.2</td>
<td>7.33 ±1.97</td>
<td>7.79 ±2.23</td>
<td>± 5%</td>
</tr>
<tr>
<td>FEF₂₅%-₇₅% (lt/sec)</td>
<td>2.07-5.43</td>
<td>3.6 ±0.96</td>
<td>3.7 ±1.18</td>
<td>± 5%</td>
</tr>
<tr>
<td>MVV (lt/min)</td>
<td>98-179</td>
<td>109.57 ±35.91</td>
<td>124.51 ±34.69</td>
<td>± 3%</td>
</tr>
<tr>
<td>MIP (cmH₂O)</td>
<td>68.4-112.6</td>
<td>86.9 ±31.2</td>
<td>100.82 ±34.5</td>
<td>± 3%</td>
</tr>
<tr>
<td>MEP (cmH₂O)</td>
<td>75.1-159.1</td>
<td>107.36 ±43.3</td>
<td>126.9 ±43.1</td>
<td>± 3%</td>
</tr>
<tr>
<td>P_{tc}CO₂ (mmHg)</td>
<td>35-45</td>
<td>34.9 ±2.9</td>
<td>37.3 ±3.5</td>
<td>± 14%</td>
</tr>
</tbody>
</table>

6.9 Forced expiratory volumes

The differences in forced expiratory volumes between the chronic neck pain and control group were examined by using paired t-tests. The results are presented in Table 6.12. The results show that the Forced Expiratory Volume in one second (FEV$_1$) and the Forced Vital Capacity (FVC) are significantly reduced in patients with chronic neck pain in comparison with the healthy controls (p<0.05). However, no significant difference was found in the FEV$_1$/FVC ratio between the two groups (p>0.05). The same conclusions derive from the use of the non-parametric Wilcoxon signed rank test (Appendix XVII). The forced expiratory volumes of the chronic neck pain and control group are graphically presented in Figure 6.7. Table 6.11 presents the normal values for the FEV$_1$ (2.59-5.38 lt), the FVC (3.04-5.44lt) and the FEV$_1$/FVC (74.64-87) in parallel with their measured values and the measurement error of the equipment used (Hankinson et al, 1999; Ruppel, 2009).

Table 6.12: Forced expiratory volumes. This table presents the differences in forced pulmonary volumes between the chronic neck pain and the control group.

<table>
<thead>
<tr>
<th>Variable</th>
<th>M$_{neckpain}$(SD)</th>
<th>M$_{control}$(SD)</th>
<th>M. Diff. (95% CI)</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td>FEV$_1$ (lt)</td>
<td>3.27 (+0.76)</td>
<td>3.46 (+0.79)</td>
<td>-0.19 (-0.37, -0.02)</td>
<td>0.04*</td>
</tr>
<tr>
<td>FVC (lt)</td>
<td>3.85 (+0.91)</td>
<td>4.18 (+0.91)</td>
<td>-0.32 (-0.53, -0.12)</td>
<td>0.003**</td>
</tr>
<tr>
<td>FEV$_1$/FVC</td>
<td>84.5 (+5.4)</td>
<td>82.9 (+5.8)</td>
<td>1.6 (-1, 4.1)</td>
<td>0.22</td>
</tr>
</tbody>
</table>

*p<0.05, **p<0.01, FEV$_1$: Forced Expiratory Volume in one second, FVC: Forced Vital Capacity, M: Mean, SD: Standard Deviation, p: probability
The differences between the chronic neck pain and control group in respiratory flows were examined by using paired t-tests. The results are presented in Table 6.13. The results show that the patients with chronic neck pain have reduced forced expiratory flow at the 25% of the forced expiration and reduced peak inspiratory flow in comparison with the healthy controls (p<0.05). However, no significant difference was observed for the groups in the forced expiratory flow from the 25% to the 75% of the forced expiration, in the 50% and 75% of the forced expiration and in the Peak Expiratory Flow (PEF) (p>0.05). The findings when the differences were examined with the non-parametric Wilcoxon signed rank test were similar with the difference that PEF was found to be significantly reduced in the
chronic neck pain group (Appendix XVII). This disagreement led to the use of the Kolmogorov-Smirnov test which revealed that the differences in PEF between the groups are not normally distributed (p<0.05). Thus, the use of the non-parametric finding for the difference in PEF between the groups might be preferable. The differences in forced expiratory flows between the chronic neck pain and the control group are graphically presented in Figure 6.8. The descriptives and the normal values for the PEF (5.83-11.2 lt/sec) and FEF_{25\%-75\%} (2.07-5.43 lt/sec) are presented in parallel with the measurement error of the equipment used in Table 6.11 (Hankinson et al, 1999; Ruppel, 2009).

Table 6.13: Respiratory flows. This table presents the differences in respiratory flows between the chronic neck pain and the control group.

<table>
<thead>
<tr>
<th>Variable</th>
<th>M_{neckpain}(SD)</th>
<th>M_{control}(SD)</th>
<th>M. Diff. (95%CI)</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td>FEF_{25%-75%} (lt/sec)</td>
<td>3.6 (±0.96)</td>
<td>3.7 (±1.18)</td>
<td>-0.06 (-0.46, 0.33)</td>
<td>0.75</td>
</tr>
<tr>
<td>FEF_{25%} (lt/sec)</td>
<td>6.12 (±1.5)</td>
<td>6.65 (±1.95)</td>
<td>-0.53 (-1.06, 0)</td>
<td><strong>0.049</strong>*</td>
</tr>
<tr>
<td>FEF_{50%} (lt/sec)</td>
<td>4.06 (±1.06)</td>
<td>4.1 (±1.35)</td>
<td>-0.04 (-0.5, 0.42)</td>
<td>0.86</td>
</tr>
<tr>
<td>FEF_{75%} (lt/sec)</td>
<td>1.6 (±0.64)</td>
<td>1.64 (±0.69)</td>
<td>-0.03 (-0.27, 0.22)</td>
<td>0.82</td>
</tr>
<tr>
<td>PEF (lt/sec)</td>
<td>7.33 (±1.97)</td>
<td>7.79 (±2.23)</td>
<td>-0.46 (-0.97, 0.05)</td>
<td>0.08</td>
</tr>
<tr>
<td>PIF (lt/sec)</td>
<td>4.03 (±1.36)</td>
<td>4.7 (±1.49)</td>
<td>-0.67 (-1.24, -0.1)</td>
<td><strong>0.03</strong>*</td>
</tr>
</tbody>
</table>

*p<0.05, M: Mean, SD: Standard Deviation, M. Diff.: Mean Difference, 95%CI: 95% Confidence Intervals, p: probability, FEF_{25\%-75\%}: Forced Expiratory Flow from the 25% to 75% of forced expiration, FEF_{25\%}: Forced Expiratory Flow at the 25% of the forced expiration, FEF_{50\%}: Forced Expiratory Flow at the 50% of forced expiration, FEF_{75\%}: Forced Expiratory Flow at the 75% of forced expiration, PEF: Peak Expiratory Flow, PIF: Peak Inspiratory Flow, lt/sec: liters/second
Figure 6.8: Respiratory flows. This table presents the differences in respiratory flows between the chronic neck pain and the control group.

FEF<sub>25%-75%</sub>: Forced Expiratory Flow from the 25% to 75% of forced expiration, FEF<sub>25%</sub>: Forced Expiratory Flow at the 25% of the forced expiration, FEF<sub>50%</sub>: Forced Expiratory Flow at the 50% of forced expiration, FEF<sub>75%</sub>: Forced Expiratory Flow at the 75% of forced expiration, PEF: Peak Expiratory Flow, PIF: Peak Inspiratory Flow, l/sec: liters/second.

6.11 Maximal voluntary ventilation

The difference in Maximal Voluntary Ventilation (MVV) between the patients with chronic neck pain and healthy control group was examined by using a paired t-test. Data was not collected for a healthy control participant as she felt dizziness during the first trial and declined from continuing the procedure. This healthy control and her matched patient with chronic neck pain were excluded from the analysis. The results are presented in Table 6.14. The findings show that patients with chronic neck pain have significantly reduced MVV in comparison to healthy controls (p<0.05). The same conclusions derive from the use of the non-parametric Wilcoxon signed rank test (Appendix XVII). The MVV for the chronic neck pain and the control group are
visually demonstrated in Figure 6.9. The descriptives and the normal values for MVV (98-179 cmH₂O) as well as the measurement error of the equipment used are presented in Table 6.11 (Neder et al, 1999).

Table 6.14: Maximal voluntary ventilation. This table presents the difference in Maximal Voluntary Ventilation (MVV) between the patients with chronic neck pain and healthy controls.

<table>
<thead>
<tr>
<th>Variable</th>
<th>M_{neck pain}(SD)</th>
<th>M_{control}(SD)</th>
<th>M. Diff. (95%CI)</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td>MVV (lt/min)</td>
<td>109.57 (±35.91)</td>
<td>124.51 (±34.69)</td>
<td>-14.94 (-24.14, -5.74)</td>
<td>0.002**</td>
</tr>
</tbody>
</table>

**p<0.01, M: Mean, SD: Standard Deviation, M. Diff.: Mean Difference, 95% CI: 95% Confidence Intervals, lt/min: litre/minute

Figure 6.9: Maximal voluntary ventilation. This figure presents the Maximal Voluntary Ventilation (MVV) for the chronic neck pain and the control group.
6.12 Respiratory muscle strength

The differences in respiratory muscle strength were examined by using paired t-tests. The findings are presented in Table 6.15. The results show that the patients with chronic neck pain have significantly reduced inspiratory and expiratory muscle strength (p<0.05), whereas the Maximal Inspiratory Pressure (MIP) to Maximal Expiratory Pressure (MEP) ratio (MIP/MEP) was not significantly different between the groups (p>0.05). The same conclusions derive when the differences were examined with the non-parametric Wilcoxon signed rank test (Appendix XVII). The MIP and MEP of the chronic neck pain and the control group are graphically presented in Figure 6.10. The normal values for the MIP (68.4-112.6 cmH~2~O) and MEP (75.1-159.1 cmH~2~O) are presented in parallel with their measured values and the measurement error of the equipment used in Table 6.11 (Evans and Whitelaw, 2009).

Table 6.15: Respiratory muscle strength. This table presents the differences in Maximal Inspiratory Pressure (MIP) and Maximal Expiratory Pressure (MEP) as well as in their ratio (MIP/MEP) between patients with chronic neck pain and healthy controls.

<table>
<thead>
<tr>
<th>Variable</th>
<th>M_{neckpain}(SD)</th>
<th>M_{control}(SD)</th>
<th>M. Diff. (95% CI)</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td>MIP (cmH<del>2</del>O)</td>
<td>86.9 (±31.2)</td>
<td>100.82 (±34.5)</td>
<td>-13.9 (-25.1, -2.7)</td>
<td>0.02*</td>
</tr>
<tr>
<td>MEP (cmH<del>2</del>O)</td>
<td>107.36 (±43.3)</td>
<td>126.9 (±43.1)</td>
<td>-19.5 (-33.6, -5.5)</td>
<td>0.008**</td>
</tr>
<tr>
<td>MIP/MEP</td>
<td>0.85 (±0.22)</td>
<td>0.81 (±0.17)</td>
<td>0.03 (-0.05, 0.12)</td>
<td>0.43</td>
</tr>
</tbody>
</table>

*p<0.05, p<0.01, M: Mean, SD: Standard Deviation, M. Diff.: Mean Difference, 95%CI: 95% Confidence Intervals, p: probability
The difference in the partial pressure of arterial carbon dioxide (P_{tc}CO_2) was examined by using a paired t-test. Data was not gathered from two healthy controls due to functional problems of the measurement tool. These participants and their matched patients with chronic neck pain were not included in the analysis. The findings are presented in Table 6.16. The results show that patients with chronic neck pain have reduced P_{tc}CO_2 in comparison with healthy controls (p<0.01). The same conclusion also derives when the non-parametric Wilcoxon signed rank test is used for examining this difference (Appendix XVII). The normal values for P_{tc}CO_2 (35-45 mmHg) and its measured values are presented in parallel with the measurement error of the equipment used in Table 6.11 (Hough, 2001). Furthermore, based on cut-off
values, it seems that 19 patients with chronic neck pain had hypocapnia (<35 mmHg) and 26 patients had normocapnia (35-45 mmHg) (Table 6.3). The $P_{tc}CO_2$ of the chronic neck pain and the control group is visually presented in Figure 6.11.

Table 6.16: Partial pressure of arterial carbon dioxide. This table presents the difference in partial pressure of arterial carbon dioxide ($P_{tc}CO_2$) between the chronic neck pain and the healthy control group.

<table>
<thead>
<tr>
<th>Variable</th>
<th>$M_{neckpain}$(SD)</th>
<th>$M_{control}$(SD)</th>
<th>M. Diff. (95% CI)</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td>$P_{tc}CO_2$ (mmHg)</td>
<td>34.9 (±2.9)</td>
<td>37.3 (±3.5)</td>
<td>-2.4 (-3.9, -1)</td>
<td>0.002**</td>
</tr>
</tbody>
</table>

**p<0.01, M: Mean, SD: Standard Deviation, M. Diff.: Mean Difference, 95%CI: 95% Confidence Intervals, p: probability.

Figure 6.11: Partial pressure of arterial carbon dioxide ($P_{tc}CO_2$). This figure presents the $P_{tc}CO_2$ for the patients with chronic neck pain and the healthy controls.
6.14 Respiratory function of the patients with chronic musculoskeletal non-spinal pain

The respiratory function of patients with chronic musculoskeletal non-spinal pain has not been used in any inferential statistics. It has been examined only for exploratory purposes and future reference. However, the descriptive statistics of their respiratory function are presented in Table 6.17.

Table 6.17: Respiratory function of patients with chronic musculoskeletal non-spinal pain. This table presents the respiratory function of patients with chronic musculoskeletal non-spinal pain.

<table>
<thead>
<tr>
<th>Variables</th>
<th>Mean (SD)</th>
<th>Median (Range)</th>
</tr>
</thead>
<tbody>
<tr>
<td>FEV&lt;sub&gt;1&lt;/sub&gt; (lt)</td>
<td>4.1 (±0.9)</td>
<td>4 (2.8)</td>
</tr>
<tr>
<td>FVC (lt)</td>
<td>4.8 (±1.2)</td>
<td>4.7 (3.4)</td>
</tr>
<tr>
<td>FEV&lt;sub&gt;1&lt;/sub&gt;/FVC (%)</td>
<td>86.4 (±3.9)</td>
<td>86.8 (13.3)</td>
</tr>
<tr>
<td>FEF&lt;sub&gt;25%-75%&lt;/sub&gt; (lt/sec)</td>
<td>4.6 (±1)</td>
<td>4.7 (3.7)</td>
</tr>
<tr>
<td>FEF&lt;sub&gt;75%&lt;/sub&gt; (lt/sec)</td>
<td>7.5 (±2.1)</td>
<td>7.5 (6.4)</td>
</tr>
<tr>
<td>FEF&lt;sub&gt;50%&lt;/sub&gt; (lt/sec)</td>
<td>5 (±1.1)</td>
<td>5.2 (3.7)</td>
</tr>
<tr>
<td>FEF&lt;sub&gt;75%&lt;/sub&gt; (lt/sec)</td>
<td>2.3 (±0.8)</td>
<td>2.1 (2.7)</td>
</tr>
<tr>
<td>PEF (lt/sec)</td>
<td>9.1 (±2.5)</td>
<td>9.8 (6.9)</td>
</tr>
<tr>
<td>PIF (lt/sec)</td>
<td>5.7 (±1.8)</td>
<td>6.2 (4.4)</td>
</tr>
<tr>
<td>VC (lt)</td>
<td>4.7 (±1.3)</td>
<td>4.6 (3.7)</td>
</tr>
<tr>
<td>IC (lt)</td>
<td>3 (±0.8)</td>
<td>3.1 (2.3)</td>
</tr>
<tr>
<td>ERV (lt)</td>
<td>1.5 (±0.6)</td>
<td>1.5 (1.5)</td>
</tr>
<tr>
<td>V&lt;sub&gt;T&lt;/sub&gt; (lt)</td>
<td>1 (±0.4)</td>
<td>1 (1.2)</td>
</tr>
<tr>
<td>MVV (lt/min)</td>
<td>147.7 (±39.4)</td>
<td>160.6 (110.6)</td>
</tr>
<tr>
<td>MIP (cmH&lt;sub&gt;2&lt;/sub&gt;O)</td>
<td>100 (±16.7)</td>
<td>99 (48)</td>
</tr>
<tr>
<td>MEP (cmH&lt;sub&gt;2&lt;/sub&gt;O)</td>
<td>119.3 (±21.1)</td>
<td>121 (74)</td>
</tr>
<tr>
<td>MIP/MEP</td>
<td>0.85 (±0.23)</td>
<td>0.82 (1.19)</td>
</tr>
<tr>
<td>PteCO&lt;sub&gt;2&lt;/sub&gt; (mmHg)</td>
<td>36.9 (±3.8)</td>
<td>37.5 (11)</td>
</tr>
</tbody>
</table>

Mdn: Median, FEV<sub>1</sub>: Forced Expiratory Volume in one second, FVC: Forced Vital Capacity, FEF<sub>25%-75%</sub>: Forced Expiratory Flow from the 25% to 75% of forced expiration, FEF<sub>25%</sub>: Forced Expiratory Flow at the 25% of the forced expiration, FEF<sub>50%</sub>: Forced Expiratory Flow at the 50% of forced expiration, FEF<sub>75%</sub>: Forced Expiratory Flow at the 75% of forced expiration, PEF: Peak Expiratory Flow, PIF: Peak Inspiratory Flow, VC: Vital Capacity, IC: Inspiratory Capacity, ERV: Expiratory Reserve Volume, V<sub>T</sub>: Tidal Volume, MVV: Maximal Voluntary Ventilation, MIP: Maximal Inspiratory Pressure, MEP: Maximal Expiratory Pressure, P<sub>e</sub>CO<sub>2</sub>: Partial pressure of arterial carbon dioxide.
6.15 Correlations of chronic neck pain deficits with respiratory function

The correlations between each chronic neck pain deficit and each respiratory parameter were examined by using the Pearson correlation coefficient. These correlations were also examined in the control group and are presented in Appendix XVII for exploratory purposes. The results for the correlations between each chronic neck pain deficit and forced pulmonary volumes, quiet breathing pulmonary volumes and flows are analytically presented in Table 6.18, whereas the correlation of these chronic neck pain deficits with the other important respiratory parameters are presented in Table 6.19 (r=0.1 means a small effect, r=0.3 means a medium effect and r=0.5 means a large effect) (Field, 2005).

In short, the results show that strength of neck flexors and extensors, pain intensity and kinesiophobia are the musculoskeletal deficits and psychological states that are mostly correlated with respiratory function. Another interesting finding is that the endurance of deep neck flexors is significantly correlated with \( P_{tc}\text{CO}_2 \). Catastrophizing is also significantly correlated with Maximal Respiratory pressures and \( P_{tc}\text{CO}_2 \), whereas the neck pain induced disability is significantly correlated only with the strength of expiratory muscles. These correlations have been also examined using the non-parametric Spearman correlation coefficient and are presented in Appendix XIX. The use of non-parametric statistics leads to similar conclusions with the use of parametric statistics. The only differences are that the peak expiratory flow is now correlated with endurance and kinesiophobia and that the significant correlations between expiratory muscle strength and pain intensity and disability and between catastrophizing and respiratory muscle strength have been lost. The most important of the examined correlations for the chronic neck pain and control group are visually demonstrated in Figures 6.12-6.18. Although endurance of deep neck flexors is theoretically considered one of the most important causes of respiratory dysfunction has not been visually presented because of the restricted number of measures it provides.
Table 6.18: Correlations between chronic neck pain deficits and respiratory parameters I. This table presents the Pearson correlation coefficient for each correlation between the chronic neck pain deficits and pulmonary volumes and flows for the chronic neck pain group.

<table>
<thead>
<tr>
<th>Variables</th>
<th>FEV₁/FVC</th>
<th>FVC</th>
<th>PEF</th>
<th>PIF</th>
<th>FEF₂₅%-₇₅%</th>
<th>VC</th>
</tr>
</thead>
<tbody>
<tr>
<td>Flexion strength</td>
<td>-0.35*</td>
<td>0.65***</td>
<td>0.64***</td>
<td>0.36*</td>
<td>-0.09</td>
<td>0.67***</td>
</tr>
<tr>
<td>Extension Strength</td>
<td>-0.33*</td>
<td>0.69***</td>
<td>0.72***</td>
<td>0.42**</td>
<td>-0.01</td>
<td>0.68***</td>
</tr>
<tr>
<td>Endurance</td>
<td>0.14</td>
<td>0.17</td>
<td>0.25</td>
<td>0.4**</td>
<td>0.14</td>
<td>0.11</td>
</tr>
<tr>
<td>Sagittal ROM</td>
<td>0.16</td>
<td>0.06</td>
<td>-0.16</td>
<td>0.11</td>
<td>-0.02</td>
<td>0.01</td>
</tr>
<tr>
<td>Transverse ROM</td>
<td>-0.01</td>
<td>0.2</td>
<td>0</td>
<td>0.25</td>
<td>-0.14</td>
<td>0.18</td>
</tr>
<tr>
<td>FHP</td>
<td>-0.04</td>
<td>0.1</td>
<td>0.05</td>
<td>0.08</td>
<td>-0.11</td>
<td>0.09</td>
</tr>
<tr>
<td>Usual pain</td>
<td>0.22</td>
<td>-0.29</td>
<td>-0.39**</td>
<td>-0.01</td>
<td>-0.01</td>
<td>-0.32*</td>
</tr>
<tr>
<td>NDI</td>
<td>0.11</td>
<td>-0.13</td>
<td>-0.22</td>
<td>-0.02</td>
<td>0.05</td>
<td>-0.12</td>
</tr>
<tr>
<td>Anxiety</td>
<td>-0.1</td>
<td>-0.26</td>
<td>-0.25</td>
<td>-0.02</td>
<td>-0.01</td>
<td>-0.22</td>
</tr>
<tr>
<td>Depression</td>
<td>-0.02</td>
<td>-0.08</td>
<td>-0.1</td>
<td>-0.12</td>
<td>0.11</td>
<td>-0.01</td>
</tr>
<tr>
<td>Kinesiophobia</td>
<td>0.14</td>
<td>-0.34*</td>
<td>-0.29</td>
<td>-0.3</td>
<td>0.11</td>
<td>-0.39**</td>
</tr>
<tr>
<td>Catastrophizing</td>
<td>0.1</td>
<td>-0.22</td>
<td>-0.23</td>
<td>-0.15</td>
<td>0.07</td>
<td>-0.26</td>
</tr>
</tbody>
</table>

*p<0.05, **p<0.01, ***p<0.001, ROM: Range of Movement, FHP: Forward head posture, NDI: Neck Disability Index, FEV₁: Forced Expiratory Volume in one second, FVC: Forced Vital Capacity, PEF: Peak Expiratory Flow, PIF: Peak Inspiratory Flow, FEF₂₅%-₇₅%: Forced Expiratory Flow from the 25% to the 75% of the forced expiration, VC: Vital Capacity.
Table 6.19: Correlations between chronic neck pain deficits and respiratory parameters II. This table presents the Pearson correlation coefficient for each correlation between the chronic neck pain deficits and Maximal Voluntary Ventilation (MVV), Maximal Inspiratory Pressure (MIP), Maximal Expiratory Pressure (MEP) and partial pressure of arterial carbon dioxide (P_{tc}CO_2) for the chronic neck pain group.

<table>
<thead>
<tr>
<th>Variables</th>
<th>MVV</th>
<th>MIP</th>
<th>MEP</th>
<th>P_{tc}CO_2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Flexion strength</td>
<td>0.57***</td>
<td>0.7***</td>
<td>0.69***</td>
<td>0.34*</td>
</tr>
<tr>
<td>Extension Strength</td>
<td>0.63***</td>
<td>0.62***</td>
<td>0.66***</td>
<td>0.35*</td>
</tr>
<tr>
<td>Endurance</td>
<td>0.22</td>
<td>0.25</td>
<td>0.22</td>
<td>0.31*</td>
</tr>
<tr>
<td>Sagittal ROM</td>
<td>0.02</td>
<td>-0.01</td>
<td>-0.05</td>
<td>-0.08</td>
</tr>
<tr>
<td>Transverse ROM</td>
<td>0.13</td>
<td>0.01</td>
<td>-0.04</td>
<td>0.04</td>
</tr>
<tr>
<td>FHP</td>
<td>0.02</td>
<td>0.01</td>
<td>-0.11</td>
<td>-0.14</td>
</tr>
<tr>
<td>Usual pain</td>
<td>-0.32*</td>
<td>-0.16</td>
<td>-0.33*</td>
<td>-0.34*</td>
</tr>
<tr>
<td>NDI</td>
<td>-0.2</td>
<td>-0.25</td>
<td>-0.35*</td>
<td>-0.19</td>
</tr>
<tr>
<td>Anxiety</td>
<td>-0.22</td>
<td>-0.28</td>
<td>-0.29</td>
<td>-0.12</td>
</tr>
<tr>
<td>Depression</td>
<td>-0.03</td>
<td>-0.08</td>
<td>-0.12</td>
<td>-0.13</td>
</tr>
<tr>
<td>Kinesiophobia</td>
<td>-0.35*</td>
<td>-0.43**</td>
<td>-0.4**</td>
<td>-0.35*</td>
</tr>
<tr>
<td>Catastrophizing</td>
<td>-0.13</td>
<td>-0.3*</td>
<td>-0.36*</td>
<td>-0.3*</td>
</tr>
</tbody>
</table>

*p<0.05, **p<0.01, ***p<0.001, ROM: Range of Movement, FHP: Forward head posture, NDI: Neck Disability Index.
Figure 6.12: Correlations between FEV$_1$/FVC ratio and chronic neck pain deficits. This figure presents the correlations between Forced Expiratory Volume in one second (FEV$_1$)/Forced Vital Capacity (FVC) ratio and a) strength of neck extensors, b) sagittal Range of Movement (ROM), c) Forward Head Posture (FHP), d) Pain intensity, e) Anxiety and f) Kinesiophobia. These correlations are presented for both the chronic neck pain group (black dots) and the control group (white dots), but inferential statistics are provided only for the chronic neck pain group.
Figure 6.13: Correlations between PEF and chronic neck pain deficits. This figure presents the correlations between Peak Expiratory Flow (PEF) and a) strength of neck extensors, b) sagittal Range of Movement (ROM), c) Forward Head Posture (FHP), d) Pain intensity, e) Anxiety and f) Kinesiophobia. These correlations are presented for both the chronic neck pain group (black dots) and the control group (white dots), but inferential statistics are provided only for the chronic neck pain group.
Figure 6.14: Correlations between Vital Capacity (VC) and chronic neck pain deficits. This figure presents the correlations between VC and a) strength of neck extensors, b) sagittal Range of Movement (ROM), c) Forward Head Posture (FHP), d) Pain intensity, e) Anxiety and f) Kinesiophobia. These correlations are presented for both the chronic neck pain group (black dots) and the control group (white dots), but inferential statistics are provided only for the chronic neck pain group.
Figure 6.15: Correlations between Maximal Voluntary Ventilation (MVV) and chronic neck pain deficits. This figure presents the correlations between MVV and a) strength of neck extensors, b) sagittal Range of Movement (ROM), c) Forward Head Posture (FHP), d) Pain intensity, e) Anxiety and f) Kinesiophobia. These correlations are presented for both the chronic neck pain group (black dots) and the control group (white dots), but inferential statistics are provided only for the chronic neck pain group.
Figure 6.16: Correlations between Maximal Inspiratory Pressure (MIP) and chronic neck pain deficits. This figure presents the correlations between MIP and a) strength of neck extensors, b) sagittal Range of Movement (ROM), c) Forward Head Posture (FHP), d) Pain intensity, e) Anxiety and f) Kinesiophobia. These correlations are presented for both the chronic neck pain group (black dots) and the control group (white dots), but inferential statistics are provided only for the chronic neck pain group.
Figure 6.17: Correlations between Maximal Expiratory Pressure (MEP) and chronic neck pain deficits. This figure presents the correlations between MEP and a) strength of neck extensors, b) sagittal Range of Movement (ROM), c) Forward Head Posture (FHP), d) Pain intensity, e) Anxiety and f) Kinesiophobia. These correlations are presented for both the chronic neck pain group (black dots) and the control group (white dots), but inferential statistics are provided only for the chronic neck pain group.
Figure 6.18: Correlations between partial pressure of arterial carbon dioxide (P\textsubscript{a}CO\textsubscript{2}) and chronic neck pain deficits. This figure presents the correlations between P\textsubscript{a}CO\textsubscript{2} and a) strength of neck extensors, b) Sagittal Range of Movement (ROM), c) Forward Head Posture (FHP), d) Pain intensity, e) Anxiety and f) Kinesiophobia. These correlations are presented for both the chronic neck pain group (black dots) and the control group (white dots), but inferential statistics are provided only for the chronic neck pain group.
6.16 Principal component analysis

Principal component analysis was performed for the chronic neck pain group in order to explore and understand the data as well as to examine whether there is any potential for data reduction in future regression models. The principal component analysis was performed using 4 variables as the sample size calculation was performed for such a number of variables. The psychological variables and pain intensity were not included as they were not assessed in healthy participants and mainly because the initial intention was the construction of regression models for predicting respiratory dysfunction included only objective outcome measures. Thus, the first two variables included were the endurance of deep neck flexors and Forward Head Posture (FHP). The third variable included was the neck muscle strength. As an index of neck muscle strength was selected the strength of neck extensors as it seems to be an important deficit presented in the chronic neck pain group which is highly correlated with respiratory dysfunction. Furthermore, the extensor muscles are of great concern during rehabilitation due to the problems they present. The last variable that was used was the neck Range of Movement (ROM). The total neck displacement in the sagittal plane was selected as an index of neck ROM not only because it is frequently restricted in patients with chronic neck pain, but also because all the other variables included in this analysis are concerned with this plane of movement.

For the analysis the Kaiser criterion was used (eigenvalues of more than 1 were kept) since the number of variables was less than 30. The “maximum iterations for convergence” (the times an optimal solution is searched by the software) was selected to be equal to 25 (Field, 2005)

The correlation matrix produced (Table 6.20) generally shows that all the variables correlate to some degree with the others and there is no variable that is highly correlated (r>0.9) with another. Furthermore, the determinant was found to be equal to 0.78 which is greater than 0.00001, suggesting that there is not any multicollinearity problem in this data. Kaiser-Meyer-Olkin measure of sampling adequacy was equal to 0.39 (less than the necessary 0.5) and the Bartlett’s test of sphericity was not found to be significant. Thus, there is no confidence that the sample size used is appropriate for this analysis. However, the principal component
analysis has been performed for exploring and understanding the existent data, rather that the absolute acceptance of the results.

Table 6.20: Correlation matrix of principal component analysis. This table presents the correlation matrix (Pearson correlation coefficients) of the endurance of deep neck flexors, the strength of neck extensors, the sagittal Range of Movement (ROM) and Forward Head Posture (FHP).

<table>
<thead>
<tr>
<th></th>
<th>Endurance</th>
<th>Ext. Strength</th>
<th>Sagittal ROM</th>
<th>FHP</th>
</tr>
</thead>
<tbody>
<tr>
<td>Endurance</td>
<td>1***</td>
<td>0.2</td>
<td>-0.03</td>
<td>-0.09</td>
</tr>
<tr>
<td>Ext. Strength</td>
<td>0.2</td>
<td>1***</td>
<td>-0.18</td>
<td>0.15</td>
</tr>
<tr>
<td>Sagittal ROM</td>
<td>-0.03</td>
<td>-0.18</td>
<td>1***</td>
<td>0.31</td>
</tr>
<tr>
<td>FHP</td>
<td>-0.09</td>
<td>0.15</td>
<td>0.31*</td>
<td>1***</td>
</tr>
</tbody>
</table>

*p<0.05, **p<0.01, ***p<0.001, Ext. strength: Extension strength.

After the initial analysis two factors were extracted. The first one had an eigenvalue of 1.36 and the second one an eigenvalue of 1.2. The factors extracted could explain 64% of the total variance. The communalities after extraction were 0.43 for neck endurance, 0.74 for strength of neck extensors, 0.64 for sagittal neck ROM and 0.76 for FHP. The loadings of each variable into each factor are presented in Table 6.21. The reproduced correlation matrix also showed that the 83% of the nonredundant residuals had absolute values of more than 0.05, something which gives rise to concerns about the appropriateness of the model.
Since after the initial factor extraction some variables like FHP and endurance loaded highly in both factors, rotation was used for improving the loading of variables onto factors. Oblique rotation was selected since there are theoretical grounds to believe that the factors correlated in some degree with each other. Furthermore, a direct oblimin oblique rotation (delta=0) was selected as the available data set is not very large.

The eigenvalues for the two factors after rotation were 1.32 for the first factor and 1.25 for the second factor. The loading of each variable onto factors after rotation are presented in Table 6.21. The loading of each variable onto each factor is visually presented in Figure 6.19.
The findings after the principal component analysis are very interesting since it leads to the extraction of two factors which are quite independent from each other. The first factor includes two variables (muscle strength of neck extensors, endurance of deep neck flexors) which represent the “muscle efficiency” component of the model, whereas the second factor includes the other two variables (sagittal ROM, FHP) which reflect “postural adaptations”. It would be interesting to perform the regression analysis using these factors instead of variables. However, this would not be scientifically sound since the model presents many weaknesses. Thus, the inadequate sample size, the bad fit of the model and mainly the fact that it does not explain a lot of variance and important information is lost suggested not to calculate factor scores for each individual and to perform the regression analysis using the initial variables as predictors instead of the factors.
Multiple regression analysis (backward stepwise) was performed for the chronic neck pain group in order to construct models for predicting respiratory function. For these regression models the main criterion for the selection of predictors was to be a biomechanical factor that has strong theoretical grounds to affect respiratory function and to provide an objective measure of physical function. Thus, strength of neck extensors, endurance of deep neck flexors, Forward Head Posture (FHP) and cervical Range of Movement (ROM) in the sagittal plane were selected as predictors.

The respiratory function parameters for which the regression models were constructed should have been recognized from the previous findings of the study as problematic in patients with chronic neck pain and to be critical components of respiratory function. Thus, regression models were constructed for the Peak Expiratory Flow (PEF), Vital Capacity (VC), Maximal Voluntary Ventilation (MVV), Maximal Inspiratory Pressure (MIP), Maximal Expiratory Pressure (MEP) and partial pressure of arterial carbon dioxide (P_{tc}CO_2). It should be noted that PEF was preferred to Peak Inspiratory Flow (PIF) because of the more reliable and valid response of the former index during the measurements.

It should be additionally mentioned that although the main regression models were performed by using 4 predictors, after statistical advice regression models with all the potential predictors were also constructed (pain and psychological states were also used as predictors). This additional analysis can provide more depth into the exploration of the potential causes of respiratory dysfunction in patients with chronic neck pain.

**Assumptions**

As far as the multiple regression assumptions are concerned all the variables were quantitative and continuous. However, the endurance of deep neck flexors cannot be considered unbounded since the data is constrained (it provides limited scores). Furthermore, a problem deriving from the regression models of 4 predictors is
that the exclusion of pain and psychosocial influences may affect the models aimed at predicting outcome measures that correlated to these excluded variables. However, the problem minimizes not only being cautious about where generalize the model, but also running exploratory regression models with all the potential predictors. Another criterion met is that none of the predictors has zero variance. For checking the multicollinearity a correlation matrix is provided (Table 6.22). This correlation matrix reveals that no pair of predictors is highly correlated (all r<0.8) and consequentially multicollinearity is not a threat. Multicollinearity was also examined by using tolerance statistics for each model separately. Tolerance of less than 0.2 are worthy of concern, whereas under 0.1 indicate a serious problem. Another important assumption has also been met as all the values of the outcome measure come from a separate entity. The assumption of independent errors was tested by using the Durbin-Watson test. If the test was less than 1 or more than 3 then this assumption had been violated. The assumptions of homoscedasticity (it was tested by using a plot of standardized residuals against standardized predicted values), normally distributed errors (it was tested by using histograms with superimposed normal curves of the regression standardized residuals) and linearity (it was also examined by using plots of standardized residuals against standardized predicted values) are discussed for each model separately. All the information about the assumptions of regression models are provided by Field (2005).

Table 6.22: Correlation matrix for all the potential predictors. This table presents the correlation matrix (Pearson correlation coefficients) for the predictors used in all the regression models of the chronic neck pain group.

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Ext. str.</td>
<td>1***</td>
<td>0.2</td>
<td>-0.18</td>
<td>0.15</td>
<td>-0.31*</td>
<td>-0.36*</td>
</tr>
<tr>
<td>Endur.</td>
<td>0.2</td>
<td>1***</td>
<td>-0.03</td>
<td>-0.09</td>
<td>-0.05</td>
<td>-0.06</td>
</tr>
<tr>
<td>Sag. ROM</td>
<td>-0.18</td>
<td>-0.03</td>
<td>1***</td>
<td>0.31*</td>
<td>0.13</td>
<td>-0.24</td>
</tr>
<tr>
<td>FHP</td>
<td>0.15</td>
<td>-0.09</td>
<td>0.31*</td>
<td>1***</td>
<td>0.02</td>
<td>-0.07</td>
</tr>
<tr>
<td>Pain</td>
<td>-0.31*</td>
<td>-0.05</td>
<td>0.13</td>
<td>0.02</td>
<td>1***</td>
<td>0.16</td>
</tr>
<tr>
<td>Kinesioph.</td>
<td>-0.36*</td>
<td>-0.06</td>
<td>-0.24</td>
<td>-0.07</td>
<td>0.16</td>
<td>1***</td>
</tr>
</tbody>
</table>

*p<0.05, **p<0.01, ***p<0.001, Ext. str.: Extension strength, Endur.: Endurance, Sag. ROM: Sagittal Range of Movement, FHP: Forward Head Posture, Kinesioph.: Kinesiophobia.
6.17.1 Regression models with 4 predictors

The regression models provided in this section are the models that answer the main question of this study as the sample size was calculated based on models of four predictors (neck extensors muscle strength, endurance of deep neck flexors, neck range of movement in the sagittal plane, forward head posture).

**Prediction of Peak Expiratory Flow (PEF)**

The regression analysis for the prediction of PEF was performed with 44 individuals due to the fact that one patient did not have data for one variable. In the model, only the muscle strength of neck extensors was kept (part correlation=0.72), whereas the sagittal range of movement (B=-0.01, β=-0.02, part correlation=-0.02, p=0.86), forward head posture (B=-0.02, β=-0.05, part correlation=0.1, p=0.65) and endurance (B=0.1, β=0.1, part correlation=0.1, p=0.31) were successively removed from the model. The final model is described in Table 6.23 and visually presented in Figure 6.20. The constructed model was found to significantly fit to the data overall (p<0.001). The multiple correlation coefficient was found to be very good (R=0.72), The $R^2$ also indicates that the model accounts for the 52% of the PEF variability ($R^2=0.52$). The adjusted $R^2$ was also found to be very close to the $R^2$ (adjusted $R^2=0.51$) suggesting that the model has very good generalizability to the population. The Durbin-Watson statistic was found to be close to 2 (Durbin-Watson statistic=2.26), showing that the assumption of independent errors has not been violated. Multicollinearity was also confirmed that is not a problem since only one predictor remained in the model. However, tolerance was also found much more than 0.2, initially when all the predictors had entered in the model (tolerance for all the predictors > 0.84). The values of standardized residuals were less than 3 for all cases and only four standardized residuals had a value of more than 2. This indicates that there was no serious problem with outliers. Moreover, the Cook’s distance was less than 1 for all these 4 values and consequentially none of them was extremely influential for the regression model. The plot of standardized residuals against standardized predicted values shows that the assumptions of homoscedasticity and
linearity have not been violated (Appendix XX). Furthermore, a histogram with a superimposed normal curve reveals that the standardized residuals are normally distributed showing that the assumption of normally distributed errors has been met (Appendix XXI). Considering all of these findings, it can be concluded in general that the model constructed for the prediction of PEF is a quite accurate and generalizable model.

Table 6.23: Regression model for the prediction of Peak Exploratory Flow (PEF). This table presents the beta values (B) with their 95% Confidence Intervals (95% CI) and their Standard Error (SE B) as well as the standardized beta values (β) for the prediction of PEF in patients with chronic neck pain.

<table>
<thead>
<tr>
<th>PEF Prediction</th>
<th>B (95% CI)</th>
<th>SE B</th>
<th>β</th>
</tr>
</thead>
<tbody>
<tr>
<td>Constant</td>
<td>4.74 (3.86, 5.63)***</td>
<td>0.44</td>
<td></td>
</tr>
<tr>
<td>Neck extensors strength</td>
<td>0.17 (0.12, 0.22)***</td>
<td>0.03</td>
<td>0.72</td>
</tr>
</tbody>
</table>

***p<0.001

Figure 6.20: Regression model for Peak Expiratory Flow (PEF). This figure presents the regression model for the prediction of PEF in patients with chronic neck pain.
**Prediction of Vital Capacity (VC)**

The regression analysis for the VC prediction was performed with 44 individuals as data was missing for one variable of one participant. During the analysis the endurance of deep neck flexors ($B=-0.02$, $\beta=-0.05$, part correlation=$-0.05$, $p=0.69$), forward head posture ($B=-0.01$, $\beta=-0.07$, part correlation=$-0.07$, $p=0.56$) and sagittal range of movement ($B=0.01$, $\beta=0.13$, part correlation=$0.13$, $p=0.25$) were successively removed from the model. Finally, only strength of neck extensors (part correlation=$0.7$) remained in the model as significant predictor. The final model is described in Table 6.24 and visually demonstrated in Figure 6.21. The generated model was found to significantly fit the data overall ($p<0.001$). The multiple correlation coefficient was very good ($R=0.7$). The $R^2$ was also very good as it shows that the model accounts for 49% of the variability of VC ($R^2=0.49$). The adjusted $R^2$ also suggests that if the model applies to the population it accounts for 2% less variability (adjusted $R^2=0.47$) suggesting that the model has quite good generalizability to the population. The Durbin-Watson statistic was found to be quite close to 2 (Durbin-Watson statistic=$1.86$), showing that the assumption of independent errors has not been violated. Multicollinearity was also confirmed that is not a problem since only one predictor remained in the model. Standardized residuals values were less than 3 for all cases and only five standardized residuals had a value of more than 2. These potential outliers were tested with the Cook’s distance and it was found that none of them was a very influential case as their Cook’s distances were well below 1. The assumption of homoscedasticity and linearity seem also not to have been violated as it seems from the plot of standardized residuals against standardized predicted values (Appendix XX). An histogram with a superimposed normal curve also reveals that the standardized residuals are normally distributed showing that the assumption of normally distributed errors has not been violated (Appendix XXI). In summary, it seems that the model constructed for the prediction of VC is also a quite accurate and generalizable model.
Table 6.24: Regression model for the prediction of Vital Capacity (VC). This table presents the beta values (B) with their 95% Confidence Intervals (95% CI) and their Standard Error (SE B) as well as the standardized beta values (β) for the prediction of VC in patients with chronic neck pain.

<table>
<thead>
<tr>
<th>VC Prediction</th>
<th>B (95% CI)</th>
<th>SE B</th>
<th>β</th>
</tr>
</thead>
<tbody>
<tr>
<td>Constant</td>
<td>2.34 (1.87, 2.8)**</td>
<td>0.23</td>
<td></td>
</tr>
<tr>
<td>Neck extensors strength</td>
<td>0.08 (0.06, 0.11)**</td>
<td>0.01</td>
<td>0.7</td>
</tr>
</tbody>
</table>

***p<0.001

Figure 6.21: Regression model for Vital Capacity (VC). This figure presents the regression model for the prediction of VC in patients with chronic neck pain.

![Regression model for Vital Capacity (VC)]
The regression analysis for the MVV prediction was performed with 44 individuals as data was missing for one variable of one participant. During the analysis the endurance of deep neck flexors (B=1.24, $\beta=0.08$, part correlation=0.08, $p=0.51$), forward head posture (B=-0.89, $\beta=-0.14$, part correlation=-0.13, $p=0.28$) and sagittal range of movement (B=0.26, $\beta=0.13$, part correlation=0.13, $p=0.27$) were successively removed from the model, whereas only the strength of neck extensors (part correlation=0.65) remained into the model as significant predictor. The final model is analytically described in Table 6.25 and graphically demonstrated in Figure 6.22. The constructed model was a significantly fit of the data overall ($p<0.001$). The multiple correlation coefficient was quite good ($R=0.65$). The $R^2$ was also satisfactory as it shows that the model accounts for 43% of the variability of MVV ($R^2=0.43$). The adjusted $R^2$ also suggests that if the model applies to the population it accounts for 2% less variability (adjusted $R^2=0.41$) suggesting that the model has quite good generalizability to the population. The Durbin-Watson statistic was found to be quite close to 2 (Durbin-Watson statistic=2.14), showing that the assumption of independent errors has been met. The fact that the final model includes only one predictor does not give rise to concerns about multicollinearity. All the standardized residuals had values of less than 3, whereas only one standardized residual had a value of more than 2. However, this potential outlier was not found to be extremely influential to the regression model as its Cook’s distance was far below 1. The plot of standardized residuals against standardized predicted values shows that the assumption of linearity has been met, whereas is does not seem that there are any serious signs of heteroscedasticity (Appendix XX). Furthermore, an histogram with a superimposed normal curve also reveals that the standardized residuals are normally distributed showing that the assumption of normally distributed errors has been met (Appendix XXI). In general, the model for the prediction of MVV also seems to be accurate and generalizable to the population.
Table 6.25: Regression model for the prediction of Maximal Voluntary Ventilation (MVV). This table presents the beta values (B) with their 95% Confidence Intervals (95% CI) and their Standard Error (SE B) as well as the standardized beta values (β) for the prediction of MVV in patients with chronic neck pain.

<table>
<thead>
<tr>
<th>MVV Prediction</th>
<th>B (95% CI)</th>
<th>SE B</th>
<th>β</th>
</tr>
</thead>
<tbody>
<tr>
<td>Constant</td>
<td>67.26 (49.81, 84.72)***</td>
<td>8.65</td>
<td></td>
</tr>
<tr>
<td>Neck extensors strength</td>
<td>2.71 (1.73, 3.69)***</td>
<td>0.49</td>
<td>0.65</td>
</tr>
</tbody>
</table>

***p<0.001

Figure 6.22: Regression model for Maximal Voluntary Ventilation (MVV). This figure presents the regression model for the prediction of MVV in patients with chronic neck pain.
The regression analysis for the prediction of MIP was performed with 44 individuals due to the fact that one patient did not provide data for one variable. In the model, only the muscle strength of neck extensors was kept (part correlation=0.63), whereas the endurance of deep neck flexors (B=1.54, \(\beta=0.11\), part correlation=0.11, \(p=0.37\)), forward head posture (B=-0.81, \(\beta=-0.14\), part correlation=-0.13, \(p=0.28\)) and sagittal range of movement (B=0.18, \(\beta=0.1\), part correlation=0.1, \(p=0.4\)) were successively removed from the model. The final model is analytically described in Table 6.26 and visually presented in Figure 6.23. The constructed model was found to significantly fit to the data overall (\(p<0.001\)). Although the multiple correlation coefficient was found to be less than the ones of the previous models (\(R=0.63\)), it was also satisfactory. The \(R^2\) also shows that the model accounts for the 39% of the MIP variability (\(R^2=0.39\)), but the adjusted \(R^2\) shows that the model accounts only 1% less for the population variability in comparison to the sample variability (adjusted \(R^2=0.38\)) suggesting that the model can confidently generalize to the population. The Durbin-Watson statistic was also found to be satisfactory (Durbin-Watson statistic=2.19), showing that the assumption of independent errors has been met. Multicollinearity was also confirmed that is not a problem since only one predictor remained in the model. The values of standardized residuals were less than 3 for all cases and only two standardized residuals had a value of more than 2. Moreover, these potential outliers were not found to be very influential for the regression model as their Cook’s distance was far below 1. The plot of standardized residuals against standardized predicted values shows that the assumption of linearity has not been violated. However, a small heteroscedasticity may be present, but it is small and does not give rise to serious concerns (Appendix XX). Furthermore, an histogram with a superimposed normal curve reveals that the distribution of standardized residuals is very similar to a normal distribution also indicating that the assumption of normally distributed errors has been met (Appendix XXI). Taking into consideration all of these findings, it seems that the model constructed for the prediction of MIP is not as good as the previously discussed models, but remains a quite accurate and generalizable model.
Table 6.26: Regression model for the prediction of Maximal Inspiratory Pressure (MIP). This table presents the beta values (B) with their 95% Confidence Intervals (95% CI) and their Standard Error (SE B) as well as the standardized beta values (β) for the prediction of MIP in patients with chronic neck pain.

<table>
<thead>
<tr>
<th>MIP Prediction</th>
<th>B (95% CI)</th>
<th>SE B</th>
<th>β</th>
</tr>
</thead>
<tbody>
<tr>
<td>Constant</td>
<td>51.2 (35.43, 66.98)***</td>
<td>7.82</td>
<td>0.63</td>
</tr>
<tr>
<td>Neck extensors strength</td>
<td>2.29 (1.41, 3.18)***</td>
<td>0.44</td>
<td>0.63</td>
</tr>
</tbody>
</table>

***p<0.001

Figure 6.23: Regression model for Maximal Inspiratory Pressure (MIP). This figure presents the regression model for the prediction of MIP in patients with chronic neck pain.
**Prediction of Maximal Expiratory Pressure (MEP)**

The regression analysis for the MEP prediction was performed with 44 individuals as data was missing for one variable of one participant. During the analysis the endurance of deep neck flexors (B=1.12, $\beta=0.06$, part correlation=0.06, $p=0.61$) and the sagittal range of movement (B=0.39, $\beta=0.16$, part correlation=0.15, $p=0.19$) were successively removed from the model. Strength of neck extensors was the only significant predictor of MEP (part correlation=0.69, $p<0.001$), whereas forward head posture was also remained in the model because it had a trend for statistical significance (part correlation=-0.21, $p=0.07$). The final model is described in Table 6.27. The generated model was found to significantly fit the data overall ($p<0.001$). The multiple correlation coefficient was very good ($R=0.7$). The $R^2$ was also very good as it shows that the model accounts for 49% of the variability of MEP ($R^2=0.49$). However, the adjusted $R^2$ showed that the model accounts for 3% less variability if it is applied to the population (adjusted $R^2=0.46$). Although the difference between $R^2$ and adjusted $R^2$ is higher than the ones of the previously discussed models, it may be considered acceptable. The Durbin-Watson statistic was found to be satisfactory (Durbin-Watson statistic=2.12), indicating that the assumption of independent errors has not been violated. Tolerance statistics also showed that there was no concern for multicollinearity (tolerance statistics=0.98). Standardized residuals values were less than 3 for all cases and only two standardized residuals had a value of more than 2. These potential outliers were tested with the Cook’s distance and it was found that none of them was a very influential case as their Cook’s distances were well below 1. The plot of standardized residuals against standardized predicted values shows that the assumptions of homoscedasticity and linearity have not been violated (Appendix XX), whereas an histogram with a superimposed normal curve also reveals that the standardized residuals are normally distributed showing that the assumption of normally distributed errors has been met (Appendix XXI). In general, the model for the prediction of MEP seems to be accurate and can generalize to the population considering always the difference in the variance that can be explained.
Table 6.27: Regression model for the prediction of Maximal Expiratory Pressure (MEP). This table presents the beta values (B) with their 95% Confidence Intervals (95% CI) and their Standard Error (SE B) as well as the standardized beta values (β) for the prediction of MEP in patients with chronic neck pain.

<table>
<thead>
<tr>
<th>MEP Prediction</th>
<th>B (95%CI)</th>
<th>SE B</th>
<th>β</th>
</tr>
</thead>
<tbody>
<tr>
<td>Constant</td>
<td>133.98 (46.82, 221.14)**</td>
<td>43.16</td>
<td></td>
</tr>
<tr>
<td>Neck extensors strength</td>
<td>3.53 (2.37, 4.69)***</td>
<td>0.57</td>
<td>0.7</td>
</tr>
<tr>
<td>Forward head posture</td>
<td>-1.67 (-3.5, 0.12)</td>
<td>0.89</td>
<td>-0.21</td>
</tr>
</tbody>
</table>

*p<0.01, **p<0.001

*Prediction of partial pressure of arterial carbon dioxide (P_{tc}CO_{2})*

The regression analysis for the prediction of P_{tc}CO_{2} was performed with 44 individuals due to the fact that one patient did not have data for one variable. In the model, only the muscle strength of neck extensors (part correlation=0.3, p=0.04) and endurance of deep neck flexors (part correlation=0.24, p=0.09) were kept, whereas the sagittal range of movement (B=0.01, β=0.04, part correlation=0.04, p=0.8) and forward head posture (B=-0.09, β=-0.17, part correlation=-0.16, p=0.25) were successively removed from the model. The final model is analytically described in Table 6.28. The constructed model was found to significantly fit to the data overall (p<0.05). The multiple correlation coefficient was found to be moderate (R=0.43) and the model can explain only the 19% of the total variability of the P_{tc}CO_{2} (R^2=0.19). The adjusted R^2 shows that the model not only explains only 19% of the variability of the predicted outcome measure, but also that this percentage drops to 15% when the model applies to the population (adjusted R^2=0.15). The Durbin-Watson statistic was found to be close to 2 (Durbin-Watson statistic=1.94), showing that the assumption of independent errors has been met. Multicollinearity was also confirmed that is not a
problem since the tolerance statistic was much higher than 0.2 (tolerance statistic=0.96). The values of standardized residuals were less than 3 for every individual case and only one standardized residual had a value of more than 2. Furthermore, this potential outlier had a Cook’s distance far less than 1, showing that there is no importantly influential outlier. The assumptions of homoscedasticity and linearity have not been violated as it seems from the plot of standardized residuals against standardized predicted values (Appendix XX). Furthermore, an histogram with a superimposed normal curve reveals that the standardized residuals are normally distributed showing that the assumption of normally distributed errors has been met (Appendix XXI). Considering all of these findings, it can be concluded that although this model for the prediction of $P_{tc}CO_2$ has met the most assumptions, it does not explain very much variability whereas its cross-validation is problematic. Thus, although it seems to have acceptable accuracy, its generalizability is questionable and it is advised to be used only for the sample of the study and not for the population.

Table 6.28: Regression model for the prediction of partial pressure of arterial carbon dioxide ($P_{tc}CO_2$). This table presents the beta values (B) with their 95% Confidence Intervals (95% CI) and their Standard Error (SE B) as well as the standardized beta values (β) for the prediction of $P_{tc}CO_2$ in patients with chronic neck pain.

<table>
<thead>
<tr>
<th>$P_{tc}CO_2$ Prediction</th>
<th>B (95% CI)</th>
<th>SE B</th>
<th>β</th>
</tr>
</thead>
<tbody>
<tr>
<td>Constant</td>
<td>26.51 (18.55, 34.47)**</td>
<td>3.94</td>
<td></td>
</tr>
<tr>
<td>Neck extensors strength</td>
<td>0.1 (0.01, 0.2)*</td>
<td>0.05</td>
<td>0.31</td>
</tr>
<tr>
<td>Endurance</td>
<td>0.3 (-0.05, 0.66)</td>
<td>0.18</td>
<td>0.25</td>
</tr>
</tbody>
</table>

*p<0.05, ***p<0.001
6.17.2 Regression analysis with all the potential predictors

Regression analysis was also performed for the prediction of respiratory function in the chronic neck patients, by using all the potential predictors. Thus, not only neck muscle strength, endurance of deep neck flexors, forward head posture and cervical range of movement, but also usual pain intensity, anxiety, depression, kinesiophobia and catastrophizing were examined as predictors. It should be noted that although this is an analysis without a sound sample size calculation, there are references which support that this sample size is adequate (Norman and Streiner, 2000). The rationale followed for the analysis was the same as previously. The regression analysis for each respiratory parameter was again performed by using 44 individuals. After the performance of this analysis, the models constructed for the prediction of peak expiratory flow, vital capacity, maximal voluntary ventilation and maximal expiratory pressure were the same as the ones provided previously and therefore only the removal of the non-significant predictors is described. However, the models for the prediction of maximal inspiratory pressure and partial pressure of carbon dioxide have some important changes and are presented below.

**Prediction of Peak Expiratory Flow (PEF)**

After the common input of all the potential predictors into the model for the prediction of PEF, depression (\(B=-0.02, \beta=-0.03, \text{part correlation}=-0.02, p=0.87\)), sagittal range of movement (\(B=-0.01, \beta=-0.03, \text{part correlation}=-0.02, p=0.83\)), kinesiophobia (\(B=-0.01, \beta=-0.03, \text{part correlation}=-0.02, p=0.84\)), catastrophizing (\(B=0.01, \beta=0.04, \text{part correlation}=0.03, p=0.78\)), anxiety (\(B=-0.01, \beta=-0.03, \text{part correlation}=-0.03, p=0.8\)), forward head posture (\(B=-0.01, \beta=-0.04, \text{part correlation}=-0.04, p=0.73\)), endurance of deep neck flexors (\(B=0.1, \beta=0.12, \text{part correlation}=0.11, p=0.29\)) and pain intensity (\(B=-0.02, \beta=-0.18, \text{part correlation}=-0.17, p=0.12\)) were successively removed from the model. Strength of neck extensors was the only predictor remained in the model (part correlation=0.72, \(p<0.001\)). The model constructed was exactly the same with the one provided in Table 6.23.
**Prediction of Vital Capacity (VC)**

After the common input of all the potential predictors into the model for the prediction of VC, endurance of deep neck flexors ($B=-0.01$, $\beta=-0.01$, part correlation=-0.01, $p=0.98$), anxiety ($B=-0.01$, $\beta=-0.03$, part correlation=-0.03, $p=0.86$), forward head posture ($B=0.01$, $\beta=0.04$, part correlation=-0.02, $p=0.78$), catastrophizing ($B=-0.01$, $\beta=-0.06$, part correlation=-0.04, $p=0.7$), pain intensity ($B=-0.01$, $\beta=-0.1$, part correlation=-0.09, $p=0.41$), sagittal range of movement ($B=0.01$, $\beta=0.11$, part correlation=0.1, $p=0.36$), depression ($B=0.04$, $\beta=0.14$, part correlation=0.13, $p=0.24$) and kinesiophobia ($B=-0.02$, $\beta=-0.15$, part correlation=-0.14, $p=0.21$) were successively removed from the model. Strength of neck extensors was the only predictor remained in the model (part correlation=0.7, $p<0.001$). The model constructed was exactly the same with the one provided in Table 6.24.

**Prediction of Maximal Voluntary Ventilation (MVV)**

After the common input of all the potential predictors into the model for the prediction of MVV, depression ($B=0.34$, $\beta=0.04$, part correlation=0.02, $p=0.85$), anxiety ($B=-0.7$, $\beta=-0.09$, part correlation=-0.07, $p=0.55$), endurance of deep neck flexors ($B=1.18$, $\beta=0.08$, part correlation=0.07, $p=0.53$), forward head posture ($B=-0.79$, $\beta=-0.12$, part correlation=-0.11, $p=0.34$), sagittal range of movement ($B=0.18$, $\beta=0.09$, part correlation=0.08, $p=0.49$), pain intensity ($B=-0.27$, $\beta=-0.14$, part correlation=-0.13, $p=0.26$), catastrophizing ($B=0.51$, $\beta=0.17$, part correlation=0.15, $p=0.22$) and kinesiophobia ($B=-0.63$, $\beta=-0.12$, part correlation=-0.11, $p=0.34$) were successively removed from the model. Strength of neck extensors was the only predictor remained in the model (part correlation=0.65, $p<0.001$). The model constructed was exactly the same with the one provided in Table 6.25.
After the common input of all the potential predictors into the model for the prediction of MIP, forward head posture (B=-0.07, β=-0.01, part correlation=-0.01, p=0.94), catastrophizing (B=-0.17, β=-0.06, part correlation=-0.05, p=0.71), sagittal range of movement (B=0.08, β=0.05, part correlation=0.04, p=0.73), pain intensity (B=0.2, β=0.12, part correlation=0.11, p=0.37), anxiety (B=-0.9, β=-0.13, part correlation=-0.11, p=0.35), depression (B=0.76, β=0.09, part correlation=0.09, p=0.47) and endurance of deep neck flexors (B=1.82, β=0.13, part correlation=0.13, p=0.27) were successively removed from the model. Strength of neck extensors was the only significant predictor in the model (part correlation=0.5, p<0.001), whereas kinesiophobia was also included (part correlation=-0.22, p=0.07). The final model is analytically described in Table 6.29.

The constructed model was found to significantly fit to the data overall (p<0.001). The multiple correlation coefficient was found to be good (R=0.66). The R² also shows that the model accounts for the 44% of the MIP variability (R²=0.44) and the adjusted R² shows that the model accounts for 3% less variability when the model is applied to the population (adjusted R²=0.41). The Durbin-Watson statistic was also found to be satisfactory (Durbin-Watson statistic=2.29), showing that the assumption of independent errors has been met. Multicollinearity was also confirmed that is not a problem (tolerance=0.86). The values of standardized residuals were less than 3 for all cases and only two standardized residuals had a value of more than 2. Moreover, these potential outliers were not found to be very influential for the regression model as their Cook’s distance was far below 1. The plot of standardized residuals against standardized predicted values shows that the assumptions of homoscedasticity and linearity have not been violated (Appendix XXII). Furthermore, an histogram with a superimposed normal curve reveals that the standardized residuals are normally distributed also indicating that the assumption of normally distributed errors has been met (Appendix XXII). Considering all of these findings, the constructed model for the prediction of MIP seems to be a quite accurate and generalizable model.
Table 6.29: Regression model for the prediction of Maximal Inspiratory Pressure (MIP) (all the predictors). This table presents the beta values (B) with their 95% Confidence Intervals (95% CI) and their Standard Error (SE B) as well as the standardized beta values (β) for the prediction of MIP in patients with chronic neck pain.

<table>
<thead>
<tr>
<th>MIP Prediction</th>
<th>B (95% CI)</th>
<th>SE B</th>
<th>β</th>
</tr>
</thead>
<tbody>
<tr>
<td>Constant</td>
<td>92.14 (45.13, 139.14)***</td>
<td>23.27</td>
<td></td>
</tr>
<tr>
<td>Neck extensors strength</td>
<td>1.98 (1.05, 2.91)***</td>
<td>0.46</td>
<td>0.54</td>
</tr>
<tr>
<td>Kinesiophobia</td>
<td>-1.06 (-2.2, 0.09)</td>
<td>0.57</td>
<td>-0.23</td>
</tr>
</tbody>
</table>

***p<0.001

**Prediction of Maximal Expiratory Pressure (MEP)**

After the common input of all the potential predictors into the model for the prediction of MEP, anxiety (B=0.16, β=0.02, part correlation=0.01, p=0.92), catastrophizing (B=-0.21, β=-0.06, part correlation=-0.04, p=0.72), endurance of deep neck flexors (B=0.83, β=0.04, part correlation=0.04, p=0.71), kinesiophobia (B=-0.6, β=-0.1, part correlation=-0.08, p=0.48), pain intensity (B=0.33, β=-0.14, part correlation=-0.14, p=0.22), depression (B=-1.89, β=-0.16, part correlation=-0.14, p=0.21) and sagittal range of movement (B=0.39, β=0.16, part correlation=0.15, p=0.19) were successively removed from the model. Strength of neck extensors was the only significant predictor (part correlation=0.69, p<0.001), whereas forward head posture was also included (part correlation=-0.21, p=0.07). The final model was exactly the same with the one provided in Table 6.27.
Prediction of partial pressure of arterial carbon dioxide ($P_{tc}CO_2$)

After the common input of all the potential predictors into the model for the prediction of $P_{tc}CO_2$, sagittal range of movement ($B=-0.01$, $\beta=-0.01$, part correlation=$-0.01$, $p=0.95$), catastrophizing ($B=-0.02$, $\beta=-0.07$, part correlation=$-0.05$, $p=0.71$), anxiety ($B=0.12$, $\beta=0.19$, part correlation=$0.15$, $p=0.27$), depression ($B=-0.1$, $\beta=-0.14$, part correlation=$-0.11$, $p=0.41$), strength of neck extensors ($B=0.06$, $\beta=0.17$, part correlation=$0.15$, $p=0.28$) and forward head posture ($B=-0.07$, $\beta=-0.13$, part correlation=$-0.13$, $p=0.35$) were successively removed from the model. Endurance of deep neck flexors (part correlation=$0.28$, $p=0.046$), kinesiophobia (part correlation=$-0.29$, $p=0.039$) and pain intensity (part correlation=$-0.27$, $p=0.049$) were remained as significant predictors into the model. The final model is analytically presented in Table 6.30.

The constructed model was found to significantly fit to the data overall ($p<0.01$). The multiple correlation coefficient was found to be moderate ($R=0.53$). The $R^2$ also shows that the model accounts only for the 28% of the $P_{tc}CO_2$ variability ($R^2=0.28$) whereas this percentage presents a 5% drop when the model applies to the population (adjusted $R^2=0.23$). The Durbin-Watson statistic was found to be satisfactory (Durbin-Watson statistic$=1.95$), showing that the assumption of independent errors has been met. Multicollinearity was also confirmed that is not a problem (tolerance$>0.97$). The values of standardized residuals were less than 3 for all cases and only one standardized residual had a value of more than 2. Moreover, this potential outlier was not found to exert any excessive influence to the model as its Cook’s distance was far below 1. The plot of standardized residuals against standardized predicted values shows that the assumptions of heteroscedasticity and linearity have not been violated whereas an histogram with a superimposed normal curve reveals that the standardized residuals are normally distributed indicating that the assumption of normally distributed errors has been met (Appendix XXII). In conclusion, this model for the prediction of $P_{tc}CO_2$ seems to be accurate but only for the sample used in the study as it is difficult to generalize to the population.
Table 6.30: Regression model for the prediction of partial pressure of arterial carbon dioxide (P_{tc}CO_2) (all the predictors). This table presents the beta values (B) with their 95% Confidence Intervals (95% CI) and their Standard Error (SE B) as well as the standardized beta values (β) for the prediction of P_{tc}CO_2 in patients with chronic neck pain.

<table>
<thead>
<tr>
<th>P_{tc}CO_2 Prediction</th>
<th>B (95% CI)</th>
<th>SE B</th>
<th>β</th>
</tr>
</thead>
<tbody>
<tr>
<td>Constant</td>
<td>33.17 (24.34, 42)***</td>
<td>4.37</td>
<td></td>
</tr>
<tr>
<td>Endurance</td>
<td>0.34 (0.01, 0.68)*</td>
<td>0.17</td>
<td>0.28</td>
</tr>
<tr>
<td>Kinesiophobia</td>
<td>-0.12 (-0.23, -0.01)*</td>
<td>0.06</td>
<td>-0.29</td>
</tr>
<tr>
<td>Usual pain</td>
<td>-0.04 (-0.08, 0)*</td>
<td>0.02</td>
<td>-0.28</td>
</tr>
</tbody>
</table>

*p<0.05, ***p<0.001
7. Discussion
7. DISCUSSION

The aim of this chapter is to discuss and explain the findings of the study. After characterizing the sample of the study, the findings about the musculoskeletal and psychological states of patients with chronic neck pain are discussed. Then, a discussion about the main findings of the study regarding the respiratory function of patients with chronic neck pain follows. After this discussion, a new model for the mechanisms leading patients with chronic neck pain to respiratory dysfunction is provided. Finally, a discussion follows about the limitations and clinical implications of the study and directions for further research are suggested.

7.1 Sample

The patients with chronic idiopathic neck pain were recruited from different areas of Greece, but the most of them either were living or were working in Lamia. Half of them were living in urban areas whereas the other half were from semi-urban or rural areas. Half of patients had sitting or sedentary work whereas the other half had physical work. Most patients also participated in moderately physical activities and were similarly active to the healthy controls.

71% of patients with chronic neck pain were females being consistent with the literature about the higher incidence of neck pain in female population (Andrianakos et al, 2002; Cote et al, 2003; Webb et al, 2003). In terms of central tendency, patients with chronic idiopathic neck pain were middle-aged with moderate height and weight. Their Body Mass Index (BMI) also shows that they were normal to slightly overweight. However, patients of a wide range of age, height and weight were recruited and this variability should be carefully considered during discussion of the findings.

98% of the patients were right-handed, but most of them experienced bilateral neck pain. 71% of patients also suffered from headaches, and 30% of patients arm symptomatology. However, considering the fact that about 21.7% of pain sufferers (Bouhassira et al, 2008) and specifically the 17.8% of patients with neck pain are
The usual experience of patients’ pain was rated as moderate, whereas during the measurements they described themselves as suffering from mild neck pain. This fact has as a result the findings of the study to represent mostly the permanent musculoskeletal and psychological changes of neck pain and less the temporary inhibiting results of neck pain to these systems because the usual pain intensity was selected for the analysis as a more stable pain index. The majority of the patients had neck pain complaints for 3-4 days per week and the chronicity of their symptoms was about 6 years although it was highly variable among different individuals. Despite the average long duration of symptoms their pain was not highly disabling as most of them presented with mild neck pain related disability. Finally, patients with chronic neck pain were considered as a slightly anxious group, but they did not present with any depression. The patients were also mildly to moderately kinesiophobic, and had mild to moderate catastrophizing thoughts.

The healthy participants were matched in gender, age, height and weight with patients with chronic neck pain and did not present any statistically significant difference. Furthermore, although non-matched and non-statistically tested, all the other demographics of healthy participants such as hand-dominance, work type and living area were similar to the chronic neck pain group.

The group of patients with chronic non-spinal pain was also recruited from different areas of Greece and the 70% was living in urban areas. This slightly increased percentage, in comparison with the chronic neck pain group, may be justified by the better access to cities’ population for sample recruitment or it might be a random result due to the small sample size of this group. The sample included five patients with knee pain, two with ankle pain, one with hip pain, one with shoulder pain and one with foot pain. Seven of them had unilateral and the three bilateral chronic pain. 70% of this sample was also working in jobs of high sitting demand. It was a young-aged group which included more men (60%) than the chronic neck pain group and it was a sample of higher height and weight, but of similar BMI and physical activity. Based on descriptive statistics, the usual pain of this group was also higher than the pain during the measurements, but both of them were less than the pain experienced by the patients with chronic neck pain. The pain chronicity was also
less for the chronic non-spinal pain group (about 3 years), but the pain frequency was similar. Finally, this group had similar anxiety and depression to the chronic neck pain group, but it was more kinesiophobic with less catastrophizing thoughts.

7.2 Non-pulmonary deficits in chronic neck pain

In short, the findings of this study show that patients with chronic neck pain have reduced endurance of their deep neck flexors (p<0.01) and reduced range of movement (p<0.05). In terms of neck muscle strength, it was found that their neck extensors were weak (p<0.05), whereas the strength of their neck flexors was not found to be significantly different from the strength of healthy individuals (p=0.08). Patients with chronic neck pain were also found to have a similar forward head posture to the healthy controls (p>0.05). Finally, patients with chronic neck pain were not found to be more anxious or depressed from healthy individuals (p>0.05). These results are analytically described and explained in the following subsections.

7.2.1 Neck muscle strength

The findings of the current study show that patients with chronic neck pain have decreased strength of neck extensors (p<0.05), but the strength of neck flexors (p=0.08) and the flexors/extensors strength ratio were not different from the healthy control group (p>0.05).

The significant reduction in strength of neck extensors is in agreement with the existing literature (Chiu and Lo, 2002; Ylinen et al, 2004; Cagnie et al, 2007a; Rezasoltani et al, 2010; Scheuer and Friedrich, 2010; Lindstrom et al, 2011). In this study the strength of neck extensors was reduced by 16.3%. Although all the previous studies agree with this reduction, different reduction percentages have been noted ranging from 15.9% (Cagnie et al, 2007a) to 42.3% (Rezasoltani et al, 2010). The variety in this percentage may be explained by the different demographics and pathology characteristics of the samples used by different researchers as well as the variability in measurement protocols (Strimpakos, 2011b).
In the current study, the strength of neck flexors was reduced by 10.6%, but this drop presented only a trend to be significant (p=0.08). The findings from most other researchers show that the strength of neck flexors is reduced in patients with chronic neck pain (Chiu and Lo, 2002; Ylinen et al, 2004; O’Leary et al, 2007; Rezasoltani et al, 2010; Scheuer and Friedrich, 2010; Lindstrom et al, 2011) although some researchers have not detected such a reduction in strength (Falla et al, 2004a; Cagnie et al, 2007a). However, the findings by Cagnie et al (2007a) can be explained by the fact that the groups were matched only in terms of gender and by the unequal sample sizes. Furthermore, although the second study by Falla et al (2004a) did not reach statistical significance it revealed an important trend for decreased strength of neck flexors. However, in this study dynamometry was used only for electromyographic purposes without emphasizing in the assessment of neck muscle strength.

The disagreement of the current study with the findings from the majority of the other studies may be potentially explained by the samples used in each study. For example, Chiu and Lo (2002) used a control group which is younger than the patient group, Lindstrom et al (2011) and O’Leary et al (2007) used a more pain-disabled group, Scheuer and Friedrich (2010) used bigger sample sizes and whiplash patients were not excluded whereas Razasoltani et al (2010) do not provide enough information to make a judgment about the condition of their neck pain patients. Furthermore, the variability of the assessment protocols in these studies may additionally explain this disagreement as the order of assessment, the number of the trials, the recording of mean or best value, the testing position and potential diurnal effects are all reasons that can affect neck muscle performance (Strimpakos, 2011b). All of these differences may explain the relative differences between the current and the previous studies. However, the fact that the most studies agree that chronic neck pain leads to reduced strength of neck flexors in parallel with the fact that the current findings also present a trend towards significance supports the assertion that chronic neck pain results in reduced strength of neck flexors. Nevertheless, this conclusion cannot be accepted with confidence for the sample used in this study.

Similar conclusions were derived for the muscle strength of neck flexors to muscle strength of neck extensors (F/E) ratio. Although F/E ratio was found to be increased by 1.6% in patients with chronic neck pain, it was not significant. This
finding is in disagreement with the results from previous studies (Cagne et al, 2007a, Rezasoltani et al, 2010) where an increase of the F/E ratio was found to be significant. The increase of this ratio may suggest the existence of muscle imbalances in the neck as the strength of the neck extensors seems to be relatively more affected. The greater relative weakness of neck extensors may be explained by the fact that a prolonged sitting position, which is a known risk factor for neck pain (Ferrari and Russell, 2003), leads to a continuous activation of neck extensors rendering them more prone to the development of muscle fatigue and weakness (Johnston et al, 2008a). However, this does not seem to be the case in the current study as the increase of F/E ratio was not found to be significant. This disagreement might be the result of differences in the neck pain condition of patients or the fact that in contrast to the other two studies, where the sitting position was used for the assessment of neck muscle strength, the current study used the standing position. The fact that the standing position may not be the position reliable for pain elicitation when pain derives from sitting posture may give rise to these different findings. Furthermore, the measurement of neck muscle strength in sitting position may be increased by a relative push from the legs (Strimpakos, 2011b) and consequentially give rise to a decreased F/E ratio. Finally, sitting posture leads to an increased forward head posture (Hanten et al, 2000) altering the force-length ratio of cervical muscles and consequentially alters the F/E ratio.

The reduced neck muscle strength can be attributed to many factors. The reduced neck muscle strength may be mainly attributed to changes in motor control and muscle adaptations. The inhibition of activity of deep cervical muscles (Falla et al, 2004b) may lead to an unstable cervical spine affecting the force production of muscles attached to this region. Furthermore, hyperactivity of superficial cervical muscles (Falla et al, 2003) may lead to production of less force for the same amount of activity. In addition, the coordination of cervical muscles may change to minimize the use of painful muscles (Falla and Farina, 2008) inhibiting the optimal coordination pattern for producing maximal force. Reduction in force production can be also affected by muscular adaptations. Muscle atrophy, connective tissue infiltration (Elliott et al, 2006), disturbed mitochondrial function, reduced ATP and reduced capillary to fiber ratio have all been observed in patients with chronic neck pain, affecting their ability to produce maximal force (Kadi et al, 1998). Finally, psychological states such as kinesiophobia (Grip et al, 2007) may also play an
important role in this muscle strength reduction as patients may be unwilling to exert maximal efforts due to a phobia arising from previous pain experience.

7.2.2 Cervical range of movement

In this study, it was also found that patients with chronic neck pain have significantly reduced cervical Range of Movement (ROM) in all the planes. This reduction was found to be 8.6% for sagittal (p<0.01), 8.7% for transverse (p<0.001) and 11% for the frontal range of movement (p<0.01). Furthermore, all the individual movements were found to be significantly decreased (p<0.05) with the exception of flexion where a 4% drop was not found to be significant (p>0.05).

These findings are in agreement with conclusions from previous researchers (Rix and Bagust, 2001; Chiu and Lo, 2002; Lee et al, 2005; Cagnie et al, 2007b; Grip et al, 2007; Vogt et al, 2007; Grip et al, 2008; Sjolander et al, 2008) although different findings are also present (Johnston et al, 2008b; Cheng et al, 2010). However, these differences may be justified by the smaller sample size used by Cheng et al (2010) and Johnston et al (2008b). Furthermore, Cheng et al (2010) used a much younger sample and Johnston et al (2008b) only office workers who are less prone to degenerative changes of the cervical spine which could have resulted in less influence on cervical motion. However, although these two studies did not reach statistical significance, a trend towards cervical mobility reduction was still present.

The only movement that was not found to be restricted in the patients of the current study was neck flexion. This fact can be explained by the difficulties to estimate the real natural head position during ROM assessment. This difficulty can finally lead to an underestimation or overestimation of half-cycle neck motions and additionally explains why full-plane motions were additionally assessed (Strimpakos, 2011a). Another explanation could be that a great number of patients in the current study had a sedentary work which included a prolonged sitting posture. In case this sitting posture was accompanied by prolonged flexion of trunk and neck, this might give rise to muscle plastic changes (Gajdosik, 2001) which could be clinically observed as restriction of cervical extension due to shortness of neck flexors, but not of cervical flexion.
The reduction in cervical ROM can be attributed to various factors. Reduced cervical ROM may initially be a protective mechanism for pain-sensitive structures (Lee et al, 2005). Abnormal segmental mobility (Dvorak et al, 1988) may further compromise cervical ROM, whereas kinesiophobia (Grip et al, 2007) may restrain patients with chronic neck pain from using the whole cervical ROM in their daily life due to previous neck pain experience. Prolonged maintenance in a shortened position can lead cervical muscles to lose their maximal length and extensibility whereas an increased abundance and remodeling of connective tissue can further compromise movement due to increased stiffness (Gajdosik, 2001). The adoption of a forward head posture is also implicated for muscle structural changes and reduced cervical ROM (Lau et al, 2010) but the patients of the current study did not present such a posture and their cervical ROM reduction may be more likely attributed to degenerative changes, segmental hypomobility, pain inhibition, kinesiophobia and consequential cervical muscle shortening.

7.2.3 Neck muscle endurance

The findings of the current study suggest that the endurance of deep neck flexors is compromised in patients with chronic idiopathic neck pain as they present with a significant 6.6% drop (p<0.01). The reduced endurance of cervical muscles is in agreement with findings by electromyographic studies (Falla et al, 2003; Falla et al, 2004a; Falla et al, 2004c; Jull et al, 2004; Kumar et al, 2007; Johnston et al, 2008a; Johnston et al, 2008b; Cheng et al, 2010) which reveal an increased activation of superficial cervical muscles suggesting that these muscles become quickly fatigued as they need to be more active to produce the same amount of force. Furthermore, the findings of the current study are also in agreement with conclusions by other researchers who used time-dependant or other clinical tests for assessing neck muscle endurance of deep and superficial neck muscles (Harris et al, 2005; Lee et al, 2005; O’Leary et al, 2007; Peolsson and Kjellman, 2007). The only disagreement comes from a study by Edmondston et al (2011), but a comparatively reduced chronicity of neck pain and a small sample size may have rendered difficult the detection of endurance deficits in this study. However, still in this study the authors purport that
the increased variability of test performance in patients with chronic neck pain is indicative of endurance deficits. Thus, the findings of the current study in parallel with the existing literature suggests that patients with chronic neck pain have impaired endurance not only of their superficial muscles, but also of their deep muscles which in turn may influence regional stability (Comerford and Mottram, 2001a).

The reduced endurance of cervical muscles in patients with chronic neck pain can be explained by muscle fiber transformation and changes in motor unit synchronization. More specifically, in chronic neck pain patients the change of slow-twitched type I into fast-twitched type IIb muscle fibers (Uhlig et al, 1995) render cervical muscles more prone to fatigue as they lose their ability to bear loads for a prolonged time. Other structural changes such as atrophy, fatty infiltration (Elliott et al, 2006), disturbed mitochondrial function, reduced ATP and reduced capillary to fiber ratio may also affect force-maintenance abilities of cervical muscles (Kadi et al, 1998). The reduced endurance of deep cervical muscles which is potentially related to their poor activation (Falla et al, 2004b) can also justify the increased myoelectric activity of superficial muscles as a compensatory mechanism with a consequential greater fatigability (Falla, 2004). Pain elicitation may also be a factor inhibiting patients from performing an activity for prolonged time. Pain can lead to a permanent change in the optimal force production patterns towards pain-inhibiting patterns and these changes may finally lead to a reduced ability of cervical muscles to produce force continuously and consistently (Falla and Farina, 2008). Finally, psychological states such as phobia, anxiety and depression may be also considered as potential causes for reduced cervical muscle endurance as they impede patients from exerting psychological effort and performing consistently in an activity for a prolonged time (Strimpakos, 2011b).

7.2.4 Forward head posture

The patients with chronic neck pain in the current study were not found to have any change in their head posture as the 3% forward increase was found to be statistically insignificant (p>0.05). This finding is in contrast with some research findings (Yip et al, 2008; Lau et al, 2009; Lau et al, 2010) about existence of an
increased FHP in chronic neck pain. However, it is in agreement with a great number of studies which fail to detect this postural change in these patients (Hanten et al, 2000; Szeto et al, 2002; Lee et al, 2005; Edmondston et al, 2007; Kapreli et al, 2009).

The major reason for this inconsistency and disagreement between the studies does not seem to be related to neck pain characteristics such as severity, chronicity or pain intensity as patients of similar symptomatology revealed different head postures. The most likely reason may be the different causes of neck pain. This means that patients with pain of different aetiology may have different FHP or FHP is presented only in patients with chronic neck pain which is the result of specific pathologies. More specifically, patients with a usual sitting posture, working in front of a monitor, may more frequently adopt a FHP and finally develop neck pain than less sedentary individuals. However, pain may not necessarily result from a prolonged bad posture and it seems that a classification of patients with chronic neck pain is needed in order to more clearly understand the role of FHP in these patients.

7.2.5 Psychological outcomes

The findings of the current study show that patients with chronic neck pain do not have different anxiety or depression levels from the healthy controls (p> 0.05). In contrast to depression and anxiety, kinesiophobia and pain catastrophizing could not be directly compared between patients and healthy individuals since both of these psychological states are not experienced and therefore were not assessed in healthy people. However, based on patients’ ratings, it can be concluded that catastrophizing and kinesiophobia were mildly to moderately apparent in patients with chronic idiopathic neck pain.

The literature describes that depression has a close association with neck pain (Leino and Magni, 1993; Rajala et al, 1995; Mantyselka et al, 2010; Pollock et al, 2011) although this association is not supported by all researchers (Luo et al, 2004; Pool et al, 2010). The existence of depression either as a cause or as a result of neck pain is not supported by the findings of the current study. The reason for this inconsistency between studies may be considered either the result of different study designs or different samples. More specifically, the current study used for first time a
case-control design for detecting depression in patients with chronic neck pain. In the previous studies the sample was collected from the population before the participants were classified as patients or healthy individuals. Thus, although the design of the current study was more demanding, it was more appropriate for examining differences as it enabled better matching of other characteristics. Furthermore, this current study is the first which used a sample of patients with chronic idiopathic neck pain. Thus, the lack of depression in these patients may be a novel finding demonstrating differences between this group and other more psychologically stressing neck pain conditions such as acute neck pain or whiplash.

The patients of the current study were also found to be similarly anxious to the healthy control group. This finding is in contrast with the existing evidence about the association of neck pain with anxiety as researchers support that they are weakly correlated (Bru et al, 1993; Luo et al, 2004), and others conclude that anxiety can predict the development of neck pain (Leino and Magni, 1993). However, these studies are quite different from the current study where only patients with chronic idiopathic pain were used. This fact might give rise to the conclusion that anxiety does not seem to be a severe problem in the sample of patients used in the current study something which can be partially attributed to the non-traumatic nature of their condition (Sterling et al, 2003).

Interestingly, although patients with chronic neck pain did not present any difference in anxiety levels in comparison with healthy participants, the anxiety levels of both healthy participants and patients with chronic neck pain were found to have borderline anxiety. Thus, an explanation should be sought as to why this was the case. In terms of chronic neck pain, a potential explanation is the increase of adrenaline as a result of anxiety. The adrenaline may lead to a stimulation of β2-receptors and commence a pro-inflammatory cascade of events increasing the pain experience. Furthermore, anxiety can affect autonomous nervous system leading to vasoconstriction of some muscles promoting muscle injury (Seaman and Cleveland, 1999). Therefore, anxious individuals seem to have an increased neck pain experience and therefore there is an increased tendency of these individuals to report chronic neck pain. Conversely, the neck pain condition by itself may render the sufferers to feel more discomfort and stress (Max et al, 2006). Considering this bi-directional
association of chronic neck pain with anxiety, it can be concluded that there are sound reasons to support the coexistence of anxiety with neck pain.

However, the explanation why healthy participants reported increased anxiety levels is less well-understood. A potential explanation can be provided by the socio-economic era under which this study was performed. The great majority of the measurements were performed in 2010, which was a very difficult economical period for Greek citizens. The unknown and unsecure future of the Greek economy in parallel with the highly enhanced taxes of Greek citizens may have led the participants to feel unsafe and anxious. Thus, healthy participants may have had more focus on this situation rather than patients with chronic neck pain who may have had more focus on their pain condition. Considering all of these, it seems that both groups were anxious, but this anxiety may have derived from different reasons. Thus, it can be concluded that the patients with chronic neck pain who participated in the current study were of mild anxiety, but this anxiety could not differentiate them from healthy individuals.

7.3 Pulmonary deficits in chronic neck pain

In short, the findings of the study show that patients with chronic neck pain have decreased pulmonary volumes (p<0.05) [with the exception of tidal volume (p>0.05)], decreased peak flows (p<0.05), decreased maximal voluntary ventilation (p<0.01), decreased maximal mouth pressures (p<0.05) and decreased partial pressure of arterial carbon dioxide (p<0.01). The Forced Expiratory Volume in one second of forced expiration to Forced Expiratory Volume ratio (FEV₁/FVC) and the mean respiratory flows were not affected (p>0.05), with the exception of Forced Expiratory Flow at the 25% of forced expiration (FEF₂₅%) (p<0.05).

These findings suggest that patients with chronic neck pain tend to present with a mixed pattern of restrictive (based mainly on pulmonary volumes and FEV₁/FVC) and obstructive (based on respiratory flows) pulmonary disorder. However, the stable FEV₁/FVC ratio and the fact that only the effort-dependent PIF, PEF and FEF₂₅% measures were affected (all the other mean flows were unaffected) reduces the possibility of an obstruction and suggests that patients with chronic neck
pain present mostly a restrictive pattern of respiratory disorder. This is very similar to the existing literature about pulmonary function testing in disorders related with neuromuscular weakness (Thurlbeck and Macklem, 1970; Baydur, 1991; Stubgen et al, 1994; Tantucci et al, 1994; Matecki et al, 2001; DePalo and McCool, 2002; Yavagal and Mayer, 2002; Heliopoulos et al, 2003; Perrin et al, 2004; Hyatt et al, 2008). The findings of the study regarding the differences between the groups and the correlations of each respiratory parameter with neck pain deficits are analytically described and interpreted in the following subsections.

7.3.1 Quiet breathing pulmonary volumes

The current study shows that pulmonary volumes during quiet breathing are significantly decreased in patients with chronic idiopathic neck pain. This decrease is depicted by a 9% drop of Vital Capacity (VC) (p<0.01), 6.9% drop of Inspiratory Capacity (IC) (p<0.05) and 13.7% drop of ERV (p<0.05). However, the Tidal Volume (VT) was not found to be significantly affected (p>0.05).

Differences in VT, IC and ERV between patients with chronic neck pain and healthy people were examined for first time and there is no other study providing evidence about them. Tidal volume depends on the function of respiratory centres, respiratory muscles, and the chest wall and lung mechanics and reflects the involuntary part of breathing (Hough, 2001). The fact that patients with chronic neck pain did not present any difference in VT partially suggests that they have a normal respiratory drive. However, this index is not considered the most appropriate index for examining ventilation since breathing into spirometry apparatus with the nose occluded usually leads to overestimation of VT (Ruppel, 2009). This belief is confirmed by the findings of the current study since VT for both groups was found to be slightly more than the normal limits. Alternatively, partial pressure of carbon dioxide (PaCO₂) is an index which is usually used for examining adequacy in ventilation (Tobias, 2003). In contrast to VT, PaCO₂ was found to be reduced in patients with chronic neck pain (p<0.05) suggesting hyperventilation. The disagreement between the two indices also confirms that VT is not adequate by its self to show adequacy in ventilation and therefore changes in Respiratory Rate (RR)
should be also reported as RR increase may also lead to hyperventilation. Such an increase in RR has been reported in the literature not only in experimental pain conditions (Borgbjerg et al, 1996; Nishino et al, 1999; Kato et al, 2001), but also in a sample composed of patients with chronic idiopathic neck or shoulder pain (Nilsen et al, 2007). However, similarly to $V_T$, RR can be also falsely increased in patients who are connected to unfamiliar pulmonary function testing apparatus and especially having their noses occluded (Ruppel, 2009). Thus, $V_T$ is able to give just an estimation of ventilation.

Patients with chronic neck pain were also found to have decreased IC and ERV. Considering that IC is composed of the Inspiratory Reserve Volume (IRV) and $V_T$ in parallel with the fact that $V_T$ was not found to be affected, it can be concluded that IRV was reduced in patients with chronic neck pain. This decrease was estimated to be around 8.4%. Changes in these pulmonary volumes are not of great diagnostic value, but their reduction is consistent with restrictive disorders and more specifically with neuromuscular disorders (Thurlbeck and Macklem, 1970; Perrin et al, 2004). The findings of the current study also show that the reduction in ERV is 5.3% greater than the reduction in IRV. This finding, although it was not statistically examined, is consistent with the greater reduction in strength of expiratory muscles in comparison with the strength of inspiratory muscles (see Section 7.3.5 “Respiratory muscle strength”).

Vital capacity was also found to be reduced in patients with chronic idiopathic neck pain. The findings of this study are in disagreement with the results from the pilot study by Kapreli et al (2009), where the 3.3% reduction of VC was not found to be significant. In the current study, this reduction was found to be 5.7% higher and significant (p<0.01). This disagreement may be due to the bigger sample size used in the current study. Furthermore, the fact that spirometry in the current study was performed from a standing position in contrast to the sitting position used by Kapreli et al (2009) may have played an additional role in this disagreement since this position change alter the lung capacity (Lin et al, 2006). It should be mentioned that the reduction in VC is one of the most characteristic signs of neuromuscular disorders (de Troyer et al, 1980; Perrin et al, 2004). Finally, this reduction in VC is more consistent with restrictive rather than obstructive disorders because it was not accompanied by changes in $FEV_1/FVC$ ratio (see Section 7.3.2 “Forced pulmonary
volumes”). In long term, this reduction in VC may render the lung tissues, spinal articulations and rib cage stiffer, further contributing to the development of a restrictive pattern (de Troyer et al, 1980; Bach and Ishikawa, 2000).

A number of reasons have been proposed as causes for reduced VC. However, from the potential causes proposed by Ruppel (2009) only neuromuscular weakness and suboptimal patient effort seem to be related with reduced VC in patients with chronic neck pain. The examination of correlations between chronic neck pain deficits and VC can provide a clearer insight into the reasons for reduced VC. The findings of the current study show that VC is significantly positively correlated with strength of neck flexors (r=0.67, p<0.001) and extensors (r=0.68, p<0.001) and significantly negatively correlated with pain intensity (r=-0.32, p<0.05) and kinesiophobia (r=-0.39, p<0.01). These findings are consistent with some factors proposed by Ruppel (2009) as responsible for reduced chest wall excursion. More specifically, pain may inhibit neck pain patients to exert optimal effort for maximal VC trials. The same may happen with kinesiophobia since increased phobia for movement may impede patients from exerting full effort. Lastly, the reduced muscle strength of neck muscles which may directly or indirectly affect the strength of respiratory muscles can also lead to reduced effectiveness during VC trials (see Section 7.3.5 “Respiratory muscle strength”).

The construction of a regression model for the prediction of VC can provide further information regarding the development of this respiratory problem. More specifically, whereas strength of neck extensors, kinesiophobia and pain intensity were all correlated with VC, after their common input into a regression model only strength of neck extensors remained a significant predictor of VC. This may suggest that the reduced VC in patients with chronic neck pain is mainly a result of their reduced neck muscle strength. Kinesiophobia and pain intensity may have an indirect effect on VC through a reduction in neck muscle strength. Kinesiophobia due to past pain experience or real pain experience during movement may inhibit patients’ effort to exert maximal force. This movement inhibition can lead to a lack of activity in neck muscles which finally lose their strength due to muscle adaptive changes (Bruton, 2002). Finally, these changes can lead to reduction in respiratory muscle strength affecting pulmonary volumes (see Section 7.3.5 “Respiratory muscle strength”).
7.3.2 Forced pulmonary volumes

The findings of the present study also reveal that patients with chronic idiopathic neck pain have 5.5% significantly reduced Forced Expiratory Volume in one second (FEV$_1$) (p<0.05) and 7.7% significantly reduced Forced Vital Capacity (FVC) (p<0.01), whereas the 1.6% increase of FEV$_1$/FVC ratio was not significant (p>0.05).

The findings of the current study about FEV$_1$ and FVC are in disagreement with the findings from the pilot study by Kapreli et al (2009) where these pulmonary function indices were not statistically changed in patients with chronic neck pain. However, this disagreement seem to be the result of the much bigger sample size used in the current study as Kapreli et al (2009) also reported a 6.3% drop of FVC and 7.4% drop of FEV$_1$ in patients with chronic neck pain. Nevertheless, both the present study and the pilot study by Kapreli et al (2009) have not found changes in FEV$_1$/FVC ratio of patients with chronic neck pain.

Similarly to Vital Capacity (VC), reduced FVC and FEV$_1$ values may be observed both in obstructive and restrictive disorders (Diaz et al, 2000; DePalo and McCool, 2002). However, the fact that the FEV$_1$/FVC ratio was not reduced indicates that no obstruction was apparent (Hyatt et al, 2008). Another reason for supporting this conclusion is the fact that VC was not higher than FVC, since a higher VC than FVC is indicative of a potential obstructive disorder. In contrast, FVC was found to be slightly higher than VC and may be explained by the larger force exerted during the forced manoeuvre (Ruppel, 2009). However, the non-affected FEV$_1$/FVC ratio cannot exclude the existence of a potential restrictive disorder, since this ratio may be presented as increased or normal in restrictive disorders (Perrin et al, 2004). Thus, it seems that FEV$_1$, FVC and FEV$_1$/FVC ratio follow a pattern similarly indicative of restrictive disorders in patients with chronic neck pain.

Reduction in FVC is reported to share similar causes to reduced VC (Ruppel, 2009). The soundest reasons for FVC reduction in patients with chronic neck pain is neuromuscular weakness and exertion of suboptimal effort by the patients. More specifically, the reduced strength of respiratory muscles of patients with chronic neck pain (see Section “9.11 Respiratory muscle strength”) may lead them to a decreased
ability to produce appropriate thoracic pressures and flows for full inhalations or 
exhalations (Perrin et al, 2004). Furthermore, kinesiophobia due to a previous pain 
experience or movement inhibition due to pain may lead to non-optimal efforts by the 
patients which can lead to a recording of lower lung volumes.

Indeed, the chronic neck pain deficits which were correlated with FVC were 
the same with the ones of VC. More specifically, FVC was significantly positively 
correlated with the strength of neck flexors (r=0.65, p<0.001) and extensors (r=0.69, 
p<0.001) and significantly negatively correlated with kinesiophobia (r=-0.34, p<0.05), 
whereas its negative correlation with pain intensity presented a borderline trend (r=- 
0.29, p=0.053). Furthermore, the strength of the correlations was similar to the ones 
of the VC. Thus, similarly to VC, it can be concluded that the reduced strength of 
neck muscles, kinesiophobia due to past pain experience and movement inhibition due 
to pain are the main reasons for FVC reduction in patients with chronic neck pain. On 
the other hand, FEV₁/FVC ratio presented a negative correlation with strength of neck 
flexors (r=-0.35, p<0.05) and extensors (r=-0.33, p<0.05), but this correlation was 
weaker than the one of FVC with neck muscle strength. This correlation seems to be 
the result of the influence of neck muscle strength on FVC and it is not of high 
importance since this ratio was unaffected in patients with chronic neck pain. 
However, considering that a decrease in muscle strength is associated with an increase 
of the FEV₁/FVC ratio in parallel with the fact that an increase of FEV₁/FVC ratio is 
indicative of restrictive disorders, it can be concluded that more affected patients with 
chronic neck pain with a more eminent reduction in respiratory muscle strength are 
more prone for a more serious restrictive disorder.

7.3.3 Respiratory flows

The present study also shows that patients with chronic neck pain have a 
reduction in some of their respiratory flow indices. More specifically, patients with 
chronic neck pain presented with a significant 6% and 14% reduction in their Peak 
Expiratory Flow (PEF) (p<0.05) and Peak Inspiratory Flow (PIF) (p<0.05) 
respectively. However, their mean respiratory flows including Forced Expiratory 
Flow from 25% to 75% of forced respiration (FEF₂₅%-₇₅%), Forced Expiratory Flow at
the 50% of forced expiration (FEF$_{50\%}$) and Forced Expiration Flow at the 75% of forced expiration (FEF$_{75\%}$) were not affected ($p>0.05$) with the exception of Forced Expiration Flow at the 25% of forced expiration (FEF$_{25\%}$) which was found to be significantly reduced by 8% ($p<0.05$).

These results are seemingly in contrast with the piloting findings by Kapreli et al (2009). In the results by Kapreli et al (2009) respiratory flows were not significantly reduced in patients with chronic neck pain. This difference can be explained by the much bigger sample size used in the current study as its increased statistical power was less prone to a potential type II error. This explanation is further supported when consideration is given to descriptive statistics from the pilot study by Kapreli et al (2009) that also revealed a reduction of their respiratory flows. More specifically, FEF$_{25\%-75\%}$ was reduced by 6.4%, FEF$_{25\%}$ was reduced by 10.3%, FEF$_{50\%}$ was reduced by 6.3%, FEF$_{75\%}$ was reduced by 0.9% and PEF was reduced by 11%. In reality, it seems that the two studies not only are not in disagreement, but also that the respiratory flows of chronic neck pain patients described by Kapreli et al (2009) albeit not significant are even more affected. The slightly less compromised respiratory flows in the current study might be explained by the less pain-induced disability of the recruited sample in comparison with the sample used in the pilot study by Kapreli et al (2009). However, the greater reduction in respiratory flows in the sample used by Kapreli et al (2009) should be interpreted with caution as they may be simply the result of random chance. Finally, another interesting finding when these two studies are considered together is that the flows which were found to be most affected are the PEF and the FEF$_{25\%}$. This fact reveals that the main restrictions in patients’ respiratory flows are their peak flows and the flow during the initial phase of the forced expiration.

Reduction of respiratory flows can be observed in both obstructive and restrictive disorders including neuromuscular disorders (Stubgen et al, 1994; Perrin et al, 2004; Hyatt et al, 2008). Considering these flows in parallel with the unaffected FEV$_1$/FVC ratio (see Section 9.8 “Forced pulmonary volumes”) it becomes apparent that the reduction of respiratory flows in patients with chronic neck pain are not due to obstructive defects. However, Harrison et al (1971) describes that the reduced ability of patients to take deep breaths may lead to collapse of small peripheral airways something which implicates an obstructive component. Furthermore,
restrictive patterns cannot be excluded as prolonged breathing at low lung volumes can render the lung tissue, spinal articulations and rib cage stiffer (de Troyer et al, 1980; Bach and Ishikawa, 2000). However, one of the most important reasons for this reduction may be the reduced patients’ effort. Reduced effort during the measurements can be explained by reduction in neuromuscular efficiency, psychological states such as kinesiophobia and pain-based movement inhibition (Ruppel, 2009). The belief that low patients’ effort and weakness seems to be the main cause for reduced respiratory flows is further confirmed by the fact that the effort-independent FEF75% was unaffected. This index reflects the flow during the last phase of forced expiration which happens at the small airways and is only dependant on elastic recoil and flow resistance (Tan, 2006; Ruppel, 2009). In contrast, FEF25% which is a highly effort-dependent index as it occurs at the initial phase of forced expiration in the larger airways (Tan, 2006) was the only affected time-point flow index. Furthermore, the reduced peak respiratory flows which are highly dependent on patients’ effort (Ruppel, 2009) were found to be highly affected providing further support to this belief.

Thus, it seems that the decrease in respiratory flows of patients with chronic neck pain should be mainly attributed to their reduced effort due to neuromuscular weakness, phobia for new pain experience and movement inhibition due to pain. This belief is strongly supported by the correlations examined in the current study. More specifically, PEF was found to be significantly positively correlated with strength of neck flexors (r=0.64, p<0.001) and extensors (r=0.72, p<0.001), negatively correlated with pain intensity (r=-0.39, p<0.01) and an important trend was observed for the negative correlation between PEF and kinesiophobia (r=-0.29, p=0.056). The direct and indirect impact of neck muscle weakness on the respiratory pump may lead to weakness of respiratory muscles (see Section 7.3.5 “Respiratory muscle strength”). This respiratory weakness can lead to a non-optimal performance of forced expiratory manoeuvres and consequentially to reduced PEF. Reduced respiratory flows can be also due to patients’ decreased effort during the forced expiratory manoeuvre (Ruppel, 2009). This decreased effort may also be the result of movement phobia due to previous pain experiences or due to the result of movement inhibition due to pain.

PIF was found to be significantly positively correlated with strength of neck flexors (r=0.36, p<0.05) and extensors (r=0.42, p<0.01) and endurance of deep neck
flexors ($r=0.4$, $p<0.01$), whereas a significant trend was observed for the negative correlation between PIF and kinesiophobia ($r=-0.3$, $p=0.055$). The reduced strength of neck muscles and the existence of kinesiophobia seemed to affect PIF similarly to the way they affect PEF. However, in contrast to PEF, PIF was also positively correlated with endurance of deep neck flexors. The reduced performance of deep neck flexors can cause segmental instability of the cervical and thoracic spine (Key et al, 2008a; Key et al, 2008b) with a consequential change in rib cage mechanics. This change in rib cage mechanics may also lead to changes in the function of respiratory muscles impeding their optimal function during forced expiration (Kapreli et al, 2008). Furthermore, the fact that the association with endurance deficits was observed only for PIF and not for PEF, may be explained by the more direct association of neck muscles with inspiration. Impairments in deep neck muscles are usually accompanied by a compensatory hyperactivity and consequentially increased fatigability of superficial neck muscles such as sternocleidomastoid, scaleni and trapezius (Falla et al, 2004a; Falla et al, 2004c) which directly participate in forced inspiration. Thus, the increased fatigability of these muscles does not allow them to bear loads efficiently for a prolonged time and they quickly appear weak. This weakness is also apparent during forced inspiration and may be the reason for a more significant association of endurance with PIF rather than PEF.

Another interesting finding is that in contrast to PEF, PIF was not found to be associated with pain intensity. This finding is quite unexpected since neck muscles seem to have an anatomically closer association with forced inspiration rather than forced expiration (Legrand et al, 2003). Clinically, this finding may suggest that the respiratory dysfunction in patients with chronic neck pain can be mainly attributed to the pathology of other neck muscles such as to the dysfunction of the local stabilizer system. However, these findings seem to be logical considering that peak respiratory flows are highly effort-dependent and that pain intensity was found to associated only with maximal expiratory and not with maximal inspiratory strength (see Section 7.3.5 “Respiratory muscle strength”).

Finally, the regression models constructed for the prediction of PEF provide some additional information about the development of this respiratory dysfunction. More specifically, although kinesiophobia, strength of neck extensors and pain intensity were all correlated with PEF, after their common input into the regression
model only the strength of neck extensors appeared as a significant predictor of PEF. This fact may be indicative that the reduction in PEF is mainly an effect of reduced neck muscle strength of patients with chronic neck pain, whereas kinesiophobia and pain intensity may have a indirect influence on PEF through a further reduction in neck muscle strength. Thus, it can be concluded that kinesiophobia and pain may restrain patients from exerting maximal force. This fact may lead to reduced activity of neck muscles giving rise to muscle plastic changes and consequentially to a permanent reduction of neck muscle strength (Bruton, 2002) with its known effects on respiratory muscle strength and consequentially on peak flows (see Section 7.3.5 “Respiratory muscle strength”).

7.3.4 Maximal voluntary ventilation

The findings of the current study also reveal that patients with chronic neck pain have a significant 12% reduction of their Maximal Voluntary Ventilation (MVV) (p<0.01). This finding is in absolute agreement with the preliminary findings by Kapreli et al (2009), who found a significant 14% drop of MVV in patients with chronic neck pain.

Maximal voluntary ventilation is a general index of respiratory function depending on airway resistance, respiratory muscle function, lung and chest wall compliance and ventilator control mechanisms (Heliopoulos et al, 2003; Jardins, 2008). Although this index is usually reduced in obstructive disorders due to increased airway resistance and mucus production, there are not sound reasons to believe that such a disorder is apparent in patients with chronic neck pain especially considering their normal FEV1/FVC ratio (see Section 7.3.2 “Forced pulmonary volumes”). MVV is also a sensitive index for restrictive neuromuscular disorders (Stubgen et al, 1994; DePalo and McCool, 2002; Heliopoulos et al, 2003). Considering this fact in parallel with the fact that restrictive disorders do not present any reduction in FEV1/FVC ratio (Perrin et al, 2004), it can be concluded that the reduced MVV in patients with chronic neck pain might be indicative of such a respiratory restriction.
The reduced MVV recordings in patients with chronic neck pain can be also attributed to greater weakness, fatigue and poorer coordination of respiratory muscles as well as in reduced effort during the procedure or defective control of ventilation (Heliopoulos et al, 2003). The reduced partial pressure of arterial carbon dioxide (PaCO$_2$) found in patients with chronic neck pain (see Section 7.3.6 “Partial pressure of carbon dioxide”) is also indicative of a defective control of ventilation. However, PaCO$_2$ was assessed during quiet breathing rather than a forced manoeuvre like MVV. Thus, MVV is more representative of ventilation during exercise and more certainly of the maximal breathing capacity during dynamic exercise, whereas PaCO$_2$ provides information about usual ventilation (Heliopoulos et al, 2003; Tobias, 2003).

The soundest explanation for the reduced MVV in patients with chronic neck pain seems to be the dysfunction of respiratory muscles and patients’ suboptimal effort (see Section 7.3.5 “Respiratory muscle strength”). Kinetic control changes due to an impaired local and global muscular system may also lead to an uncoordinated function of respiratory muscles (see Section 7.5 “Respiratory dysfunction model in chronic neck pain”). The decreased strength, endurance and co-ordination of respiratory muscles can lead to a less efficient performance of the highly effort-dependent MVV manoeuvre, as the respiratory muscles become less able to overcome the elastic recoil and airway resistance efficiently and consistently. Furthermore, patients with chronic neck pain may also reveal reduction of their MVV recordings due to decreased effort which can be attributed either to psychological states such as kinesiophobia or to movement inhibition due to neck pain.

Impaired neural drive can be an additional explanation for the reduced MVV in patients with chronic neck pain. In a review by Gariepy et al (2010), it is purported that passive or active movements of any body part can induce activation of respiratory system. This fact reveals that there is an obvious connection between somatic afferents and respiratory centers. In terms of chronic neck pain this could mean that the impaired proprioception of cervical muscles could lead to an altered neural drive in respiratory muscles affecting respiratory muscle strength and especially the muscle coordination-sensitive MVV. However, this theory was based on animal studies and cannot be absolutely accepted for humans.

The correlations examined in the present study give further evidence for an association between neck pain deficits and MVV reduction. MVV was found to be
significantly positively correlated with strength of neck flexors ($r=0.57$, $p<0.001$) and extensors ($r=0.63$, $P<0.001$) and significantly negatively correlated with pain intensity ($r=-0.32$, $p<0.05$) and kinesiophobia ($r=-0.35$, $p<0.05$). The reasons for these associations are believed to be the same to the ones proposed for pulmonary volumes and flows in the previous sections. More specifically, the reduction in neck muscle strength may have a direct and indirect impact on the function of respiratory muscles either due to their close anatomical association (Legrand et al, 2003) or due to the consequential muscle imbalances in the cervico-thoracic spine (Key et al, 2008a; Key et al, 2008b) resulting in alteration of rib cage mechanics and reduced performance of respiratory muscles (Kapreli et al, 2008). This reduction in strength of respiratory muscles seems to be one of the most important reasons for the impaired MVV in patients with chronic neck pain (Heliopoulos et al, 2003). The other two correlations may additionally depict a reduced effort of patients during the MVV manoeuvre as kinesiophobia may result in movement avoidance due to past pain experience and pain may directly inhibit movement.

Finally, the regression models constructed for the prediction of MVV can provide further information about the route of this respiratory problem. More specifically, after the common input of all the non-pulmonary deficits into the model, the correlations of pain intensity and kinesiophobia were not still significant. In contrast to these variables, the strength of neck extensors remained as the only significant predictor of MVV. This fact reveals what has already been discussed for the prediction of respiratory flows and pulmonary volumes. Thus, strength of neck muscles seems to be the main reason for MVV reduction in patients with chronic neck pain via its direct and indirect effects on respiratory muscle strength (see Section 7.3.5 “Respiratory muscle strength”). Kinesiophobia and pain intensity seem to both have mainly an indirect impact on MVV through a reduction of neck muscle strength. Their impact on neck muscle strength may be justified by the inhibition of patients’ maximal force either from phobia due to past pain experience or directly due to neck pain which in long-term lead to muscular deconditioning (Bruton, 2002).
7.3.5 Respiratory muscle strength

The present study also shows that patients with chronic neck pain have significantly reduced strength of their inspiratory and expiratory muscles. More specifically, Maximal Inspiratory Pressure (MIP) significantly decreased by 13.8% (p<0.05) and Maximal Expiratory Pressure (MEP) significantly decreased by 15.4% (p<0.01) in patients with chronic neck pain.

These results are in agreement with the 21.5% drop of MIP and the 16.5% drop of MEP found by Kapreli et al (2009). However, although both studies found significant decreases in respiratory strength, the current study shows a higher decrease for MEP rather than MIP being in contrast to the relatively higher decrease in MIP observed by Kapreli et al (2009). Nevertheless, although the higher relative reduction of MEP is supported to be consistent with neuromuscular disorders (Inkley et al, 1974; Bach and Ishikawa, 2000) this is not always the case (Baydur, 1991). However, the fact that the difference between the decrease of MIP and MEP is not supported by any statistical significance does not contribute to the notion that the one or the other respiratory strength index is more affected. Furthermore, considering that the MIP/MEP ratio was not different between the groups (p>0.05), it can be concluded that the two respiratory indices were similarly reduced in patients with chronic neck pain. Thus, the belief that the direct anatomical association of cervical area with forced inspiration could lead to relatively more affected inspiratory muscles is not supported by the research findings.

Maximal respiratory pressures are highly effort-dependent and represent the strength of respiratory muscles. Reduction in respiratory muscle strength can be observed in both restrictive and obstructive disorders. MIP is more sensitive in diaphragm and other inspiratory muscles problems, hyperinflation, chest wall disorders and chest wall or spinal deformities, whereas MEP is mostly dependent on abdominal and other expiratory muscles as well as on elastic recoil of thorax and lungs (Ruppel, 2009). Both of these indices are also very sensitive in neuromuscular disorders and their reduction is manifested much earlier than any other reduction in lung volumes (Inkley et al, 1974; de Troyer et al, 1980; Baydur, 1991; Stubgen et al, 1994; Matecki et al, 2001; DePalo and McCool, 2002; Yavagal and Mayer, 2002;
Based on the fact the maximal respiratory pressures represent respiratory strength and are highly effort-dependent it can be concluded that the reduction observed in patients with chronic neck pain reveal a reduced neuromuscular strength. This decreased respiratory strength, which according to the previous sections seems to be one of the most important factors for the reduction observed in pulmonary volumes, flows and maximal voluntary ventilation, can be attributed not only to a faulty mechanic of respiratory muscles, but also to decreased patients’ effort due to phobia or pain.

In patients with chronic neck pain a number of reasons have been proposed by Kapreli et al (2008) as potential explanations for this reduction in respiratory muscle strength. This respiratory weakness seems in the short-term to be mainly based on the faulty biomechanical function of respiratory muscles due to changes in rib cage mechanics and in the long-term to a chronic adaptation of respiratory muscles to this faulty biomechanical function. According to the same model by Kapreli et al (2008) changes in rib cage mechanics may arise in patients with chronic neck pain for a number of reasons including reduced strength and endurance of neck muscles, faulty head posture, deficits in cervical proprioception, reduced cervical Range of Movement (ROM), pain and psychological states.

More specifically, these changes in rib cage mechanics may be attributed to changes in the force-length curve and muscle imbalances of the cervical muscles, to a thoracic spine instability or ultimately to changes of spinal motor patterns. Firstly, the altered force-length curve of the cervical muscles may result in muscle imbalances influencing their neighboring areas such as the thoracic spine (Comerford and Mottram, 2001a; Key et al, 2008a; Key et al, 2008b) and ultimately altering rib cage mechanics (Andriacchi et al, 1974; Kapreli et al, 2008). This altered force-length curve of the cervical muscles may arise from: the increased weakness and fatigability of global neck muscles (especially of sternocleidomastoid, scaleni and trapezius) as there is an over-pull or under-pull during movement; neck ROM changes as they may alter the length of cervical muscles; altered head posture as it can lead to muscle length and fascia changes; and psychological states such as kinesiophobia which may further reduce extensibility of the cervical muscles due to prolonged avoidance of movements (Gossman et al, 1982; Norris, 1995; Comerford and Mottram, 2001a; Kapreli et al, 2008; Key et al, 2008a; Key et al 2008b). Secondly, changes in rib cage
mechanics may arise from thoracic spine instability, which in turn may be the result of a segmental instability of the cervical area due to a reduced activation and endurance of the deep cervical muscles (Andriacchi et al, 1974; Comerford and Mottram, 2001a; Kapreli et al, 2008; Key et al, 2008a; Key et al 2008b). Finally, impaired neck proprioception in patients with chronic neck pain may also change rib cage mechanics due to a change in spinal motor patterns. This change of spinal motor patterns can be attributed to cortical and subcortical reorganization of the nervous system due to the pain-based altered afferent input (Kapreli and Athanasopoulos, 2006; Gariepy et al, 2010). All of these factors which seem to contribute to changes in rib cage mechanics may finally lead to altered function and performance of all respiratory muscles including diaphragm, intercostals and abdominals (Kapreli et al, 2008).

Although the role of forward head posture has been highlighted as quite important for the development of respiratory dysfunction and has been found to be correlated with pulmonary function of patients with chronic neck pain in a previous pilot study (Kapreli et al, 2009), it does not seem to be a factor able to justify the respiratory problems in these patients as it was not found to be an existent trait in both the current study and the pilot study by Kapreli et al (2009). Furthermore, although proprioception is strongly believed to be a highly important factor for the development of this respiratory dysfunction (Kapreli et al, 2008), its real contribution and role is unknown as the lack of reliable measurement tools for assessing neck proprioception did not permit its investigation.

Although a number of neck pain deficits have been proposed as potential causes of respiratory dysfunction, MIP was found to be significantly positively correlated with strength of neck flexors (r=0.7, p<0.001) and extensors (r=0.62, p<0.001) and significantly negatively correlated with kinesiophobia (r=-0.43, p<0.01) and catastrophizing (r=-0.3, p<0.05), whereas the negative correlation of MIP with anxiety presented a borderline trend (r=-0.28, p=0.06). These results reveal the strong influence of the neck muscle weakness and psychological states on respiratory muscle strength. Reduced neck muscle strength has already been discussed and that it may directly or indirectly influence rib cage biomechanics and respiratory function leading to reduced performance of respiratory muscles. Its direct influence derives from the common function of the sternocleidomastoid, scaleni and trapezius in both neck
movement and inspiration (Legrand et al, 2003), whereas its indirect influence derives from changes in rib cage mechanics through muscles imbalance (Kapreli et al, 2008). Kinesiophobia, catastrophizing and anxiety can generate a combined emotional state leading patients with chronic neck pain to further restrain from movement and activities leading to prolonged pain and disability and to further deterioration of the neck pain deficits. Therefore, these psychological states may further contribute to the development of respiratory dysfunction in these patients.

Although the same correlations were observed for MEP (with strength of neck flexors: r=0.69, p<0.001; with strength of neck extensors: r=0.66, p<0.001, with kinesiophobia: r=-0.4, p<0.01; with catastrophizing: r=-0.36, p<0.05; with anxiety: r=-0.29, p=0.058), it was additionally negatively correlated with pain (r=-0.33, p<0.05) and pain-induced disability (r=-0.35, p<0.05). This fact can directly explain why pain intensity was correlated with Peak Expiratory Flow (PEF), but not with Peak Inspiratory Flow (PIF) as peak flows are highly effort-dependent (see Section 7.3.3 “Respiratory flows”). However, the fact that only MEP was correlated with pain intensity and disability is an unexpected finding since MIP was expected to be more associated with pain and disability due to the more direct anatomical association of the cervical region with forced inspiration. For example, it would be expected that the reduced strength, endurance, extensibility or the existence of trigger points (trapezius, sternocleidomastoid and scalene) which are frequently associated with neck pain (Lee et al, 2005; Rezasoltani et al, 2010) could have a more eminent role in reduced performance during forced inspiratory manoeuvre because of weakness or pain inhibition. The explanation of this finding as a random finding does not seem to be sound as the correlation of MIP with pain and disability is one of the poorest correlations found in the study. However, the truth might be hidden by the fact that the recorded pain intensity and disability represented usual pain experienced during daily life activities and not during the measurements. Although, usual pain intensity was selected as a more stable index for examining respiratory dysfunction in patients with chronic neck pain, the analysis of correlations by using patients’ pain intensity during the measurements might have given different results. Nevertheless, these findings reveal that the weakness of respiratory muscles in patients with chronic neck pain cannot be mainly attributed to the common function of sternocleidomastoid, scaleni and trapezius on both neck movement and respiration, but this weakness is a
multidimensional dysfunction whom causes should be also sought in combination with the biomechanical and psychological mechanisms of other neck pain problems.

The regression models constructed for the prediction of MEP and MIP provide additional information for the development of this respiratory weakness in patients with chronic neck pain. After the common input of all the potential predictors into the models, MIP was only predicted by strength of neck extensors and kinesiophobia, whereas MEP was only predicted by strength of neck extensors and Forward Head Posture (FHP).

According to these results, it seems again that the reduction in strength of neck muscles is the most important reason underlying the decrease in respiratory strength. Although this could be attributed to a generalized weakness of patients, the same physical activity levels (p>0.05) of the two groups does not justify such a stipulation. Furthermore, the exclusion of significant correlates of MIP and MEP such as catastrophizing, anxiety and pain intensity by the models might reveal that they only have an indirect effect on respiratory weakness. Kinesiophobia also seems to have an indirect effect on MEP reduction, but its role is more eminent for the MIP prediction. Finally, the existence of FHP in the prediction model of MEP is quite interesting trend. This trend, which was also observed by Kapreli et al (2009), is that as the FHP increases, the strength of expiratory muscles improves. Although normally the opposite would be expected, this finding might be justified as a compensatory mechanism for increasing respiratory strength through force-length changes of cervical and cervico-respiratory muscles. This association could be also justified by the confounding influence of exercise as excessive uninstructed exercise could lead not only to muscle tightness and consequentially length and head posture changes (Comerford and Mottram, 2001a; Sahrmann, 2002), but also to increase of respiratory strength (O’Donnell et al, 1998) although such an association is lacking of research evidence.

Despite the fact that FHP remained in the model as predictor of respiratory muscle strength the facts that: it was not significantly different between the groups; it was not correlated with any of the respiratory variables; its unusual trend for respiratory strength increase which is lacking of sound scientific explanations; its appearance in only one prediction model all contribute to the conclusion that its role should be carefully taken into consideration and that the possibility that it was a
random finding cannot be excluded. On the other hand, there are valid reasons to believe that kinesiophobia may have both a direct and indirect impact on respiratory muscle weakness. It can directly influence respiratory muscle performance due to phobia for new pain experience during the forced respiratory strength manoeuvres and indirectly due to cervical movement avoidance which in long-term can lead to muscular adaptive changes (Gajdosik, 2001). These muscular changes can lead to a permanent neck muscle weakness which may further compromise respiratory function either directly due the common action of sternocleidomastoids, trapezius and scaleni to the neck movement and respiration or indirectly due to changes in rib cage mechanics (Kapreli et al, 2008). Furthermore, the more direct association of kinesiophobia with MIP can be explained by the common anatomical association of the cervical area with inspiration although as it has already been discussed that other findings contribute to the notion that the problem is more complex. Finally, in terms of the removed predictors, the removal of catastrophizing can be explained by its common theoretical concept with kinesiophobia and the increased pain anticipation it causes (Sullivan et al, 2001), whereas pain may indirectly lead to a further compromise of respiratory strength through its negative effects on neck muscle strength (Gajdosik, 2001; Falla and Farina, 2008).

### 7.3.6 Partial pressure of arterial carbon dioxide

Another important and unique finding of the current study is that patients with chronic neck pain present a significant 6.4% decrease in their partial pressure of arterial carbon dioxide (PaCO$_2$) (p<0.01). Although such changes in other respiratory parameters are discussable in terms of clinical significance, in terms of blood gases these changes may lead to serious pathological conditions such as hypocapnia and hypercapnia (Hough, 2001).

The current literature has occasionally provided evidence to support that pain conditions may lead to hyperventilation and reduced PaCO$_2$ (Borgbjerg et al, 1996; Nishino et al, 1999; Kato et al, 2001). However, these studies are based on experimental pain conditions and how well results can be generalized to real chronic pain conditions is unknown. An old study by Glynn et al (1981) provides support to
the findings of the current study as it was found that patients with pain and especially those who had spinal pain had reduced PaCO₂. However, the patients with spinal pain had exclusively low back pain rather than neck pain. In a more recent study by Nilsen et al (2007) patients with both neck and shoulder pain were recruited, but its results cannot absolutely support the findings of the current study not only due to the inclusion of patients with shoulder pain which render the sample less homogeneous, but also due to the fact that only respiratory rate was assessed. Thus, the lack of PaCO₂ assessment in parallel with the fact that respiratory rate was not accompanied by the assessment of tidal volume does not allow for conclusions about the existence of PaCO₂ reduction in these patients. Thus, it can be concluded that although in the current study patients with chronic neck pain were found to have reduced PaCO₂, this finding can only be in partial agreement with the existent literature as there is no other evidence about the existence of hypocapnia in chronic neck pain.

The findings of the current study also reveal another important finding about blood gases. PaCO₂ not only was reduced in patients with chronic neck pain, but it was also slightly below 35 mmHg which is the defining value for the existence of hypocapnia (Reid and Chung, 2004). Patients with chronic neck pain present a quite similar respiratory symptomatology to the one met in restrictive and especially neuromuscular disorders (Thurlbeck and Macklem, 1970; Pass and Bolton, 1988; Baydur, 1991; Stubgen et al, 1994; Tantucci et al, 1994; Matecki et al, 2001; DePalo and McCool, 2002; Yavagal and Mayer, 2002; Heliopoulos et al, 2003; Perrin et al, 2004). However, although restrictive disorders related to neuromuscular weakness have been purported to lead to hypercapnia, this tends to be true only at the late stage of neuromuscular respiratory failure, as these patients initially manifest hypocapnia (Harrison et al, 1971).

The principal physiologic causes of hypocapnia are concerned with hyperventilation as overbreathing washes out the CO₂ stores of the body (Hough, 2001; Laffey and Kavanagh, 2002). The connection of hypocapnia with hyperventilation is so close that they are clinically considered synonymous (Gardner and Bass, 1989). In the literature there is a number of conditions described as potential causes of this disorder. Pulmonary, cardiovascular, metabolic and central nervous system disorders are all related to hypocapnia (Laffey and Kavanagh, 2002). However, these causes cannot provide explanation for the hypocapnia detected in
patients with chronic neck pain because participants with such conditions were excluded from the study. Furthermore, pregnancy, fever and sepsis are also causes of hypocapnia (Laffey and Kavanagh, 2002), but such conditions were not apparent in the chronic neck patients of this study. Drugs such as salicylates, methylophantines, β-adrenergic agonists and progesterone are also related with hypocapnia (Laffey and Kavanagh, 2002), but these drugs were not included in the medical treatment of the patients who participated in the current study. The only of these drugs that were received by the patients with chronic neck pain were salicylates, but they were used just occasionally, by a small percentage of the participants and not the day of the measurements. These facts in parallel with the fact that hypocapnia is related only with overdoses of salicylates (Samet et al, 1960) and salicylate poisoning (Vale, 2007) suggest that they had a minimal or unimportant role in the hypocapnia observed in the patients of this study. Finally, small airway collapse has also been proposed as a cause of hypocapnia because it decreases the lung compliance (Harrison et al, 1971). However, small airway collapse does not seem to be the case in the patients used in the current study because they had normal Forced Expiratory Flow at the 75% of forced expiration (FEF75%) which is indicative for normal airflow in the small airways. Thus, psychosomatic hyperventilation (Henry and Sessle, 1985; Holt and Andrews, 1989) and hypoxia (Pass and Bolton, 1988; Laffey and Kavanagh, 2002) seem to be the only sound mechanisms for hypocapnia in chronic neck pain.

According to the first mechanism hypocapnia can derive either from pain or from psychological states. A usually described mechanism for this blood gases disturbance is that pain results in release of pain neurotransmitters, such as substance P, which have stimulatory effects on respiratory function leading to hyperventilation and hypocapnia (Henry and Sessle, 1985). Hypocapnia in patients with chronic neck pain can be also attributed to psychological states, such as anxiety and phobia, which have known stimulatory effects on ventilation mainly because of adrenaline release and stimulation of the autonomous nervous system (Holt and Andrews, 1989; Seaman and Cleveland, 1999). Finally, taking into consideration that hyperventilation has analgesic effects (Chalaye et al, 2009), this might be a chronic adaptation of patients with chronic neck pain in order to decrease their pain. However, although this mechanism can help neck pain sufferers to self-regulate their pain intensity, this
mechanism leads them in a hypocapnic state. This adaptation may finally become a permanent condition due to a reprogramming of respiratory centers (Hough, 2001).

The second potential mechanism for hypocapnia in patients with chronic neck pain is related with hypoxia. More specifically, patients with chronic neck pain present weakness of their respiratory muscles (see Section 7.3.5 “Respiratory muscle strength”). According to Pass and Bolton (1988), respiratory muscle weakness leads to reduction of lung volumes as the muscles do not have the appropriate strength to fully expand the lungs. This change in lung volumes leads to a bad ventilation/perfusion matching, because the changes in ventilation are not accompanied by similar changes in lung perfusion. The blood shunt deriving from this ventilation/perfusion mismatching results in hypoxia. Although this hypoxia stimulates increased respiratory rate and depth, the increased effort due to the respiratory muscle weakness leads to a rapid shallow breath. This increase in respiratory rate can eliminate CO$_2$ to such extent that hypocapnia results.

Hypocapnia is a quite serious condition affecting a number of body systems. More specifically, a reduced level of PaCO$_2$ leads to alkalosis due to a consequential rise in pH of the cerebrospinal fluid and blood (Hough, 2001; Laffey and Kavanagh, 2002; McLaughlin, 2009). This results in a constriction of the smooth muscles of vessels, gut and bronchi. The oxygenation of tissues is affected not only because of this vasoconstriction-based reduction in blood flow, but also because of the reduced release of oxygen and nitric oxide by haemoglobin. The importance of nitric oxide for the oxygenation of tissues is mirrored to its vasodilatory action which inhibits the adhesion, activation and aggregation of platelets (McLaughlin, 2009). Finally, the pH increase may reduce plasma calcium and potassium, excite neuromuscular junctions and lead to sensory disturbances (Folgering and Snik, 1988; Hough, 2001).

All of these changes may lead patients with hypocapnia to a number of symptoms. More specifically, cerebral vasoconstriction may lead to dizziness, faintness, confusion, visual disturbances, headaches and hallucinations, whereas coronary vasoconstriction may lead to angina, atypical chest pain, coronary artery spasm and adrenaline-induced electrocardiographic changes which are frequently misdiagnosed as a heart disease especially when they are accompanied by tachycardia and arrhythmias (Hough, 2001; McLaughlin, 2009). The hypocapnia-based headache is of special interest as it can be proposed as an alternative explanation for the
mechanism of cervicogenic headache. The constriction of bronchi is also implicated with the existence of bronchospasm, asthma and breathlessness. The gastrointestinal system is also affected as an increased tone, motility and sensitivity is observed (McLaughlin, 2009). Finally, fatigue, disorientation, paraesthesia, muscle cramps and impaired glucose metabolism are also frequently observed due to the respiratory alkalosis (Hough, 2001).

Although the results suggest that patients with chronic neck pain have hypocapnia, this should be carefully considered in order to avoid potential misconclusions. The PaCO$_2$ level of these patients was assessed by transcutaneous blood gas monitoring. Although transcutaneous assessment is considered a valid and reliable method for assessing blood gases (Cuvelier et al, 2005; Domingo et al, 2006; Rodriguez et al, 2006; Vivien et al, 2006; Storre et al, 2007; Hinkelbein et al, 2008; Maniscalco et al, 2008), it may slightly underestimate PaCO$_2$ and it is less precise in comparison with the “gold standard” blood gas analysis (Hinkelbein et al, 2008). This fact may reveal that patients with chronic neck pain may not have hypocapnia, but only reduced PaCO$_2$. However, in this case PaCO$_2$ would seem to be borderline normal with an important trend towards hypocapnia. Nevertheless, the fact that this decrease in PaCO$_2$ in comparison with norms was observed only in patients with chronic neck pain and not in their healthy controls is an important indication for hypocapnia in these pain sufferers. Finally, considering that pain intensity is significantly correlated with PaCO$_2$ level, it may be concluded that patients with higher neck pain intensity are more prone to hyperventilate and manifest hypocapnia.

The correlations examined in the present study help to understand the development of hypocapnia in patients with chronic neck pain. The PaCO$_2$ of patients with chronic neck pain was found to be significantly positively correlated with strength of neck flexors ($r=0.34$, $p<0.05$) and extensors ($r=0.35$, $p<0.05$) and endurance of deep neck flexors ($r=0.31$, $P<0.05$) and significantly negatively correlated with pain intensity ($r=-0.34$, $p<0.05$), kinesiophobia ($r=-0.35$, $p<0.05$) and catastrophizing ($r=-0.3$, $p<0.05$). The association of PaCO$_2$ with pain intensity and psychological states confirm some of the initial hypotheses about the origins of the hypocapnia observed in patients with chronic neck pain. Kinesiophobia has already been discussed in that it can lead to hyperventilation due to adrenaline release and stimulation of the autonomous nervous system (Holt and Andrews, 1989; Seaman and
Catastrophizing may further increase kinesiophobia because it is believed that a tendency to catastrophize, results in a further avoidance of movements and activities (Sullivan et al, 2001) and consequentially can further affect PaCO₂. Pain is also a known reason for hyperventilation due to the stimulatory effects of pain neurotransmitters, such as substance P, on respiratory function (Henry and Sessle, 1985).

The association of hypocapnia with the reduced neck muscle strength and endurance is less explored. Although neck muscle strength was found to have a much weaker correlation with PaCO₂ in comparison to its correlations with the other respiratory indices, this correlation was quite significant (r=0.34-0.35, p<0.05). However, a potential explanation is the fact that reduced neck muscle strength leads to respiratory muscle weakness (see Section 7.3.5 “Respiratory muscle strength”). As it has been previously been discussed, this weakness in respiratory muscles may successively lead, to reduced lung volumes, ventilation/perfusion mismatch, blood shunt, hypoxia, increased respiratory rate and finally hypocapnia (Pass and Bolton, 1988).

A similar conclusion can be derived for the association of PaCO₂ with endurance. However, in contrast to the neck muscle strength, clinical tests of endurance are additionally affected by psychology, emotion and motivation of participants to maintain effort for prolonged time (Strimpakos, 2011b). This fact suggests that reduced endurance may also incorporate a psychological component which may be relative to the PaCO₂ reduction observed in patients with chronic neck pain. However, considering the fact that the craniocervical flexion test is not a pure time-dependent test, its psychological component is expected to be less important in relation with other time-dependent neck endurance tests and it may not be a factor in the current study.

Although neck muscle strength and endurance may indirectly lead to hypocapnia through respiratory muscle weakness, it seems that they may be also a result of hypocapnia. The current literature reveals an association of hypocapnia with muscle fatigue (Folgering and Snik, 1988; Natelson et al, 2007). More specifically, hypocapnia leads to increased excitability of nerves, muscles and neuromuscular junctions. This increased excitability is attributed to the reduction of the free calcium ion concentration in the plasma due to the respiratory alkalosis accompanying
hypocapnia. These neurophysiologic events can lead to an increase of reflex activities and muscle tone predisposing to muscle fatigue (Folgering and Snik, 1988). Thus, it seems that hypocapnia should be considered not only an effect but also a cause of reduced neck muscle strength and endurance.

The regression models constructed for the prediction of PaCO$_2$ may provide more depth into the understanding of the development of hypocapnia in patients with chronic neck pain. More specifically, after the common input of all the non-pulmonary variables into the model, the effects of strength of neck extensors and catastrophizing vanished and only pain intensity, kinesiophobia and endurance of deep neck flexors remained into the model as significant predictors of PaCO$_2$. This fact provides further support to the stipulations suggested previously about the development of hypocapnia in chronic neck pain patients. The removal of catastrophizing from the model can be justified by its indirect effect on hypocapnia through kinesiophobia as well as through an increased pain anticipation which may be experienced by patients with catastrophizing thoughts. Neck muscle strength was also removed from the model, something which reveals its low unique contribution to the development of hypocapnia. Although pain intensity and kinesiophobia have known mechanisms leading to hypocapnia, the existence of reduced endurance of deep neck flexors among the significant predictors of hypocapnia is less explored and might suggest that this respiratory disturbance might also have a biomechanical component. However, the soundest explanations for the existence of neck muscles endurance into the model is either due to the fact that reduced endurance may lead to hypocapnia through respiratory muscle weakness and ventilation/perfusion mismatching (Pass and Bolton, 1988) or due to the fact that hypocapnia is a cause rather than an effect of muscle fatigue due to an increase in excitability of neuromuscular junctions (Folgering and Snik, 1988).

### 7.4 Patients with chronic musculoskeletal non-spinal pain

In the current study, the respiratory function of patients with chronic non-spinal musculoskeletal pain was also assessed in parallel with the other two groups. The use of such a group may help to understand the biomechanical effects of neck
pain on respiratory function as distinct from the psychosocial and biochemical effects of pain which will be common in both pain groups. However, it should be noted that this group was included for exploratory purposes and its small sample size and non-matching nature does not permit statistically valid comparisons to be made between the groups.

Based on descriptive rather than inferential statistics, in comparison to the other two groups the patients with chronic non-spinal musculoskeletal pain were found to have increased Forced Expiratory Volume in one second (FEV$_1$) and Forced Vital Capacity (FVC), whereas the FEV$_1$/FVC ratio remained normal. The normal FEV$_1$/FVC suggests no obstruction, and the increased forced pulmonary volumes may exclude the existence of a restrictive disorder. Indeed, the increased pulmonary volumes in this group were not unexpected due to the different anthropometric characteristics between groups. Thus, the increased forced pulmonary volumes is believed to be mainly the result of the non-spinal pain patients’ younger age, predominant male gender and higher height and weight (Jubber, 2004; Harms, 2006; Ruppel, 2009). The same explanation seems to apply to the justification of the increased quiet breathing volumes, flows and Maximal Voluntary Ventilation (MVV) observed in this group of patients.

The strength of respiratory muscles also seems to be increased in comparison with neck pain group, but it seems to be quite similar to the group of healthy participants. Although this fact biomechanically explains why patients with chronic neck pain had reduced volumes, flows and MVV in comparison with patients with non-spinal musculoskeletal pain, it cannot explain the similar respiratory strength to the control group. This similarity is not unexpected, but as the other effort-dependent spirometric indices were also found to be increased in the non-spinal pain group, a higher respiratory strength would be also expected. One potential explanation is that patients with chronic non-spinal pain were more kinesiophobic than the other two groups. The relatively increased kinesiophobia in this group may be explained by the fact that some types of pain in this group such as knee pain may be more disabling in daily life activities such as walking. Furthermore, the increased kinesiophobia may be explained by the fact that a younger and more athletic group is related with more strenuous activities which lead to a higher phobia for pain and new injury. Based on the previously discussed regression models, kinesiophobia seems to have a more
direct and eminent role for the reduction of respiratory strength in comparison with its effects on the other spirometric indices. Thus, the fact that patients with chronic non-spinal pain are more kinesiophobic in parallel with the fact that kinesiophobia has a more close association with respiratory weakness can explain why respiratory strength was not found to be as affected as the other spirometric indices in patients with non-spinal musculoskeletal pain. Nevertheless, it should be mentioned again that the existence of a matched non-spinal pain group could lead to quite different conclusions.

The most important finding regarding this sample is that patients with chronic non-spinal pain have similar partial pressure of arterial carbon dioxide (PaCO₂) to the healthy control group and therefore higher PaCO₂ in comparison with patients with chronic neck pain. This fact may suggest that the reduction in PaCO₂ is a problem associated mostly by patients with chronic neck pain and not by patients with non-spinal pain. Thus, it may strengthen the argument that beside pain and phobia, other biomechanical factors might be related to the existence of hypocapnia in patients with chronic neck pain. However, this observation may be the result of the higher pain intensity, frequency and duration observed in patients with chronic neck pain as the pain was found to be related to hypocapnia level. Thus, if patients with non-spinal pain experienced similar pain characteristics to patients with chronic neck pain, the PaCO₂ may be not different between the two pain groups. Furthermore, the pain in different body regions may be experienced differently altering the psychological influences of pain. Finally, it should be also considered that females are more prone to hyperventilation and consequentially to hypocapnia (Kilbride et al, 2003). Thus, considering that the non-spinal pain group included more males, it seems that this group may be less prone to hyperventilation and hypocapnia.

In conclusion, the results derived from the sample of patients with chronic non-spinal pain are not particularly helpful for extrapolation of any valid conclusions about their respiratory effects in comparison with patients with chronic neck pain. The reason for this limitation can be attributed mainly to the non-matching of patients with non-spinal neck pain with the other two groups, the small sample size as well as to the lack of homogeneity (patients with non-spinal pain had complaints in variable body areas including hip, knee, ankle, foot and shoulder). Nevertheless, although these
findings do not allow for valid comparisons, they do suggest that any future studies should include this third group as a valuable reference group.

7.5 Respiratory dysfunction model in chronic neck pain

The findings of this study help to obtain a better insight into the development of respiratory dysfunction of patients with chronic neck pain. This understanding has led to the amendment of the model initially proposed by Kapreli et al (2008) regarding the development of respiratory dysfunction in these patients. The new model is based on knowledge obtained by the differences and correlations examined in the current study in parallel with a scientifically valid theoretical background and is presented in Figure 7.1.

This model has been constructed considering each neck pain deficit as independent from each other although as it has already been discussed that each of these deficits may be either a cause or effect of each other. Furthermore, this model has been constructed based on unidirectional causality paths although causality in the opposite direction is also possible. The reason for this is that the model is aimed at describing how neck pain deficits can lead to respiratory dysfunction and not how these respiratory deficits may further compromise neck function. Thus, these selections were done under the rationale of simplifying interpretation of the model. Furthermore, this model is based on deficits that were found in this study to be apparent in patients with chronic neck pain and to be correlated with respiratory parameters. Thus, potential neck pain deficits such as forward head posture, range of movement, anxiety and depression were removed from the model although their potential contribution to the development of this respiratory dysfunction cannot be theoretically ignored.
Figure 7.1: Respiratory dysfunction model for patients with chronic neck pain.

Continuous line: it is strongly supported. Dashed line: it is weakly supported. Red boxes: Non-pulmonary deficits of chronic neck pain. Green boxes: Pulmonary deficits of chronic neck pain. Grey boxes: Proposed mechanisms. Blue box: Deficits which were not examined or were not found significant contributors to respiratory dysfunction. MVV: Maximal Voluntary Ventilation, SCM: Sternocleidomastoid, SCL: Scaleni, TRA: Trapezius, V/Q: Ventilation/Perfusion, FEF$_{25\%}$: Forced Expiratory Flow at 25% of forced expiration, FHP: Forward Head Posture, ROM: Range of Movement.
This model was also developed without taking the role of neck proprioception into consideration. Proprioceptive deficits lead to alteration of sensory inputs, nervous system reorganization and finally to changes in motor control patterns (Kapreli and Athanasopoulos, 2006) which potentially alter the rib cage mechanics and the function of respiratory muscles. Although there is a strong belief that neck proprioception is a significant factor for the development of respiratory disturbances in patients with chronic neck pain, the lack of reliable measurement tools (Strimpakos et al, 2006) and the failure to develop a reliable assessment protocol for neck proprioception in the pilot phase of this study did not permit its assessment. Thus, every reader of this model is strongly advised to always consider neck proprioception as a neck pain deficit potentially belonging to this model.

According to this model, chronic neck pain may be accompanied by two primary respiratory manifestations. The first main respiratory manifestation of patients with chronic neck pain is a reduction in the strength of their respiratory muscles. This respiratory weakness can lead to reduction of peak flows and pulmonary volumes as the respiratory muscles are less able to overcome the resistance of the elastic recoil of the lungs (Perrin et al, 2004). This respiratory weakness is also depicted in the reduction of maximal voluntary ventilation which is a general index of respiratory performance. The weakness of respiratory muscles in patients with chronic neck pain seems to be the result of many neck pain mechanisms including pain, psychological states, neck muscle weakness and fatigue of deep neck flexors.

Respiratory function can be influenced by impaired function of neck muscles. Neck muscles can be categorized as local or global. Local muscles are dynamic structures of high spindle density being responsible for optimal posture, muscle balance and segmental instability (Comerford and Mottram, 2001a; Key et al, 2008a; Key et al 2008b). Their stabilizing role has made them to be alternative called as “active ligaments” (Bastide et al, 1989) and they have a role of stabilizing and controlling the movement (Comerford and Mottram, 2001a; Key et al, 2008a). Global muscles are larger muscles and although some of them have also a stabilizer role, these are the muscles which are responsible for movement production (Comerford and Mottram, 2001a; Key et al, 2008a). However, the optimal performance of these muscles prerequisites segmental stability of the related articulations which is provided by the local muscles. Thus, the optimal co-operation of both local and global system
is necessary in order for movement execution to be appropriately performed (Comerford and Mottram, 2001a; Key et al, 2008a; Key et al, 2008b).

In the current study, the function of cervical muscles of patients with chronic neck pain was affected as it was found that there is weakness of their neck extensors (global system), discussable weakness of their neck flexors (global system) and fatigue of their deep neck flexors (local system). Weakness of neck muscles may directly influence respiratory function as sternocleidomastoid, trapezius and scaleni are muscles which participate in both neck movement and inspiration (Palastanga et al, 2002; Legrand et al, 2003). Thus, it becomes obvious that weakness of these muscles can lead to a simultaneous reduction in strength of neck and respiratory muscles. Furthermore, the weakness of neck muscles can lead to changes in force-length curve and muscles imbalances (Gossman et al, 1982). These imbalances can cause a generalized instability due to uncontrolled movement and change the rib cage mechanics which consequentially affect the biomechanical function of respiratory muscles including diaphragm, intercostals and abdominals (Kapreli et al, 2008).

The weakness of respiratory muscles may also be attributed to fatigue of deep neck flexors (local system). Although, the fatigue of deep neck flexors seems to be a weaker contributor to the development of respiratory muscle weakness, it may also contribute to the alteration of rib cage biomechanics. More specifically, dysfunction of these muscles can seriously affect kinetic control not only of the neck area, but also of neighboring articulations such as thoracic spine (Comerford and Mottram, 2001a; Key et al, 2008a; Key et al, 2008b). Considering the close biomechanical association of thoracic spine with rib cage (Andriacchi et al, 1974), it seems that this spinal instability can affect the mechanical function of rib cage. Kapreli et al (2008) explain that during respiration there is an eminent need for spinal stability which lead to an optimal action of the muscles in terms of moving the ribs up and down. Thus, poor motor control of cervical muscles and consequentially spinal instability can lead to changes in rib cage mechanics altering the force-length curves of the related respiratory muscles such as diaphragm, abdominals and intercostals and leading them to adapted contraction patterns (Kapreli et al, 2008).

Kinesiophobia is also implicated with this respiratory weakness as muscles can be observed as weak due to a reduced patients’ effort which can be attributed to movement phobia from previous pain experiences. Kinesiophobia may also contribute
to this weakness due to muscular adaptive changes deriving from a permanent suboptimal performance of both neck and respiratory muscles (Gajdosik, 2001; Bruton, 2002). Thus, these changes can be observed in both neck and respiratory muscles contributing both directly and indirectly to this respiratory dysfunction. Catastrophizing may also indirectly lead to respiratory dysfunction as it leads to increased pain anticipation which is a significant contributor to this respiratory dysfunction. However, its contribution to respiratory weakness may be also attributed to its close association with kinesiophobia (Sullivan et al, 2001).

Pain is also an important contributor to the development of respiratory muscles weakness. Pain can lead to movement inhibition without permitting patients to demonstrate their optimal neck muscle strength. This inhibition may also lead to a prolonged neck movement limitation (Falla and Farina, 2008) which consequentially leads to muscular adaptive changes leading to a permanent reduction in neck muscle strength (Gajdosik, 2001; Bruton, 2002). Furthermore, initial temporary changes in motor control, due to the inhibition of activity of painful muscles and the compensatory increased activity of non-painful muscles, can finally lead to reorganization of the nervous system and changes in motor control of muscles related to the cervical region (Jull et al, 2004). These changes in motor control patterns are not optimal for maximal force production (Falla and Farina, 2008) and therefore neck muscles become weaker. This neck muscle weakness can finally lead to respiratory muscle weakness with the mechanisms described in the previous paragraphs. Although, these changes are mostly related to neck muscle strength and indirectly affect respiratory muscle strength, the direct influence of pain on respiratory muscle strength cannot be ignored as many patients tend to have neck pain during the respiratory manoeuvres. Thus, the strength of respiratory muscles can be directly affected by neck pain following similar mechanisms with those previously discussed.

The second main respiratory manifestation of patients with chronic neck pain is a reduction in partial pressure of arterial carbon dioxide (PaCO₂) which in more severe occasions may lead to hypocapnia. This hypocapnia can derive from different neck pain mechanisms. The first reason for development of hypocapnia is the neck pain by itself, as substance P, a pain neurotransmitter, has stimulatory effects on respiratory function leading patients with chronic neck pain to hypeventilation and consequentially to hypocapnia (Henry and Sessle, 1985). The second reason for the
development of hypocapnia is kinesiophobia, as phobia leads to release of adrenaline and stimulation of autonomous nervous system which finally leads patients with chronic neck pain to hypeventilation and hypocapnia (Holt and Andrews, 1989; Seaman and Cleveland, 1999). The third potential reason for hypocapnia in patients with chronic neck pain is the respiratory muscle weakness. Respiratory muscle weakness as it has already been discussed may result from neck pain, psychological states and disturbed global and local muscle system. Weakness of respiratory muscles lead to a reduction of lung volumes and a consequential ventilation/perfusion mismatch as perfusion does not follow the changes in ventilation. This generates a ‘shunt’ which results in less oxygenation of tissues. The body tries to compensate for this hypoxia with an increase in respiratory rate and depth. However, the weakness of patients might lead them to have a rapid shallow breath. This increase in respiratory rate may finally lead patients with chronic neck pain to hypocapnia (Pass and Bolton, 1988).

7.6 Clinical Implications

The findings of the current study are rich in clinical implications for assessment, treatment and drug prescription in patients with chronic neck pain. In terms of assessment, the findings of the current study suggest a change in clinical reasoning in patients with chronic neck pain. The current assessment strategies focus only on musculoskeletal impairments deriving directly from neck pain. This partial assessment of chronic neck pain may lead to ignorance of important aspects of this complaint which may have a negative impact on the general health and daily life of sufferers. The conclusions of the current study about existence of respiratory dysfunction in chronic neck pain suggest the incorporation of respiratory components into the clinical assessment of these patients. The parallel assessment of chronic neck pain deficits and states such as kinesiophobia, pain intensity and neck muscle endurance and strength can significantly help the understanding of respiratory dysfunction of each patient as these factors seem to play an important role for the development of this dysfunction.
The assessment of patients with chronic neck pain is further helped by the prediction models constructed in the study. This study has provided some accurate and generalizable models for the prediction of respiratory muscle weakness, pulmonary volumes, respiratory flows and maximal voluntary ventilation of patients with chronic neck pain. Considering these models, it seems that a simple measurement of neck muscle strength can provide a reasonably accurate prediction for the respiratory function of these patients. However, the generalization of the model constructed for the prediction of hypocapnia in these patients is discussable and it seems that its validity should be further examined before applying it to patients with chronic neck pain. Nevertheless, the existence of these models provide clinicians with an appropriate and time-effective way to assess their respiratory function without using any pulmonary function testing equipment which is rarely available in physiotherapy clinics.

The findings of this study also give rise to important clinical implications about treatment of patients with chronic neck pain. Patients with chronic neck pain may benefit from modern therapeutic approaches such as respiratory synkinesis, where movement is accompanied by a specific breathing pattern (Lewit, 2010). These techniques are very useful for facilitating the desired neck muscles during treatment. For example, neck flexion facilitates expiration and neck extension facilitates inspiration. Another example is that traction of the cervical spine is facilitated during expiration (Lewit, 2010). Thus, these techniques not only improve the coordination between the musculoskeletal and respiratory system, but can be also helpful for a more appropriately application of manual techniques.

However, although “respiratory synkinesis” exercises may improve the treatment of patients with chronic neck pain, they do not appropriately address the respiratory problems of patients with chronic neck pain, as they mainly focus on how respiratory manoeuvres can improve movement execution. An initial thought about the rehabilitation of respiratory problems of patients with chronic neck pain could be that the rehabilitation of neck muscle strength and endurance as well the management of kinesiophobia and pain could lead to improvement of respiratory function as it has been found to change in parallel with the previously mentioned neck pain deficits. However, such a belief is lacking a deeper understanding of pain-induced motor control changes. Pain conditions such as chronic neck pain may induce changes in the
nervous system altering the relative participation of muscles to movements (Falla and Farina, 2008). These changes become permanent motor responses which remain even if the chronic neck pain has been resolved (Comerford and Mottram, 2001b). According to this fact, changes in respiratory function may remain even if the chronic neck pain and its associated deficits have been treated. Thus, future rehabilitation protocols are advised to incorporate therapeutic techniques which are directed not only towards musculoskeletal impairments, but also towards the respiratory system. According to the findings of this study, these techniques should be mainly concerned with the resolution of respiratory weakness and hypocapnia.

The current literature provides several suggestions for the rehabilitation of such respiratory symptoms. More specifically, several inspiratory muscle training devices are commercially available. These devices are able to provide different degrees of resistance during patients’ breathing. Exercising with devices has been found to improve the strength of inspiratory muscles (Hart et al, 2001). The development of technology has also provided computer-based games driven by respiratory efforts (Vilozni et al, 1994). Thus, respiratory function of patients with chronic neck pain may be improved by the use of such equipment as they may help to increase the strength, endurance and coordination of their respiratory muscles. On the other hand, the exercise of expiratory muscles seems to be less important as expiration is highly passive. However, abdominal exercises cannot be rejected, as they may be proven useful for the improvement of expiration.

Another potential intervention for patients with chronic neck pain could be exercises for increasing lung volumes. These exercises are frequently applied in patients with restrictive lung disorders (Westerdahl et al, 2005). However, the suitability of these lung re-expansion exercises in patients with chronic neck pain is questionable considering that hyperventilation and hypocapnia may be also apparent.

Suggestions about the treatment of hypocapnia should be also carefully considered. Although, teaching patients the correct breathing pattern may initially seem to be the best method for treating hypocapnia, the problem is more complicated. In reality hypocapnia can be induced by voluntary or involuntary mechanisms. In the first case, considering the analgesic effects of hyperventilation (Chalaye et al, 2009), hyperventilation might be a voluntary respiratory response of patients in order to decrease their neck pain. Thus, physiotherapists’ intervention for teaching the correct
breathing pattern might lead to an increase of neck pain experience. However, if neck pain is treated, this breathing pattern might remain as a maladaptive breathing pattern because of reprogramming of the respiratory centers (Hough, 2001) and breathing reeducation could be a potential treatment goal. In the second case, hypocapnia may be a result of hyperventilation induced by the stimulation of the respiratory centers due to phobia (Holt and Andrews, 1989) or pain (Henry and Sessle, 1985) or by hypoxia due to a ventilation/perfusion mismatch (Pass and Bolton, 1988). In these cases, it does not seem that breathing re-education may have negative consequences to patients’ respiration. Thus, in involuntary hyperventilation, hypocapnia might be treated by breathing reeducation exercises (Bruton and Holgate, 2005; Clifton-Smith and Rowley, 2011). However, breathing exercises in patients with chronic neck pain have never been investigated and their effectiveness on hypocapnia renders a critical point of future interventional studies.

The results of the study also provide important clinical implications in terms of drugs prescription. Analgesic and anti-inflammatory drugs have been found to alter respiratory function (Samet et al, 1960; Moren et al, 1997). Thus, considering the already affected respiratory function of patients with chronic neck pain, the uncontrolled use of such drugs could further contribute to this respiratory dysfunction. However, the findings of this study do not provide any evidence about the suitability or the optimal frequency for the distribution of these drugs. Nevertheless, there are obvious implications about the description of drugs in a more attentive and controlled manner.

7.7 Limitations

Although the current study provides very important information, the validity of its findings might be affected by some limitations. The first limitations are concerned with the methodology selected. More specifically, the sample recruitment of the current study was not random. A random selection of the sample would induce less bias to the findings of the study (Bowling and Ebrahim, 2005). However, the difficulty in recruiting participants especially considering the strict eligibility criteria
of the study rendered the selection of a convenience sampling method practically unavoidable.

Another methodological limitation is that the assessor of this study was not blind to the participants’ condition. Although this fact theoretically induces bias to the findings of the study (Bowling and Ebrahim, 2005), it was unavoidable. The reason for this is the fact that this study was undertaken as a part of a Doctor of Philosophy (PhD) degree research project where the main investigator had also to take part in the measurement procedure. Furthermore, still in the case where the use of a blind observer would be available, it does not seem that this would be a real blinding. This is because of the fact that the assessor should have been an individual with a health sciences-based education in order to appropriately perform the measurements. However, such an assessor would understand the real condition of individuals during the measurement procedure even if he/she was initially blind to the group allocation of each participant.

The third important methodological limitation is the fact that the assessment of each participant was quite long including a number of testing procedures. This fact gives rise to important testing effects as the initial measurement might have had effects on participants’ conditions which could remain during the later measurements. However, the assessment protocol of the study was designed as carefully as it could in order to reduce the testing effects to the minimum giving special consideration to the protection of respiratory parameters from testing effects. Nevertheless, potential changes in neck pain intensity during the study procedure cannot be ignored.

A further limitation of the current study is the lack of homogeneity regarding participants’ demographics as the participants of the study were of variable gender and age. Although this is not a problem for the examination of differences between the groups due to the strict individual matching, it might affect the correlations examined. However, although a subgroup analysis could help to understand whether the magnitude of correlations is different for different genders, this study was not aimed at examining the moderating effects of gender. Instead of this, this study included patients with chronic neck pain in a prevalence similar to the one observed in epidemiological studies (Andrianakos et al, 2002; Cote et al, 2003; Webb et al, 2003) rendering the results more generalizable. Furthermore, the sample used in the current
study included predominantly female participants, rendering difficult the examination of correlations in the subgroup of males with chronic neck pain.

Another unavoidable problem with the current study was the participation of patients who mainly suffered from mild to moderate neck pain. Although, the initial aim of the study was the generalization of the findings in all patients with chronic idiopathic neck pain, severely affected patients rarely took part in this study. This can be explained by the fact that severely affected patients would not want to participate and potentially deteriorate their condition by participating in the long assessment procedure of the study. This fact may have biased the findings towards patients with mild to moderate chronic neck pain although it is expected that patients with more severe and disabling neck pain would have demonstrate a greater effect on respiratory function.

Another potential limitation is the assessment period and timing of assessment. The measurements of all the individuals for the completion of this study took about one year. Furthermore, some participants were assessed after their job whereas other participants were assessed during the weekend. Thus, the environmental changes in parallel with the non-standardized work-related fatigue may have led to a different response of participants to the measurements. However, considering the great number of participants and the difficulties during the sample recruitment, such a standardization seems to be an unreal expectation as it was impossible for participants to be available the same time point. Nevertheless, although the validity threats should be always considered during the interpretation of the results, the fact that the most of patients with chronic neck pain and healthy controls were assessed in parallel leads to an unofficial matching of these factors.

Similar problems derive from the fact that the use of drugs and the participation in physiotherapy interventions were not consistent among all the patients with chronic neck pain. For example, the use drugs may have led some more affected patients to provide different estimations of their normal musculoskeletal and respiratory condition. Furthermore, participation in physiotherapy programs by some individuals may have led them to be presented better than the expected during the measurements. However, patients were never asked to stop taking their usual medication or from taking part in physiotherapy interventions as this rationale does not apply to ethical principles and the study was essentially pragmatic in nature.
Another discussable limitation is the use of a transcutaneous assessment tool for recording the partial pressure of arterial carbon dioxide (PaCO2). Although it cannot be considered a serious limitation of the study as this assessment method has been validated by many researchers (Cuvelier et al, 2005; Domingo et al, 2006; Rodriguez et al, 2006; Vivien et al, 2006; Storre et al, 2007; Hinkelbein et al, 2008; Maniscalco et al, 2008), it is not as valid and reliable as the “gold standard” blood gas analysis. However, the more direct nature and inconvenience caused by the latter meant direct assessment was not possible and transcutaneous assessment of PaCO2 was selected as the best alternative.

An additional limitation of the current study could also be the fact that respiratory rate was not assessed. Although, hyperventilation is the physiologic cause of hypocapnia (Laffey and Kavanagh, 2002) and these two conditions are clinically considered synonymous (Gardner and Bass, 1989), the additional assessment of respiratory rate could provide a confirmation about the mechanisms proposed for hypocapnia in patients with chronic neck pain.

Finally, an important limitation of the study is the lack of proprioception assessment. Although a thorough literature review was performed aimed at detecting a reliable measurement tool for its assessment in patients with chronic neck pain, it failed to justify the use of any such a tool. The protocols suggested in these studies were not satisfactory either due to various methodological and statistical inaccuracies or due to disappointing conclusions in terms of their reliability (Loudon et al, 1997; Strimpakos et al, 2006; Swait et al, 2007). The only promising protocol was provided by Lee et al (2006) although it was only occasionally moderately reliable. However, although before the implementation of the current study, the protocol by Lee et al (2006) was replicated, it was found to be reliable only in terms of intra-class correlation coefficients, whereas SDD and SEM were unacceptable. The investigation of neck proprioception is very important in order to obtain a deeper understanding of the development of respiratory dysfunction in chronic neck pain, as it is related with changes in motor control strategies and its existence is strongly supported to affect respiratory function (Kapreli et al, 2008). Thus, its examination and its association with respiratory function should render an important clinical question in future studies as it seems to be theoretically related with the most of the respiratory indices and
especially with maximal voluntary ventilation which partially depicts deficits in neuromuscular coordination.

7.8 Further research

The importance of the findings of the current study for both researchers and clinicians necessitates the further exploration of the respiratory dysfunction in patients with chronic neck pain. These new studies should be directed towards improvement of the methodology and advancement of the findings of the current study as well as investigation of research questions that were not examined in this study.

A potential objective of future studies could be to overcome the limitations of the present study. However, this is not an easy task. Blinding of assessors is difficult due to the fact that the symptoms and complaints of participants during the assessment procedure may reveal participants’ real condition. Furthermore, the participation of patients with more severe neck pain cannot be guaranteed as patients of more severe condition tend to avoid such an assessment procedure. Moreover, direct blood sampling from patients with neck pain and especially from healthy participants is difficult to obtain in practice. However, some suggestions about addressing the other limitations is possible. For example, patients who receive drugs or physiotherapy may be excluded from the research protocol although researchers should be aware that this decision could lead to a very low response rate during sample recruitment. Random sampling could be available if a specialized neck clinic with a great number of sufferers exists. Furthermore, this could help to reduce the time taken to recruit subjects due to the easier accessibility to patients with chronic neck pain. Finally, although the testing effects are unavoidable, they could be reduced if the researchers reduced the number of tests and focused on specific differences and correlations to reduce the number of variables examined. However, this decision would impede a more global understanding about the relationship of chronic neck pain to respiratory dysfunction.

Another important question for future studies is the role of neck proprioception in the development of respiratory dysfunction. Proprioception has been suggested as a critical neck pain deficit for the development of respiratory dysfunction
in patients with chronic neck pain (Kapreli et al, 2008). The examination of neck proprioception may give a different or a deeper understanding for the development of this respiratory dysfunction. However, the lack of reliable measurement tools did not allow its assessment. Thus, one of the most important points of future studies is suggested to be the development of valid and reliable tools for the assessment of neck proprioception and then for this to be directed to the understanding of its role in the development of respiratory dysfunction in patients with chronic neck pain.

An alternative way of spirometry may also render a point of interest for future studies. Future studies may include spirometry before and after bronchodilators. The use of bronchodilators would help to examine whether an airways obstruction is hidden behind the seemingly normal spirometric values. However, these future studies should carefully consider that the use of bronchodilators are suggested only for individuals who are of high clinical suspicion for airflow obstruction (Ruppel, 2009) and that the administration of such drugs in patients with chronic neck pain and healthy individuals is discussable in terms of ethics.

The current study also gives rise to important clinical implications for doctors and health scientists regarding the management of patients with chronic neck pain. Thus, new studies are also suggested to examine the role of drugs for the treatment of neck pain not only focusing on pain experience, but also taking into consideration the respiratory adverse-effects of these drugs as they could further compromise the already affected respiratory function (Morgen et al, 1997). Furthermore, randomized controlled trials should also investigate the effectiveness of respiratory physiotherapy as an additional intervention to the usual physiotherapy care of patients with chronic neck pain.

Future studies are also recommended in terms of including a third group of patients with chronic musculoskeletal pain. This group should exclude patients with spinal pain because it may influence respiratory function in a way similar to chronic neck pain. The use of such a group will help to discriminate between the respiratory effects of neck pain from the effects of musculoskeletal pain in general giving more focus on the biomechanical effects of chronic neck pain rather that its biochemical- and psychological-based influences on respiratory function. Although such a group was used in the current study, the fact that it was of insufficient sample size and that it was not matched with the chronic neck pain group did not allow for valid conclusions.
These studies may be helped by the descriptive findings of the current study in order for a more appropriate methodology to be designed.

Another point of future research interest is the examination of the model proposed about the development of respiratory dysfunction in patients with chronic neck pain. The aim of this study was not to design a model of causality for this dysfunction and therefore the analysis performed was not directed to this aim. However, the findings of the study in parallel with theoretical knowledge from the existent literature led to suggestions about the mechanisms which lead to this dysfunction. For developing and examining the validity of such a model more sophisticated analysis such as mediation analysis, path analysis and structure equation modeling are needed (Norman and Streiner, 2000). Thus, researchers are suggested to test the validity of this model or alternative models by using these more sophisticated analysis techniques and by recruiting more participants in order to correspond to the sample size needs of such analyses.

Finally, one of the most interesting suggestions is the development of classification systems. This study included patients with chronic idiopathic neck pain. However, the term “idiopathic” by itself does not declare the cause of neck pain. Thus, patients of completely different neck pain causes such as osteoarthritis and postural neck pain were included. In reality, it is not clear whether the respiratory dysfunction is found in any specific type of neck pain. Furthermore, the existence of some neck pain deficits which were not found to be significant may be potentially found in a specific type of neck pain and not in each sufferer. Thus, an adequately powered study to enable subgroup analysis would help to understand whether this respiratory dysfunction is generally observed in patients with chronic neck pain or whether some patients are more prone to develop respiratory dysfunction and whether this dysfunction is characterized mainly from hypocapnia or weakness of respiratory muscles. This would potentially lead to a classification system which would have a tremendous effect on appropriately directing physiotherapy interventions in patients with chronic neck pain.
8. Conclusions
8. CONCLUSIONS

Chronic neck pain is one of the most frequent musculoskeletal complaints and is estimated that about two thirds of people suffer from neck pain at some time in their lives. Chronic neck pain is not a single pain condition as it is accompanied by variable muscular, neurological, sensory and psychological manifestations affecting the daily life of sufferers. The current rehabilitation approaches treat neck pain focusing mostly on the neuromusculoskeletal aspects of this complaint. However, these approaches may lead to ignorance of other important manifestations of chronic neck pain in other body systems such as the development of respiratory dysfunction.

The need for a better understanding of problems met by patients with chronic neck pain led to the development of a model for explaining how chronic neck pain may lead to respiratory dysfunction. According to this model pain can stimulate respiration whereas drugs consumption may suppress it. Additionally, respiratory function was believed to be affected by changes in rib cage mechanics deriving from postural changes, muscle imbalances and segmental instability due to reduction in strength and endurance of neck muscles. Deficits in neck proprioception were also implicated for changes in rib cage mechanics because of joint deafferentation and changes in spinal motor patterns. Furthermore, reduced neck mobility was also believed to contribute to this alteration of rib cage biomechanics. Psychological states such as anxiety and kinesiophobia were also provided as potential explanations for changes in rib cage biomechanics either because they stimulate autonomous nervous system or because they impede patients from movement execution with consequential alteration of chest biomechanics. All these factors were finally believed to lead dysfunction of respiratory muscles.

Although this model provided a scientifically sound explanation for the development of respiratory dysfunction in chronic neck pain, the existence of respiratory dysfunction in these patients was supported only by piloting findings. Thus, this study was designed aimed at examining whether patients with chronic neck pain have affected any of their respiratory function parameters including partial pressure of carbon dioxide which was previously totally unexplored. Furthermore, this study examined, for first time, which are the associations of the musculoskeletal and
psychological states of chronic neck pain sufferers with this respiratory dysfunction. Ultimately, this study was aimed at putting together, for first time, all the musculoskeletal and psychological states of patients with chronic neck pain in a model for predicting this respiratory dysfunction.

The theoretical assumptions of the model found support by the findings of the current study and the evidence provided led to an amendment and better understanding of this model. Patients with chronic neck pain were found to have compromised respiratory function presenting a restrictive pattern similar to the one presented in neuromuscular disorders. The respiratory dysfunction of patients with chronic neck pain is mainly manifested as respiratory weakness and hypocapnia. Respiratory muscle weakness can be mainly attributed to the direct and indirect effects of neck muscle weakness, fatigue of deep neck muscles, kinesiophobia, catastrophizing and pain intensity on rib cage mechanics and patients’ effort. The existence of respiratory weakness may further compromise respiratory function as it leads to reduced pulmonary volumes, reduced peak flows and reduced maximal voluntary ventilation. Hypocapnia is the second major respiratory manifestation of patients with chronic neck pain. Hypocapnia may be a further result of respiratory muscle weakness as well as of pain intensity and kinesiophobia. Hypocapnia, in the most severe cases, is a serious condition which can affect the function of many body systems including the cardiovascular, pulmonary and gastrointestinal system as well increasing the excitability of neuromuscular junctions further contributing to the development of muscle weakness and fatigue in patients with chronic neck pain.

The respiratory dysfunction developed in these patients gives rise to important clinical implications about assessment, treatment and drug prescription in patients with chronic neck pain. The assessment of patients with chronic neck pain should not focus merely on their neuromusculoskeletal impairments, but it should additionally include assessment of their respiratory function. Similarly, therapists are advised to adopt a more global consideration of human body during the development of their therapeutic protocols including also techniques for the improvement of patients’ respiratory function. Finally, considering the effects of drugs on respiration, they are advised to be prescribed in a more attentive and controlled manner.

However, considering the fact that the current literature does not provide enough evidence regarding the respiratory dysfunction in patients with chronic neck
pain, future research should be mainly directed towards the examination of the role of proprioception in this respiratory dysfunction, the examination of the effectiveness of respiratory physiotherapy in these patients and finally the development of classification systems for clearly understanding who exactly neck pain patients are more prone to develop this respiratory dysfunction. The answering of these questions by future researchers could help not only to enhance the scientific knowledge in this relatively unexplored area, but also to promote optimal therapeutic protocols and to provide the foundations for a better clinical reasoning.
References
REFERENCES


Appendices
Appendix II

Technological Educational Institute of Lamia
School of Health and Caring Professions
Department of Physiotherapy

ETHICAL COMMITTEE

Dr Ioannis Poulis MA, PhD
Lecturer in Physiotherapy
Department of Physiotherapy
3rd km, Old National Road
351 00, Lamia
+30 22310 60205
ipoulis@teliam.gr

Lamia, October 27, 2009

Reference Number 23

Today, Tuesday 27th October, 2009, at 12.00pm, at the office of the Lecturer in Physiotherapy, Ioannis Poulis, the meeting of the Ethical Committee of the Department of Physiotherapy was convened.

In accordance with the decision of the General Meeting of the Department of Physiotherapy (ref. 118/02-10-2008), the Ethical Committee consists of the following members:

Ioannis Poulis (president)
Georgios Paras (member)
Georgios Panoutsopoulos (substitute member)

Mr. Nikolaos Strimpakos (member) was excluded from this procedure because he was involved in this research study as a supervisor.

Following detailed study of the application of the research proposal by Mr. Dimitriadis Zacharias (number 938/07-09-2009), titled,

"Respiratory dysfunction in patients with chronic neck pain"

and based on the information included in the application form, the Ethical Committee comprised of the above, has decided that:

Since the research proposal conforms to the national standards of physiotherapeutic ethics and safeguards the respect of the volunteers included in the study, it has been granted the approval of the Ethical Committee of The Department of Physiotherapy.

The members:

Dr Ioannis Poulis
Dr Georgios Panoutsopoulos
Dr Georgios Paras

Department of Physiotherapy, TEI of Lamia, 3rd km, Old National Road Lamia–Athens, 351 00
Mr Zacharias Dimitriadis,
61 Anagnostopoulou Street,
Peristeri
Attica
Greece 12135

8th February 2010

Dear Zacharias,

Committee on the Ethics of Research on Human Beings
Dimitriadis: Respiratory dysfunction in chronic neck pain (ref 09274)

I write to confirm that the Committee reviewed the above project on 1st February 2010 and gave it ethical approval subject to agreeing that the records should be kept for 10 years and amending the information sheet to remind participants that, as they were already suffering from neck pain, the exercise might cause further pain and discomfort. In your email of 5th February you were able to confirm these changes and so I am able to confirm, in return, that the project now has full ethical approval.

This approval is effective for a period of five years and if the project continues beyond that period it must be submitted for review. It is the Committee’s practice to warn investigators that they should not depart from the agreed protocol without seeking the approval of the Committee, as any significant deviation could invalidate the insurance arrangements. We also ask that any information sheet should carry a University logo or other indication of where it came from.

Finally, I would be grateful if you could complete and return the attached forms at the end of the project or by January 2011 whichever is earlier.

We hope the research goes well.

Yours sincerely

Dr T P C Stibbs
Secretary to the Committee

Cc Professor Jackie Oldham
Progress or Completion Report Form on an Approved Project

The Committee's procedures require those responsible for projects which have been approved by the Committee to report on any of the following:

* Any incident, accident or untoward event associated with the project (*Please note that if the incident constitutes an accident or dangerous occurrence, the usual Health and Safety reporting mechanism must still be used*)
* Any variation in the methods or procedures in the approved protocol
* A termination or abandonment of the project (with reasons)
* A report on completion of the project or a progress report 12 months after approval has been given.

The report should be sent to the Secretary to the Committee, Dr T P C Stibbs, Room 2.005, John Owens Building, University of Manchester, Manchester, M13 9PL (*tel: 0161-275-2206/2046*).

Project:  *Respiratory dysfunction in chronic neck pain* (ref 09274)
Appendix IV  

Participant information sheet

Title: “Respiratory Dysfunction in Chronic Neck Pain”

Dear Sir/Madam

We invite you to take part in our research which is performed by the University of Manchester in collaboration with the Technological Educational Institute (TEI) of Lamia. Before deciding whether you will participate in this study you should read the information below in order to understand the reason for which we conduct this study. There is no need for you to reply immediately, but you can think about it and you can discuss it with others. If the information provided is not clear we would be happy to provide you with any clarifications.

Which is the aim of the study?

The aim of the study is to examine whether patients with chronic neck pain have respiratory dysfunction and to understand which neck pain deficits are related with this respiratory dysfunction. The duration of the experiment will be about 2 hours and 30 minutes.

Why I have been selected?

You have been selected because you have neck pain and the appropriate characteristics needed to lead our research to valid conclusions. Including you, 45 patients with chronic neck pain will take part in this study.

Is my participation to this study compulsory?

It is not compulsory for you to take part. Your participation is voluntary. In case you take the decision to take part you will have to sign a consent form. Still in case you will take part you will be free to withdraw from the study without giving any reason. Your negative response to our study will have no impact to you from our Institute.

What will happen to me if I decide to take part?

In case you accept to take part to this research you should come to the Cardiorespiratory laboratory, Physiotherapy Department, School of Health and Caring Professions, TEI Lamia in a day and time according to your needs after discussion with the researcher. You should come just one time and the measurements will last for about 2 hours and 30 minutes. The experiment will include a series of simple and safe procedures during which your neck strength, endurance, range of movement, head posture, pain, psychological states as well as the arterial blood gases, pulmonary volumes and respiratory muscle strength will be assessed.

Are there any limitations?

In case you decide to take part please come to the lab with convenient clothes and prepare to be able to remove your upper clothes during the measurements. Please also be prepared to remove your shoes at any time.
Are there any potential dangers?

Our study includes only measurements with measurement tools which have been frequently used in clinical practice and research. These measurements have no known danger for the participants. In some occasions a slight temporary dizziness has been noted. Furthermore, the exercise might cause pain and discomfort, but these effects will be temporary.

Are there any benefits from my participation?

In case you will participate and if it will be found that patients with chronic neck pain have respiratory dysfunction, you will be offered a rehabilitation program for this problem. The results of the study will also help to the better understanding of the chronic neck pain and its accompanied symptoms potentially leading to the development of better therapeutic protocols for this problem.

What will happen after the end of my participation?

After the end of the measurements your participation to the study stops. After the end of the study you will be free to contact the researcher for any question you have regarding the study. If you are interested about the data collected during your participation we can inform you either by post or by personal contact.

What if something goes wrong?

If you are harmed by taking part in this research project, there are no special compensation arrangements. If you are harmed due to someone’s negligence, then you may have grounds for a legal action but you may have to pay for it. Regardless of this, if you wish to complain, or have any concerns about any aspect of the way you have been approached during the course of this study, the normal University complaints mechanisms should be available to you.

Will my taking part in this study be kept confidential?

If you agree to take part in this study, your details will be known only to reliable people from the TEI of Lamia and the University of Manchester. No one else will have access to your data. Any information about you, which leaves the University, will have your name removed so that you cannot be recognised from it.

What will happen with the results of the study?

The results of the study will be used in order to obtain a clearer understanding of the chronic neck pain. It is also possible for the results to be used in conferences and publications in scientific journals. Your name will not be mentioned in any of the conferences or the publications. If you wish, these results can be sent to you.

Contact for further information:

Dimitriadis Zacharias, PT, MSc
Physiotherapy Department, School of Health and Caring Professions, TEI Lamia
Phone number: 6947250304
e-mail: ZDimitriadis@teilam.gr

Date: __/__/

Thank you for your time and we wish to see you again in our study.
Appendix V  “Respiratory dysfunction in chronic neck pain”

CONSENT FORM

If you are happy to participate please complete and sign the consent form below

1. I confirm that I have read the attached information sheet on the above project and have had the opportunity to consider the information and ask questions and had these answered satisfactorily

2. I understand that my participation in the study is voluntary and that I am free to withdraw at any time without giving a reason and without detriment to any treatment/service

3. I understand that photographs will be taken

4. I agree to the use of anonymous quotes

5. I agree to my GP being informed of my participation in the study

6. I agree that any data collected may be passed to other researchers

I agree to take part in the above project

ID and name of participant: __________________________ Date: __________________________ Signature: __________________________

Name of person taking consent: __________________________ Date: __________________________ Signature: __________________________

Please Initial Box

Appendix VI  General Health Questionnaire

1. PARTICIPANT DETAILS

ID: __________

Group:  ☐ Chronic Neck Pain  ☐ Healthy  ☐ Chronic non-spinal pain
Name and Surname: __________________________
Phone number: ___________________________
Home address: ___________________________
Doctor’s name: ___________________________
Assessment date: __________
Assessment time: __________

2. GENERAL QUESTIONS

2.1 Gender  ☐ Male  ☐ Female

2.2 Age: ___________ years

2.3 Weight: __________ kilograms

2.4 Height: __________ centimeters

2.5 You are  ☐ Right handed  ☐ Left handed  ☐ Ambidextrous

2.6 I live in a:
   ☐ Urban area  ☐ Semi urban area  ☐ Rural area

2.7 My work is mostly:
   ☐ Laborious  ☐ Sitting

   Clarify: _____________________________________________
3. MEDICAL HISTORY

3.1 Do you have a medical diagnosis of chronic neck pain? ☐ Yes ☐ No

3.2 Do you have pain for at least 6 months with pain complaints for at least once per week? ☐ Yes ☐ No

3.3 Have your pain begun after any neck injury (e.g. car crash)? ☐ Yes ☐ No

3.4 Do you feel pain in a body region other than neck? ☐ Yes ☐ No

In which body area and for how long?

<table>
<thead>
<tr>
<th>Area:</th>
<th>Duration:</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
</tbody>
</table>

3.4 Do you know whether you have any of the following conditions?

- Malignancy history ☐ Yes ☐ No
- Diabetes ☐ Yes ☐ No
- Cirrhosis ☐ Yes ☐ No
- AIDS ☐ Yes ☐ No
- Infection ☐ Yes ☐ No
- Unexplained weight loss ☐ Yes ☐ No
- Fever ☐ Yes ☐ No
- Night sweats ☐ Yes ☐ No
- Numbness at the extremities ☐ Yes ☐ No
- Weakness at the extremities ☐ Yes ☐ No
- Headaches ☐ Yes ☐ No
- Vomiting ☐ Yes ☐ No
- Speech disorders ☐ Yes ☐ No
- Visual disorders ☐ Yes ☐ No
- Balance disorders ☐ Yes ☐ No
- Urinary disorders ☐ Yes ☐ No
- Hyperparathyroidism ☐ Yes ☐ No
- Dysphagia ☐ Yes ☐ No
- Pain in other regions ☐ Yes ☐ No
- Breast problems ☐ Yes ☐ No
- Uterine problems ☐ Yes ☐ No
- Skin infections ☐ Yes ☐ No
- Chronic cough ☐ Yes ☐ No
3.5 Do you have any injury history? □ Yes □ No

Clarify:
_______________________________________________________________
_______________________________________________________________

3.6 Do you have any history of neck or chest surgery?
□ Yes □ No

Surgeries in other body regions?
□ Yes □ No

Clarify:

Surgery_________________________ When: _________________________
Surgery_________________________ When: _________________________
Surgery_________________________ When: _________________________
Surgery_________________________ When: _________________________

3.7 Is your residence or job in a place which serious compromises your respiratory function? □ Yes □ No

If yes, clarify:
_______________________________________________________________
_______________________________________________________________

3.8 Do you know whether you have any psychiatric, neurological, respiratory or cardiovascular problems? □ Yes □ No

If yes, clarify:
_______________________________________________________________
_______________________________________________________________

3.9 Do you smoke; □ Yes □ No Packages/year: _____________

If yes how many cigarettes per day? ____________ cigarettes/day

For how long? ______ years ______ months

If no did you smoke in the past? □ Yes □ No

If yes how many cigarettes per day? ____________ cigarettes/day

For how long? ______years ______months

How many years have you cut it off? _______ years
3.10 Do you take any drugs? □ Yes □ No

If yes write the drugs you take the dose and the frequency.

i Drug:______________________________ Dose:______________________________ Frequency:______________________________

ii Drug:______________________________ Dose:______________________________ Frequency:______________________________

iii Drug:______________________________ Dose:______________________________ Frequency:______________________________

iv Drug:______________________________ Dose:______________________________ Frequency:______________________________

3.11 Do you have taken any drugs today? □ Yes □ No

How much time ago? __________________________

3.12 Do you currently participate in any physiotherapeutic intervention? □ Yes □ No

If yes, what exactly, how frequently and for how long?

Therapeutic modalities:________________________________________________________
Duration:________________________________________________________
Frequency:________________________________________________________

3.13 How you pain is changed after the physiotherapy;
□ Improved □ Worsened □ No change

3.14 Inform us for whatever you think is important about your health that has not been covered from the previous questions.

__________________________________________________________________________
__________________________________________________________________________
__________________________________________________________________________
__________________________________________________________________________
__________________________________________________________________________
Appendix VII  Pain History and Symptoms Questionnaire

A. PAIN AREA
Please draw in the following body chart the regions you feel local and radiating pain as well as the areas you feel numbness, weakness and headaches.

1.

2. The pain and symptoms appear mainly:
   - [ ] Right
   - [ ] Left
   - [ ] Both equally
B. PAIN INTENSITY

Please answer the following questions marking on the line of each question the pain intensity. The start of each line means “no pain”, whereas the end of the line means “the worst pain someone can experience”:

a) How much is your neck pain at the moment?

No pain _________________________________ Worst pain

b) How much is your usual neck pain?

No pain _________________________________ Worst pain

c) How much is your neck pain at its best?

No pain _________________________________ Worst pain

d) How much is your neck pain at its worst?

No pain _________________________________ Worst pain
C. PAIN FREQUENCY

α) For how long do you feel neck pain? ______________________
β) How many times you experience it per week? ______________________
γ) How long it takes to stop? ______________________
γ) When did you feel neck pain for first time in your life? ______________________
δ) The symptoms were similar to now? □ Yes □ No

Clarify: ____________________________________________________________
____________________________________________________________________
____________________________________________________________________
____________________________________________________________________

D. PAIN QUALITY
How you would describe the pain you experience?

- Intermittent □ Yes □ No
- Continuous □ Yes □ No
- Variable □ Yes □ No
- Dull □ Yes □ No
- Intense □ Yes □ No
- Superficial □ Yes □ No
- Deep □ Yes □ No
- Acute □ Yes □ No
- Diffused □ Yes □ No
- Localized □ Yes □ No
- Radiating □ Yes □ No
- Pulsating □ Yes □ No

E. PAIN BEHAVIOUR IN POSITIONS AND ACTIVITIES

α) When your neck pain appears;

   During movement □ Yes □ No
   During relaxation □ Yes □ No

β) Describe the position which usually alleviates your neck pain.

____________________________________________________________________

γ) Describe the position which usually deteriorates your neck pain.

____________________________________________________________________

345
F. PAIN DETERIORATION/IMPROVEMENT

The last days my neck pain has been:

☐ Improved    ☐ Worsened    ☐ The same

G. 24-HOUR PAIN BEHAVIOUR

My pain...

...awake me during night ☐ Yes ☐ No
...does not leave me to sleep ☐ Yes ☐ No
...is worst during morning ☐ Yes ☐ No
...is worst during night ☐ Yes ☐ No

H. ACCOMPANYING SYMPTOMS

Beside pain, do you have any of the following symptoms (Mark on the body chart)?

<table>
<thead>
<tr>
<th>Symptom</th>
<th>☐ Yes</th>
<th>☐ No</th>
</tr>
</thead>
<tbody>
<tr>
<td>Weakness</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Stiffness</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Numbness</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hyposensitivity</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Spasm</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Dizziness</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Tinnitus</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Vertigo</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Headache</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Migraine</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cervicogenic headache</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Tension-type headache</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Please complete the following questions about your physical activity:

1. Which is your main occupation?.........................................................1-3-5

2. At work I sit  
   Never / Seldom / Sometimes / Often / Always.................................1-2-3-4-5

3. At work I stand  
   Never / Seldom / Sometimes / Often / Always.................................1-2-3-4-5

4. At work I walk  
   Never / Seldom / Sometimes / Often / Always.................................1-2-3-4-5

5. At work I lift heavy loads  
   Never / Seldom / Sometimes / Often / Always.................................1-2-3-4-5

6. After working I am tired  
   Very often / Often / Sometimes / Seldom / Never .........................5-4-3-2-1

7. At work I sweat  
   Very Often / Often / Sometimes / Seldom / Never .........................5-4-3-2-1

8. In comparison of others of my own age I think my work is physically  
   Much heavier / Heavier / As heavy / Lighter / Much lighter ..............5-4-3-2-1

9. Do you play sports?  
   Yes / No

   If Yes:  
   -What sport do you play more frequently?.................................
     Intensity:  0.76 (low) /  1.26 (medium) /  1.76 (high)

   -How many hours do you play a week?  
     <1 hour / 1-2 hours / 2-3 hours / 3-4 hours / >4 hours ......0.5/1.5/2.5/3.5/4.5

   -How many months do you play in a year?  
     <1 months / 1-3 months / 4-6 months / 7-9 months / >9 months  
       0.04 / 0.17 / 0.42 / 0.67 / 0.92
Do you play a second sport?

Yes / No

If Yes:
- What sport do you play more frequently? ............................................
  Intensity: 0.76 (low) / 1.26 (medium) / 1.76 (high)

- How many hours do you play a week?
  <1 hour / 1-2 hours / 2-3 hours / 3-4 hours / >4 hours.......0.5/1.5/2.5/3.5/4.5

- How many months do you play in a year?
  <1 months / 1-3 months / 4-6 months / 7-9 months / >9 months

  0.04 / 0.17 / 0.42 / 0.67 / 0.92

10. In comparison with others of my own age I think my physical activity during leisure time is
  Much more / More / The same / Less / Much less..............................5-4-3-2-1

11. During leisure time I sweat
  Very often / Often / Sometimes / Seldom / Never.............................5-4-3-2-1

12. During leisure time I play sport
  Never / Seldom / Sometimes / Often / Very often.........................1-2-3-4-5

13. During leisure time I watch television
  Never / Seldom / Sometimes / Often / Very often.............................1-2-3-4-5

14. During leisure time I walk
  Never / Seldom / Sometimes / Often / Very often.............................1-2-3-4-5

15. During leisure time I cycle
  Never / Seldom / Sometimes / Often / Very often.............................1-2-3-4-5

16. How many minutes do you walk and/or cycle per day to and from work, school and shopping?
  <5 minutes / 5-15 minutes / 15-30 minutes / 30-45 minutes / >45 minutes

  ........................................................................................................1-2-3-4-5
Appendix IX  

**Neck Disability Index**  
Vernon and Mior (1991)

This questionnaire has been designed to give the doctor information as to how your neck pain has affected your ability to manage in everyday life. Please answer every section and mark in each section only ONE box which applies to you. We realize you may consider that two of the statements in any one section relate to you, but just mark the box which most closely describes your problem.

**SECTION 1 – PAIN INTENSITY**
- □ I have no pain at the moment.
- □ The pain is very mild at the moment.
- □ The pain is moderate at the moment.
- □ The pain is fairly severe at the moment.
- □ The pain is very severe at the moment.
- □ The pain is the worst imaginable at the moment.

**SECTION 2 - PERSONAL CARE (Washing, Dressing, etc.)**
- □ I can look after myself normally without causing extra pain.
- □ I can look after myself normally but it causes extra pain.
- □ It is painful to look after myself and I am slow and careful.
- □ I need some help but manage most of my personal care.
- □ I need help every day in most aspects of self care.
- □ I do not get dressed, I wash with difficulty and stay in bed.

**SECTION 3 - LIFTING**
- □ I can lift heavy weights without extra pain.
- □ I can lift heavy weights but it gives extra pain.
- □ Pain prevents me from lifting heavy weights off the floor, but I can manage if they are conveniently positioned, for example on a table.
- □ Pain prevents me from lifting heavy weights, but I can manage light to medium weights if they are conveniently positioned.
- □ I can lift very light weights.
- □ I cannot lift or carry anything at all.

**SECTION 4 - READING**
- □ I can read as much as I want to with no pain in my neck.
- □ I can read as much as I want to with slight pain in my neck.
- □ I can read as much as I want with moderate pain in my neck.
- □ I can’t read as much as I want because of moderate pain in my neck.
- □ I can hardly read at all because of severe pain in my neck.
- □ I cannot read at all.
SECTION 5 - HEADACHES
☐ I have no headaches at all.
☐ I have slight headaches which come infrequently.
☐ I have moderate headaches which come infrequently.
☐ I have moderate headaches which come frequently.
☐ I have severe headaches which come frequently.
☐ I have headaches almost all the time.

SECTION 6 - CONCENTRATION
☐ I can concentrate fully when I want to with no difficulty.
☐ I can concentrate fully when I want to with slight difficulty.
☐ I have a fair degree of difficulty in concentrating when I want to.
☐ I have a lot of difficulty in concentrating when I want to.
☐ I have a great deal of difficulty in concentrating when I want to.
☐ I cannot concentrate at all.

SECTION 7 - WORK
☐ I can do as much work as I want to.
☐ I can only do my usual work, but no more.
☐ I can do most of my usual work, but no more.
☐ I cannot do my usual work.
☐ I can hardly do any work at all.
☐ I can’t do any work at all.

SECTION 8 - DRIVING
☐ I can drive my car without any neck pain.
☐ I can drive my car as long as I want with slight pain in my neck.
☐ I can drive my car as long as I want with moderate pain in my neck.
☐ I can’t drive my car as long as I want with because of moderate pain in my neck.
☐ I can hardly drive at all because of severe pain in my neck.
☐ I can’t drive my car at all.

SECTION 9 - SLEEPING
☐ I have no trouble sleeping.
☐ My sleep is slightly disturbed (less than 1 hour sleepless).
☐ My sleep is mildly disturbed (1-2 hours sleepless).
☐ My sleep is moderately disturbed (2-3 hours sleepless).
☐ My sleep is greatly disturbed (3-5 hours sleepless).
☐ My sleep is completely disturbed (5-7 hours sleepless).

SECTION 10 - RECREATION
☐ I am able to engage in all my recreation activities with no neck pain at all.
☐ I am able to engage in all my recreation activities, with some pain in my neck.
☐ I am able to engage in most, but not all of my usual recreation activities because of pain in my neck.
☐ I am able to engage in few of my usual recreation activities because of pain in my neck.
☐ I can hardly do any recreation activities because of pain in my neck.
☐ I can’t do any recreation activities at all.
### Hospital Anxiety and Depression Scale
(Zigmond and Snaith, 1983)

Please read the following questions and mark the box which more appropriately describes how you feel the last week.

<table>
<thead>
<tr>
<th>Question</th>
<th>Options</th>
<th>Score</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>I feel tense or ‘wound up’:</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Most of the time</td>
<td></td>
<td>3</td>
</tr>
<tr>
<td>A lot of the time</td>
<td></td>
<td>2</td>
</tr>
<tr>
<td>Occasionally</td>
<td></td>
<td>1</td>
</tr>
<tr>
<td>Not at all</td>
<td></td>
<td>0</td>
</tr>
<tr>
<td><strong>I feel as if I am slowed down:</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Nearly all the time</td>
<td></td>
<td>3</td>
</tr>
<tr>
<td>Very often</td>
<td></td>
<td>2</td>
</tr>
<tr>
<td>Sometimes</td>
<td></td>
<td>1</td>
</tr>
<tr>
<td>Not at all</td>
<td></td>
<td>0</td>
</tr>
<tr>
<td><strong>I still enjoy the things I used to enjoy:</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Definitely as much</td>
<td></td>
<td>0</td>
</tr>
<tr>
<td>Not quite so much</td>
<td></td>
<td>1</td>
</tr>
<tr>
<td>Only a little</td>
<td></td>
<td>2</td>
</tr>
<tr>
<td>Hardly at all</td>
<td></td>
<td>3</td>
</tr>
<tr>
<td><strong>I get a sort of frightened feeling like ‘butterflies’ in the stomach:</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Very definitely and quite badly</td>
<td></td>
<td>3</td>
</tr>
<tr>
<td>Yes, but not too badly</td>
<td></td>
<td>2</td>
</tr>
<tr>
<td>A little, but it doesn’t worry me</td>
<td></td>
<td>1</td>
</tr>
<tr>
<td>Not at all</td>
<td></td>
<td>0</td>
</tr>
<tr>
<td><strong>I get a sort of frightened feeling as if something awful is about to happen:</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Very definitely and quite badly</td>
<td></td>
<td>3</td>
</tr>
<tr>
<td>Yes, but not too badly</td>
<td></td>
<td>2</td>
</tr>
<tr>
<td>A little, but it doesn’t worry me</td>
<td></td>
<td>1</td>
</tr>
<tr>
<td>Not at all</td>
<td></td>
<td>0</td>
</tr>
<tr>
<td><strong>I can laugh and see the funny side of things:</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>As much as I always could</td>
<td></td>
<td>0</td>
</tr>
<tr>
<td>Not quite so much now</td>
<td></td>
<td>1</td>
</tr>
<tr>
<td>Definitely not so much now</td>
<td></td>
<td>2</td>
</tr>
<tr>
<td>Not at all</td>
<td></td>
<td>3</td>
</tr>
<tr>
<td><strong>I have lost interest in my appearance:</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Definitely</td>
<td></td>
<td>3</td>
</tr>
<tr>
<td>I don’t take as much care as I should</td>
<td></td>
<td>2</td>
</tr>
<tr>
<td>I may not take quite as much care</td>
<td></td>
<td>1</td>
</tr>
<tr>
<td>I take just as much care as ever</td>
<td></td>
<td>0</td>
</tr>
<tr>
<td><strong>Worrying thoughts go through my mind:</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>A great deal of the time</td>
<td></td>
<td>3</td>
</tr>
<tr>
<td>A lot of the time</td>
<td></td>
<td>2</td>
</tr>
<tr>
<td>From time to time, but not too often</td>
<td></td>
<td>1</td>
</tr>
<tr>
<td>Only occasionally</td>
<td></td>
<td>0</td>
</tr>
<tr>
<td><strong>I look forward with enjoyment to things:</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>As much as I ever did</td>
<td></td>
<td>0</td>
</tr>
<tr>
<td>Rather less than I used to</td>
<td></td>
<td>1</td>
</tr>
<tr>
<td>Definitely less than I used to</td>
<td></td>
<td>2</td>
</tr>
<tr>
<td>Hardly at all</td>
<td></td>
<td>3</td>
</tr>
<tr>
<td><strong>I feel cheerful</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Not at all</td>
<td></td>
<td>3</td>
</tr>
<tr>
<td>Not often</td>
<td></td>
<td>2</td>
</tr>
<tr>
<td>Sometimes</td>
<td></td>
<td>1</td>
</tr>
<tr>
<td>Most of the time</td>
<td></td>
<td>0</td>
</tr>
<tr>
<td><strong>I get sudden feelings of panic:</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Very often</td>
<td></td>
<td>3</td>
</tr>
<tr>
<td>Quite often</td>
<td></td>
<td>2</td>
</tr>
<tr>
<td>Not very often</td>
<td></td>
<td>1</td>
</tr>
<tr>
<td>Not at all</td>
<td></td>
<td>0</td>
</tr>
<tr>
<td><strong>I feel restless as I have to be on the move:</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Very much indeed</td>
<td></td>
<td>3</td>
</tr>
<tr>
<td>Quite a lot</td>
<td></td>
<td>2</td>
</tr>
<tr>
<td>Not very much</td>
<td></td>
<td>1</td>
</tr>
<tr>
<td>Not at all</td>
<td></td>
<td>0</td>
</tr>
<tr>
<td><strong>I can sit at ease and feel relaxed:</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Definitely</td>
<td></td>
<td>0</td>
</tr>
<tr>
<td>Usually</td>
<td></td>
<td>1</td>
</tr>
<tr>
<td>Not often</td>
<td></td>
<td>2</td>
</tr>
<tr>
<td>Not at all</td>
<td></td>
<td>3</td>
</tr>
<tr>
<td><strong>I can enjoy a good book or radio or TV program:</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Often</td>
<td></td>
<td>0</td>
</tr>
<tr>
<td>Sometimes</td>
<td></td>
<td>1</td>
</tr>
<tr>
<td>Not often</td>
<td></td>
<td>2</td>
</tr>
<tr>
<td>Very seldom</td>
<td></td>
<td>3</td>
</tr>
</tbody>
</table>
Appendix XI  Tampa Scale for Kinesiophobia  
(Miller et al, 1991)

Below, there is a list of phrases which have been used by some patients in order to describe how they feel about their disease. Please mark at which point you agree or disagree with each statement having in your mind your own condition.

1 = strongly disagree  
2 = disagree  
3 = agree  
4 = strongly agree

<table>
<thead>
<tr>
<th>Statement</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. I’m afraid that I might injury myself if I exercise</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td>2. If I were to try to overcome it, my pain would increase</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td>3. My body is telling me I have something dangerously wrong</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td>4. My pain would probably be relieved if I were to exercise</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td>5. People aren’t taking my medical condition seriously enough</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td>6. My accident has put my body at risk for the rest of my life</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td>7. Pain always means I have injured my body</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td>8. Just because something aggravates my pain does not mean it is dangerous</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td>9. I am afraid that I might injure myself accidentally</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td>10. Simply being careful that I do not make any unnecessary movements is</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td>the safest thing I can do to prevent my pain from worsening</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td>11. I wouldn’t have this much pain if there weren’t something potentially</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td>dangerous going on in my body</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td>12. Although my condition is painful, I would be better off if I were</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td>physically active</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td>13. Pain lets me know when to stop exercising so that I don’t injure myself</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td>14. It’s really not safe for a person with a condition like mine to be</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td>physically active</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td>15. I can’t do all the things normal people do because it’s too easy for</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td>me to get injured</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td>16. Even though something is causing me a lot of pain, I don’t think it’s</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td>actually dangerous</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td>17. No one should have to exercise when he/she is in pain</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
</tr>
</tbody>
</table>
Appendix XII  

**Pain Catastrophizing Scale**


Everyone experiences painful situations at some point in their lives. Such experiences may include headaches, tooth pain, joint or muscle pain. People are often exposed to situations that may cause pain such as illness, injury, dental procedures or surgery.

INSTRUCTIONS: We are interested in the types of thoughts and feelings that you have when you are in pain. Listed below are thirteen statements describing different thoughts and feelings that may be associated with pain. Using the following scale, please indicate the degree to which you have these thoughts and feelings when you are experiencing pain.

<table>
<thead>
<tr>
<th>RATING</th>
<th>0</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
</tr>
</thead>
<tbody>
<tr>
<td>MEANING</td>
<td>Not at all</td>
<td>To a slight degree</td>
<td>To a moderate degree</td>
<td>To a great degree</td>
<td>All the time</td>
</tr>
</tbody>
</table>

When I’m in pain…

<table>
<thead>
<tr>
<th>Number</th>
<th>Statement</th>
<th>Rating</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>I worry all the time about whether the pain will end</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>I feel I can’t go on</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>It’s terrible and I think it’s never going to get any better</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>It’s awful and I feel that it overwhelms me</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>I feel I can’t stand it anymore</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>I become afraid that the pain will get worse</td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>I keep thinking of other painful events</td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>I anxiously want the pain to go away</td>
<td></td>
</tr>
<tr>
<td>9</td>
<td>I can’t seem to keep it out of my mind</td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>I keep thinking about how much it hurts</td>
<td></td>
</tr>
<tr>
<td>11</td>
<td>I keep thinking about how badly I want the pain to stop</td>
<td></td>
</tr>
<tr>
<td>12</td>
<td>There’s nothing I can do to reduce the intensity of the pain</td>
<td></td>
</tr>
<tr>
<td>13</td>
<td>I wonder whether something serious may happen</td>
<td></td>
</tr>
</tbody>
</table>
Appendix XIII

Results of the first pilot study - Proprioception

Zebris Test-Retest Reliability using the Constant Error as the Proprioception Index

Table XIIIa: Test-Retest reliability of Zebris for “Natural Head Position to Flexion Target” test using the constant error as the index of proprioception. Each line describes the Zebris reliability after a specific number of repetitions.

<table>
<thead>
<tr>
<th>Test-Retest Reliability for “Natural Head Position to Flexion Target” test</th>
<th>Grand Mean</th>
<th>ICC (95%CI)</th>
<th>SEM</th>
<th>SDD (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Trial 1</td>
<td>1.85</td>
<td>0.5 (0.08, 0.76)</td>
<td>2.92</td>
<td>438.16</td>
</tr>
<tr>
<td>Trial 1-2</td>
<td>2.62</td>
<td>0.57 (0.17, 0.8)</td>
<td>2.94</td>
<td>310.98</td>
</tr>
<tr>
<td>Trial 1-3</td>
<td>3.41</td>
<td>0.53 (0.12, 0.78)</td>
<td>3.32</td>
<td>270.17</td>
</tr>
<tr>
<td>Trial 1-4</td>
<td>4.13</td>
<td>0.6 (0.22, 0.82)</td>
<td>3.19</td>
<td>213.78</td>
</tr>
<tr>
<td>Trial 1-5</td>
<td>4.63</td>
<td>0.59 (0.21, 0.82)</td>
<td>3.37</td>
<td>201.42</td>
</tr>
<tr>
<td>Trial 1-6</td>
<td>5.02</td>
<td>0.62 (0.25, 0.83)</td>
<td>3.31</td>
<td>182.96</td>
</tr>
<tr>
<td>Trial 1-7</td>
<td>5.43</td>
<td>0.62 (0.25, 0.83)</td>
<td>3.42</td>
<td>174.54</td>
</tr>
<tr>
<td>Trial 1-8</td>
<td>5.82</td>
<td>0.63 (0.28, 0.84)</td>
<td>3.45</td>
<td>164.31</td>
</tr>
<tr>
<td>Trial 1-9</td>
<td>6.12</td>
<td>0.65 (0.29, 0.84)</td>
<td>3.51</td>
<td>159.17</td>
</tr>
<tr>
<td>Trial 1-10</td>
<td>6.39</td>
<td>0.66 (0.32, 0.85)</td>
<td>3.54</td>
<td>153.71</td>
</tr>
</tbody>
</table>

ICC: Intraclass Correlation Coefficient, 95%CI: 95% Confidence Intervals, SEM: Standard Error of Measurement, SDD (%): Smallest Detectable Difference (percentage of grand mean).

Table XIIIb: Test-Retest reliability of Zebris for “Flexion to Natural Head Position” test using the constant error as the index of proprioception. Each line describes the Zebris reliability after a specific number of repetitions.

<table>
<thead>
<tr>
<th>Test-Retest Reliability for “Flexion to Natural Head Position” test</th>
<th>Grand Mean</th>
<th>ICC (95%CI)</th>
<th>SEM</th>
<th>SDD (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Trial 1</td>
<td>2.84</td>
<td>0.66 (0.31, 0.85)</td>
<td>3.34</td>
<td>241.36</td>
</tr>
<tr>
<td>Trial 1-2</td>
<td>2.56</td>
<td>0.74 (0.45, 0.89)</td>
<td>3.06</td>
<td>331</td>
</tr>
<tr>
<td>Trial 1-3</td>
<td>2.49</td>
<td>0.74 (0.45, 0.89)</td>
<td>2.79</td>
<td>310.48</td>
</tr>
<tr>
<td>Trial 1-4</td>
<td>2.72</td>
<td>0.69 (0.37, 0.87)</td>
<td>2.91</td>
<td>297.19</td>
</tr>
<tr>
<td>Trial 1-5</td>
<td>2.93</td>
<td>0.72 (0.42, 0.88)</td>
<td>2.78</td>
<td>263.33</td>
</tr>
<tr>
<td>Trial 1-6</td>
<td>3.21</td>
<td>0.72 (0.41, 0.88)</td>
<td>2.71</td>
<td>233.37</td>
</tr>
<tr>
<td>Trial 1-7</td>
<td>3.43</td>
<td>0.69 (0.37, 0.87)</td>
<td>2.82</td>
<td>228.04</td>
</tr>
<tr>
<td>Trial 1-8</td>
<td>3.54</td>
<td>0.68 (0.34, 0.86)</td>
<td>2.88</td>
<td>225.32</td>
</tr>
<tr>
<td>Trial 1-9</td>
<td>3.77</td>
<td>0.7 (0.38, 0.87)</td>
<td>2.77</td>
<td>203.64</td>
</tr>
<tr>
<td>Trial 1-10</td>
<td>3.94</td>
<td>0.69 (0.36, 0.86)</td>
<td>2.83</td>
<td>198.82</td>
</tr>
</tbody>
</table>

ICC: Intraclass Correlation Coefficient, 95%CI: 95% Confidence Intervals, SEM: Standard Error of Measurement, SDD (%): Smallest Detectable Difference (percentage of grand mean).
Table XIIIc: Test-Retest reliability of Zebris for “Natural Head Position to Extension Target” test using the constant error as the index of proprioception. Each line describes the Zebris reliability after a specific number of repetitions.

<table>
<thead>
<tr>
<th>Test-Retest Reliability for “Natural Head Position to Extension Target” test</th>
<th>Grand Mean</th>
<th>ICC (95%CI)</th>
<th>SEM</th>
<th>SDD (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Trial 1</td>
<td>1.82</td>
<td>0.23 (-0.23, 0.6)</td>
<td>4.43</td>
<td>676.12</td>
</tr>
<tr>
<td>Trial 1-2</td>
<td>2.53</td>
<td>0.23 (-0.23, 0.6)</td>
<td>4.55</td>
<td>498.25</td>
</tr>
<tr>
<td>Trial 1-3</td>
<td>3.02</td>
<td>0.39 (-0.05, 0.71)</td>
<td>4.12</td>
<td>378.03</td>
</tr>
<tr>
<td>Trial 1-4</td>
<td>3.49</td>
<td>0.46 (0.04, 0.75)</td>
<td>3.98</td>
<td>315.81</td>
</tr>
<tr>
<td>Trial 1-5</td>
<td>3.75</td>
<td>0.48 (0.06, 0.76)</td>
<td>4.19</td>
<td>310.11</td>
</tr>
<tr>
<td>Trial 1-6</td>
<td>4.18</td>
<td>0.51 (0.1, 0.77)</td>
<td>4.19</td>
<td>277.92</td>
</tr>
<tr>
<td>Trial 1-7</td>
<td>4.42</td>
<td>0.55 (0.16, 0.8)</td>
<td>4.03</td>
<td>252.2</td>
</tr>
<tr>
<td>Trial 1-8</td>
<td>4.66</td>
<td>0.56 (0.17, 0.8)</td>
<td>4.03</td>
<td>240.09</td>
</tr>
<tr>
<td>Trial 1-9</td>
<td>4.89</td>
<td>0.54 (0.15, 0.79)</td>
<td>4.14</td>
<td>234.67</td>
</tr>
<tr>
<td>Trial 1-10</td>
<td>5.08</td>
<td>0.52 (0.12, 0.78)</td>
<td>4.24</td>
<td>231.38</td>
</tr>
</tbody>
</table>

ICC: Intraclass Correlation Coefficient, 95%CI: 95% Confidence Intervals, SEM: Standard Error of Measurement, SDD (%): Smallest Detectable Difference (percentage of grand mean).

Table XIIIId: Test-Retest reliability of Zebris for “Extension to Natural Head Position” test using the constant error as the index of proprioception. Each line describes the Zebris reliability after a specific number of repetitions.

<table>
<thead>
<tr>
<th>Test-Retest Reliability for “Extension to Natural Head Position” test</th>
<th>Grand Mean</th>
<th>ICC (95%CI)</th>
<th>SEM</th>
<th>SDD (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Trial 1</td>
<td>2.65</td>
<td>0.81 (0.57, 0.92)</td>
<td>2.94</td>
<td>307.33</td>
</tr>
<tr>
<td>Trial 1-2</td>
<td>1.77</td>
<td>0.86 (0.68, 0.94)</td>
<td>2.3</td>
<td>363.71</td>
</tr>
<tr>
<td>Trial 1-3</td>
<td>1.58</td>
<td>0.88 (0.72, 0.95)</td>
<td>2.04</td>
<td>359.64</td>
</tr>
<tr>
<td>Trial 1-4</td>
<td>1.58</td>
<td>0.92 (0.8, 0.97)</td>
<td>1.73</td>
<td>302.16</td>
</tr>
<tr>
<td>Trial 1-5</td>
<td>1.66</td>
<td>0.93 (0.83, 0.97)</td>
<td>1.61</td>
<td>268.63</td>
</tr>
<tr>
<td>Trial 1-6</td>
<td>1.69</td>
<td>0.93 (0.84, 0.97)</td>
<td>1.55</td>
<td>254.24</td>
</tr>
<tr>
<td>Trial 1-7</td>
<td>1.88</td>
<td>0.95 (0.87, 0.98)</td>
<td>1.44</td>
<td>212.36</td>
</tr>
<tr>
<td>Trial 1-8</td>
<td>2.03</td>
<td>0.94 (0.86, 0.98)</td>
<td>1.49</td>
<td>203.65</td>
</tr>
<tr>
<td>Trial 1-9</td>
<td>2.12</td>
<td>0.95 (0.87, 0.98)</td>
<td>1.45</td>
<td>189.13</td>
</tr>
<tr>
<td>Trial 1-10</td>
<td>2.15</td>
<td>0.94 (0.86, 0.98)</td>
<td>1.52</td>
<td>195.92</td>
</tr>
</tbody>
</table>

ICC: Intraclass Correlation Coefficient, 95%CI: 95% Confidence Intervals, SEM: Standard Error of Measurement, SDD (%): Smallest Detectable Difference (percentage of grand mean).
Zebris Test-Retest Reliability using the **Absolute Error** as the Proprioception Index

Table XIIIe: Test-Retest reliability of Zebris for “Natural Head Position to Flexion Target” test using the absolute error as the index of proprioception. Each line describes the Zebris reliability after a specific number of repetitions.

<table>
<thead>
<tr>
<th>Test-Retest Reliability for “Natural Head Position to Flexion Target” test</th>
<th>Grand Mean</th>
<th>ICC (95% CI)</th>
<th>SEM</th>
<th>SDD (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Trial 1</td>
<td>3.75</td>
<td>0.09 (-0.36, 0.5)</td>
<td>2.61</td>
<td>193.25</td>
</tr>
<tr>
<td>Trial 1-2</td>
<td>4.26</td>
<td>0.51 (0.09, 0.77)</td>
<td>2.05</td>
<td>133.33</td>
</tr>
<tr>
<td>Trial 1-3</td>
<td>4.86</td>
<td>0.56 (0.16, 0.8)</td>
<td>2.25</td>
<td>127.83</td>
</tr>
<tr>
<td>Trial 1-4</td>
<td>5.08</td>
<td>0.62 (0.25, 0.83)</td>
<td>2.31</td>
<td>118.95</td>
</tr>
<tr>
<td>Trial 1-5</td>
<td>5.83</td>
<td>0.59 (0.22, 0.82)</td>
<td>2.53</td>
<td>120.16</td>
</tr>
<tr>
<td>Trial 1-6</td>
<td>6.17</td>
<td>0.6 (0.23, 0.82)</td>
<td>2.54</td>
<td>113.96</td>
</tr>
<tr>
<td>Trial 1-7</td>
<td>6.53</td>
<td>0.62 (0.26, 0.83)</td>
<td>2.60</td>
<td>110.34</td>
</tr>
<tr>
<td>Trial 1-8</td>
<td>6.90</td>
<td>0.64 (0.28, 0.84)</td>
<td>2.62</td>
<td>105.33</td>
</tr>
<tr>
<td>Trial 1-9</td>
<td>7.17</td>
<td>0.64 (0.29, 0.84)</td>
<td>2.74</td>
<td>105.98</td>
</tr>
<tr>
<td>Trial 1-10</td>
<td>7.43</td>
<td>0.66 (0.31, 0.85)</td>
<td>2.79</td>
<td>104.05</td>
</tr>
</tbody>
</table>

ICC: Intraclass Correlation Coefficient, 95%CI: 95% Confidence Intervals, SEM: Standard Error of Measurement, SDD (%): Smallest Detectable Difference (percentage of grand mean).

Table XIIIIf: Test-Retest reliability of Zebris for “Flexion to Natural Head Position” test using the absolute error as the index of proprioception. Each line describes the Zebris reliability after a specific number of repetitions.

<table>
<thead>
<tr>
<th>Test-Retest Reliability for “Flexion to Natural Head Position” test</th>
<th>Grand Mean</th>
<th>ICC (95% CI)</th>
<th>SEM</th>
<th>SDD (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Trial 1</td>
<td>4.60</td>
<td>0.59 (0.22, 0.82)</td>
<td>2.73</td>
<td>164.64</td>
</tr>
<tr>
<td>Trial 1-2</td>
<td>4.78</td>
<td>0.68 (0.36, 0.86)</td>
<td>2.43</td>
<td>140.76</td>
</tr>
<tr>
<td>Trial 1-3</td>
<td>4.50</td>
<td>0.67 (0.33, 0.85)</td>
<td>2.29</td>
<td>141.03</td>
</tr>
<tr>
<td>Trial 1-4</td>
<td>4.57</td>
<td>0.71 (0.4, 0.87)</td>
<td>2.00</td>
<td>121.01</td>
</tr>
<tr>
<td>Trial 1-5</td>
<td>4.70</td>
<td>0.78 (0.52, 0.91)</td>
<td>1.78</td>
<td>104.83</td>
</tr>
<tr>
<td>Trial 1-6</td>
<td>4.83</td>
<td>0.78 (0.52, 0.91)</td>
<td>1.77</td>
<td>101.66</td>
</tr>
<tr>
<td>Trial 1-7</td>
<td>4.91</td>
<td>0.76 (0.48, 0.9)</td>
<td>1.87</td>
<td>105.47</td>
</tr>
<tr>
<td>Trial 1-8</td>
<td>4.97</td>
<td>0.74 (0.45, 0.89)</td>
<td>1.93</td>
<td>107.89</td>
</tr>
<tr>
<td>Trial 1-9</td>
<td>5.11</td>
<td>0.75 (0.48, 0.89)</td>
<td>1.89</td>
<td>102.73</td>
</tr>
<tr>
<td>Trial 1-10</td>
<td>5.21</td>
<td>0.75 (0.47, 0.89)</td>
<td>1.93</td>
<td>102.85</td>
</tr>
</tbody>
</table>

ICC: Intraclass Correlation Coefficient, 95%CI: 95% Confidence Intervals, SEM: Standard Error of Measurement, SDD (%): Smallest Detectable Difference (percentage of grand mean).
Table XIIIg: Test-Retest reliability of Zebris for “Natural Head Position to Extension Target” test using the absolute error as the index of proprioception. Each line describes the Zebris reliability after a specific number of repetitions.

<table>
<thead>
<tr>
<th>Trial 1- Retest Reliability for “Natural Head Position to Extension Target” test</th>
<th>Grand Mean</th>
<th>ICC (95%CI)</th>
<th>SEM</th>
<th>SDD (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Trial 1</td>
<td>4.31</td>
<td>0.06 (-0.38, 0.48)</td>
<td>2.94</td>
<td>188.97</td>
</tr>
<tr>
<td>Trial 1-2</td>
<td>4.8</td>
<td>0.32 (-0.13, 0.66)</td>
<td>2.59</td>
<td>149.8</td>
</tr>
<tr>
<td>Trial 1-3</td>
<td>5.21</td>
<td>0.48 (0.06, 0.76)</td>
<td>2.3</td>
<td>122.31</td>
</tr>
<tr>
<td>Trial 1-4</td>
<td>5.46</td>
<td>0.57 (0.19, 0.81)</td>
<td>2.28</td>
<td>115.91</td>
</tr>
<tr>
<td>Trial 1-5</td>
<td>5.79</td>
<td>0.59 (0.22, 0.82)</td>
<td>2.43</td>
<td>116.3</td>
</tr>
<tr>
<td>Trial 1-6</td>
<td>6.11</td>
<td>0.59 (0.22, 0.82)</td>
<td>2.56</td>
<td>141.99</td>
</tr>
<tr>
<td>Trial 1-7</td>
<td>6.31</td>
<td>0.65 (0.3, 0.85)</td>
<td>2.4</td>
<td>105.67</td>
</tr>
<tr>
<td>Trial 1-8</td>
<td>6.49</td>
<td>0.65 (0.3, 0.84)</td>
<td>2.47</td>
<td>105.4</td>
</tr>
<tr>
<td>Trial 1-9</td>
<td>6.71</td>
<td>0.63 (0.28, 0.84)</td>
<td>2.55</td>
<td>105.62</td>
</tr>
<tr>
<td>Trial 1-10</td>
<td>6.82</td>
<td>0.62 (0.25, 0.83)</td>
<td>2.66</td>
<td>107.98</td>
</tr>
</tbody>
</table>

ICC: Intraclass Correlation Coefficient, 95%CI: 95% Confidence Intervals, SEM: Standard Error of Measurement, SDD (%): Smallest Detectable Difference (percentage of grand mean).

Table XIIIh: Test-Retest reliability of Zebris for “Extension to Natural Head Position” test using the absolute error as the index of proprioception. Each line describes the Zebris reliability after a specific number of repetitions.

<table>
<thead>
<tr>
<th>Trial 1- Retest Reliability for “Extension to Natural Head Position” test</th>
<th>Grand Mean</th>
<th>ICC (95%CI)</th>
<th>SEM</th>
<th>SDD (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Trial 1</td>
<td>5.22</td>
<td>0.77 (0.51, 0.9)</td>
<td>2.28</td>
<td>121.14</td>
</tr>
<tr>
<td>Trial 1-2</td>
<td>4.91</td>
<td>0.78 (0.52, 0.91)</td>
<td>1.94</td>
<td>109.5</td>
</tr>
<tr>
<td>Trial 1-3</td>
<td>4.72</td>
<td>0.76 (0.48, 0.9)</td>
<td>1.89</td>
<td>111.23</td>
</tr>
<tr>
<td>Trial 1-4</td>
<td>4.84</td>
<td>0.82 (0.59, 0.92)</td>
<td>1.65</td>
<td>94.26</td>
</tr>
<tr>
<td>Trial 1-5</td>
<td>4.94</td>
<td>0.85 (0.66, 0.94)</td>
<td>1.49</td>
<td>83.67</td>
</tr>
<tr>
<td>Trial 1-6</td>
<td>5.00</td>
<td>0.86 (0.69, 0.94)</td>
<td>1.42</td>
<td>78.74</td>
</tr>
<tr>
<td>Trial 1-7</td>
<td>5.09</td>
<td>0.88 (0.72, 0.95)</td>
<td>1.36</td>
<td>74.09</td>
</tr>
<tr>
<td>Trial 1-8</td>
<td>5.24</td>
<td>0.88 (0.71, 0.95)</td>
<td>1.43</td>
<td>75.79</td>
</tr>
<tr>
<td>Trial 1-9</td>
<td>5.34</td>
<td>0.9 (0.76, 0.96)</td>
<td>1.32</td>
<td>68.7</td>
</tr>
<tr>
<td>Trial 1-10</td>
<td>5.36</td>
<td>0.89 (0.74, 0.96)</td>
<td>1.37</td>
<td>70.87</td>
</tr>
</tbody>
</table>

ICC: Intraclass Correlation Coefficient, 95%CI: 95% Confidence Intervals, SEM: Standard Error of Measurement, SDD (%): Smallest Detectable Difference (percentage of grand mean).
Appendix XIV

Results of the first pilot study - Endurance

Table XIVa: Descriptives of the three trials during the endurance test of the first pilot.

<table>
<thead>
<tr>
<th></th>
<th>Mean</th>
<th>Standard Deviation</th>
</tr>
</thead>
<tbody>
<tr>
<td>1st trial (sec)</td>
<td>36.65</td>
<td>38.04</td>
</tr>
<tr>
<td>2nd trial (sec)</td>
<td>38.65</td>
<td>32.59</td>
</tr>
<tr>
<td>3rd trial (sec)</td>
<td>35.2</td>
<td>28</td>
</tr>
</tbody>
</table>

Table XIVb: Reliability of the endurance test considering all the three trials.

<table>
<thead>
<tr>
<th></th>
<th>3 trials</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Grand Mean</td>
</tr>
<tr>
<td>Endurance (sec)</td>
<td>36.83</td>
</tr>
</tbody>
</table>

ICC: Intraclass Correlation Coefficient, 95% CI: 95% Confidence Intervals, SEM: Standard Error of Measurement, SDD: Smallest Detectable Difference (percentage of grand mean).

Table XIVc: Reliability of the endurance test considering only the last two trials.

<table>
<thead>
<tr>
<th></th>
<th>Last 2 trials</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Grand Mean</td>
</tr>
<tr>
<td>Endurance (sec)</td>
<td>36.93</td>
</tr>
</tbody>
</table>

ICC: Intraclass Correlation Coefficient, 95% CI: 95% Confidence Intervals, SEM: Standard Error of Measurement, SDD: Smallest Detectable Difference (percentage of grand mean).
Appendix XV

Results of the second pilot study – Craniocervical flexion test

Table XVa: Descriptives of the Craniocervical Flexion Test.

<table>
<thead>
<tr>
<th></th>
<th>Mean</th>
<th>Standard Deviation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Endurance 1\textsuperscript{st} assessment (mmHg)</td>
<td>23.6</td>
<td>2.4</td>
</tr>
<tr>
<td>Endurance 2\textsuperscript{nd} assessment (mmHg)</td>
<td>23.7</td>
<td>2.1</td>
</tr>
</tbody>
</table>

Table XVb: Reliability of the Craniocervical Flexion Test.

<table>
<thead>
<tr>
<th></th>
<th>Grand mean</th>
<th>ICC (95% CI)</th>
<th>SEM</th>
<th>SDD (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Endurance</td>
<td>23.7</td>
<td>0.81 (0.59, 0.92)</td>
<td>0.97</td>
<td>11.34</td>
</tr>
</tbody>
</table>

ICC: Intraclass correlation coefficient, SEM: Standard Error of Measurement, SDD: Smallest Detectable Difference (percentage of grand mean), 95%CI: 95% Confidence Intervals.
### Table XVI: Differences in neck pain deficits using non-parametric statistics

This table presents the differences between the chronic neck pain and the control group in each usual neck pain deficit by using the Wilcoxon signed rank test.

<table>
<thead>
<tr>
<th>Neck pain deficit</th>
<th>$\text{Mdn}_{\text{neckpain}}$ (Range)</th>
<th>$\text{Mdn}_{\text{control}}$ (Range)</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td>Neck flexor strength</td>
<td>8.5 (25.7)</td>
<td>9.6 (26)</td>
<td>0.12</td>
</tr>
<tr>
<td>Neck extensor strength</td>
<td>13.8 (33.8)</td>
<td>17.3 (26.8)</td>
<td><strong>0.02</strong></td>
</tr>
<tr>
<td>Neck flexor/extensor strength</td>
<td>0.68 (0.62)</td>
<td>0.6 (0.65)</td>
<td>0.13</td>
</tr>
<tr>
<td>Flexion ROM</td>
<td>69.6 (53)</td>
<td>67.7 (33.8)</td>
<td>0.13</td>
</tr>
<tr>
<td>Extension ROM</td>
<td>62.4 (57.4)</td>
<td>73.4 (69.4)</td>
<td><strong>0.004</strong> **</td>
</tr>
<tr>
<td>Sagittal ROM</td>
<td>131.9 (69)</td>
<td>136.1 (80.6)</td>
<td><strong>0.002</strong> **</td>
</tr>
<tr>
<td>Right rotation ROM</td>
<td>68.6 (44.5)</td>
<td>76.9 (32)</td>
<td>&lt;<strong>0.001</strong>*</td>
</tr>
<tr>
<td>Left Rotation ROM</td>
<td>76.6 (40.8)</td>
<td>78.3 (38.6)</td>
<td><strong>0.004</strong> **</td>
</tr>
<tr>
<td>Transverse ROM</td>
<td>142.9 (81.4)</td>
<td>155.2 (55.3)</td>
<td><strong>0.001</strong>*</td>
</tr>
<tr>
<td>Right Lateral Flexion ROM</td>
<td>44 (41.1)</td>
<td>48.1 (33.5)</td>
<td><strong>0.02</strong></td>
</tr>
<tr>
<td>Left lateral flexion ROM</td>
<td>42.6 (44.1)</td>
<td>46.2 (44)</td>
<td><strong>0.009</strong> **</td>
</tr>
<tr>
<td>Frontal ROM</td>
<td>88.3 (73.7)</td>
<td>94.7 (77.5)</td>
<td><strong>0.008</strong> **</td>
</tr>
<tr>
<td>Endurance</td>
<td>22 (10)</td>
<td>24 (10)</td>
<td><strong>0.001</strong> **</td>
</tr>
<tr>
<td>Craniocervical angle</td>
<td>49.4 (31)</td>
<td>51.2 (28.7)</td>
<td>0.14</td>
</tr>
<tr>
<td>Anxiety</td>
<td>8 (18)</td>
<td>8 (18)</td>
<td>0.18</td>
</tr>
<tr>
<td>Anxiety (Class.)</td>
<td>Bord. Abn.</td>
<td>Bord. Abn.</td>
<td>0.13</td>
</tr>
<tr>
<td>Depression</td>
<td>4 (17)</td>
<td>3 (14)</td>
<td>0.22</td>
</tr>
<tr>
<td>Depression (Class.)</td>
<td>Normal</td>
<td>Normal</td>
<td>0.7</td>
</tr>
</tbody>
</table>

*p<0.05, **p<0.01, ***p<0.001, Class.: Classification, Mdn: Median, Bord. Abn.: Borderline Abnormal, p: probability.
Appendix XVII

Differences in respiratory function (non-parametric statistics)

Table XVII: Differences in respiratory function using non-parametric statistics. This table presents the differences between the chronic neck pain and the control group in each respiratory parameter by using the Wilcoxon signed rank test.

<table>
<thead>
<tr>
<th>Respiratory parameter</th>
<th>$\text{Mdn}_{\text{neckpain}}$ (Range)</th>
<th>$\text{Mdn}_{\text{control}}$ (Range)</th>
<th>$p$</th>
</tr>
</thead>
<tbody>
<tr>
<td>FEV$_1$ (lt)</td>
<td>3.3 (3.24)</td>
<td>3.42 (3.41)</td>
<td>0.04*</td>
</tr>
<tr>
<td>FVC (lt)</td>
<td>3.78 (3.66)</td>
<td>4.07 (3.81)</td>
<td>0.002**</td>
</tr>
<tr>
<td>FEV$_1$/FVC (%)</td>
<td>84.2 (22.64)</td>
<td>82.46 (27.9)</td>
<td>0.27</td>
</tr>
<tr>
<td>FEF$_{25%-75%}$ (lt/sec)</td>
<td>3.67 (4.56)</td>
<td>3.4 (4.53)</td>
<td>0.99</td>
</tr>
<tr>
<td>FEF$_{25%}$ (lt/sec)</td>
<td>5.97 (6.41)</td>
<td>6.23 (8.72)</td>
<td>0.04*</td>
</tr>
<tr>
<td>FEF$_{50%}$ (lt/sec)</td>
<td>4.1 (4.78)</td>
<td>3.71 (5.85)</td>
<td>0.97</td>
</tr>
<tr>
<td>FEF$_{75%}$ (lt/sec)</td>
<td>1.53 (3.34)</td>
<td>1.63 (2.95)</td>
<td>0.91</td>
</tr>
<tr>
<td>PEF (lt/sec)</td>
<td>6.83 (8.74)</td>
<td>7.27 (10.07)</td>
<td>0.02*</td>
</tr>
<tr>
<td>PIF (lt/sec)</td>
<td>3.76 (5.61)</td>
<td>4.54 (6.11)</td>
<td>0.01*</td>
</tr>
<tr>
<td>VC (lt)</td>
<td>3.54 (4.93)</td>
<td>3.81 (3.79)</td>
<td>0.001**</td>
</tr>
<tr>
<td>IC (lt)</td>
<td>2.29 (2.65)</td>
<td>2.38 (2.65)</td>
<td>0.07</td>
</tr>
<tr>
<td>ERV (lt)</td>
<td>1.06 (2.73)</td>
<td>1.23 (2.24)</td>
<td>0.02*</td>
</tr>
<tr>
<td>$V_T$ (lt)</td>
<td>0.75 (2.3)</td>
<td>0.85 (1.87)</td>
<td>0.33</td>
</tr>
<tr>
<td>MVV (lt/min)</td>
<td>102.4 (157.4)</td>
<td>120.8 (142.8)</td>
<td>0.004*</td>
</tr>
<tr>
<td>MIP (cmH$_2$O)</td>
<td>84 (152)</td>
<td>98 (167)</td>
<td>0.03*</td>
</tr>
<tr>
<td>MEP (cmH$_2$O)</td>
<td>101 (208)</td>
<td>117 (186)</td>
<td>0.008**</td>
</tr>
<tr>
<td>MIP/MEP</td>
<td>0.82 (1.19)</td>
<td>0.82 (0.76)</td>
<td>0.6</td>
</tr>
<tr>
<td>$P_{tc}$CO$_2$ (mmHg)</td>
<td>35 (12)</td>
<td>37 (16)</td>
<td>0.003**</td>
</tr>
</tbody>
</table>

*p<0.05, **p<0.01, Mdn: Median, p: probability, FEV$_1$: Forced Expiratory Volume in one second, FVC: Forced Vital Capacity, FEF$_{25\%-75\%}$: Forced Expiratory Flow from the 25% to 75% of forced expiration, FEF$_{25\%}$: Forced Expiratory Flow at the 25% of the forced expiration, FEF$_{50\%}$: Forced Expiratory Flow at the 50% of forced expiration, FEF$_{75\%}$: Forced Expiratory Flow at the 75% of forced expiration, PEF: Peak Expiratory Flow, PIF: Peak Inspiratory Flow, VC: Vital Capacity, IC: Inspiratory Capacity, ERV: Expiratory Reserve Volume, TV: Tidal Volume, MVV: Maximal Voluntary Ventilation, MIP: Maximal Inspiratory Pressure, MEP: Maximal Expiratory Pressure, $P_{tc}$CO$_2$: Partial pressure of arterial carbon dioxide.
Appendix XVIII

Correlations between musculoskeletal deficits and respiratory parameters for the control group

Table XVIIIa: Correlations between musculoskeletal deficits and respiratory parameters I (controls). This table presents the Pearson correlation coefficient for each correlation between the musculoskeletal deficits and pulmonary volumes and flows for the control group.

<table>
<thead>
<tr>
<th>Variables</th>
<th>FEV$_1$/FVC</th>
<th>FVC</th>
<th>PEF</th>
<th>PIF</th>
<th>FEF$_{25%-75%}$</th>
<th>VC</th>
</tr>
</thead>
<tbody>
<tr>
<td>Flexion strength</td>
<td>0.16</td>
<td></td>
<td></td>
<td></td>
<td>0.27</td>
<td>0.61***</td>
</tr>
<tr>
<td>Extension strength</td>
<td>0.15</td>
<td></td>
<td></td>
<td></td>
<td>0.53***</td>
<td>0.58***</td>
</tr>
<tr>
<td>Endurance</td>
<td>0.03</td>
<td>-0.05</td>
<td>-0.12</td>
<td>0.17</td>
<td>-0.13</td>
<td>-0.05</td>
</tr>
<tr>
<td>Sagittal ROM</td>
<td>-0.03</td>
<td>-0.04</td>
<td>-0.21</td>
<td>0</td>
<td>-0.06</td>
<td>-0.08</td>
</tr>
<tr>
<td>Transverse ROM</td>
<td>0.09</td>
<td>-0.02</td>
<td>-0.1</td>
<td>-0.09</td>
<td>-0.05</td>
<td>0</td>
</tr>
<tr>
<td>FHP</td>
<td>-0.27</td>
<td>-0.04</td>
<td>-0.09</td>
<td>0.17</td>
<td>-0.25</td>
<td>-0.09</td>
</tr>
<tr>
<td>Anxiety</td>
<td>-0.27</td>
<td>-0.12</td>
<td>-0.23</td>
<td>-0.2</td>
<td>-0.16</td>
<td>-0.26</td>
</tr>
<tr>
<td>Depression</td>
<td>-0.15</td>
<td>-0.09</td>
<td>0.14</td>
<td>0.04</td>
<td>0.03</td>
<td>-0.14</td>
</tr>
</tbody>
</table>

*p<0.05, **p<0.01, ***p<0.001, ROM: Range of Movement, FHP: Forward head posture, FEV$_1$: Forced Expiratory Volume in one second, FVC: Forced Vital Capacity, PEF: Peak Expiratory Flow, PIF: Peak Inspiratory Flow, FEF$_{25\%-75\%}$: Forced Expiratory Flow from the 25% to the 75% of the forced expiration, VC: Vital

Table XVIIIb: Correlations between musculoskeletal deficits and respiratory parameters II (controls). This table presents the Pearson correlation coefficient for each correlation between the chronic neck pain deficits and Maximal Voluntary Ventilation (MVV), Maximal Inspiratory (MIP) and Expiratory Pressure (MEP) and partial pressure of arterial carbon dioxide (P$_{a}$CO$_2$) for the control group.

<table>
<thead>
<tr>
<th>Variables</th>
<th>MVV</th>
<th>MIP</th>
<th>MEP</th>
<th>P$_{a}$CO$_2$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Flexion strength</td>
<td>0.7***</td>
<td>0.8***</td>
<td>0.81***</td>
<td>0.01</td>
</tr>
<tr>
<td>Extension strength</td>
<td>0.71***</td>
<td>0.67***</td>
<td>0.75***</td>
<td>0.14</td>
</tr>
<tr>
<td>Endurance</td>
<td>0.07</td>
<td>0.23</td>
<td>0.01</td>
<td>0.1</td>
</tr>
<tr>
<td>Sagittal ROM</td>
<td>-0.1</td>
<td>-0.1</td>
<td>-0.3*</td>
<td>0.2</td>
</tr>
<tr>
<td>Transverse ROM</td>
<td>-0.11</td>
<td>-0.11</td>
<td>-0.18</td>
<td>0.21</td>
</tr>
<tr>
<td>FHP</td>
<td>-0.04</td>
<td>-0.02</td>
<td>-0.24</td>
<td>0.33*</td>
</tr>
<tr>
<td>Anxiety</td>
<td>-0.21</td>
<td>-0.24</td>
<td>-0.22</td>
<td>-0.11</td>
</tr>
<tr>
<td>Depression</td>
<td>0.07</td>
<td>0.08</td>
<td>0.18</td>
<td>-0.14</td>
</tr>
</tbody>
</table>

*p<0.05, **p<0.01, ***p<0.001, ROM: Range of Movement, FHP: Forward Head Posture.
Appendix XIX
Correlations between chronic neck pain deficits and respiratory parameters by using non-parametric statistics

Table XIXa: Correlations between chronic neck pain deficits and respiratory parameters I (non-parametric). This table presents the Spearman correlation coefficient for each correlation between the musculoskeletal deficits and pulmonary volumes and flows for the chronic neck pain group.

<table>
<thead>
<tr>
<th>Variables</th>
<th>FEV₁/FVC</th>
<th>FVC</th>
<th>PEF</th>
<th>PIF</th>
<th>FEF₂₅%-₇₅%</th>
<th>VC</th>
</tr>
</thead>
<tbody>
<tr>
<td>Flexion strength</td>
<td>-0.31*</td>
<td>0.58***</td>
<td>0.54***</td>
<td>0.23</td>
<td>-0.07</td>
<td>0.61***</td>
</tr>
<tr>
<td>Extension strength</td>
<td>-0.34*</td>
<td>0.55***</td>
<td>0.57***</td>
<td>0.36*</td>
<td>-0.09</td>
<td>0.62***</td>
</tr>
<tr>
<td>Endurance</td>
<td>0.01</td>
<td>0.16</td>
<td>0.3*</td>
<td>0.37*</td>
<td>0.1</td>
<td>0.08</td>
</tr>
<tr>
<td>Sagittal ROM</td>
<td>0.09</td>
<td>0.04</td>
<td>-0.19</td>
<td>0.07</td>
<td>-0.07</td>
<td>-0.01</td>
</tr>
<tr>
<td>Transverse ROM</td>
<td>-0.13</td>
<td>0.13</td>
<td>-0.1</td>
<td>0.21</td>
<td>-0.25</td>
<td>0.13</td>
</tr>
<tr>
<td>FHP</td>
<td>-0.04</td>
<td>0.15</td>
<td>0.08</td>
<td>0.07</td>
<td>-0.1</td>
<td>0.14</td>
</tr>
<tr>
<td>Usual pain</td>
<td>0.24</td>
<td>-0.29</td>
<td>-0.37*</td>
<td>0.04</td>
<td>0.04</td>
<td>-0.34*</td>
</tr>
<tr>
<td>NDI</td>
<td>0.07</td>
<td>-0.13</td>
<td>-0.22</td>
<td>0.04</td>
<td>0</td>
<td>-0.14</td>
</tr>
<tr>
<td>Anxiety</td>
<td>-0.15</td>
<td>-0.28</td>
<td>-0.28</td>
<td>-0.05</td>
<td>-0.05</td>
<td>-0.24</td>
</tr>
<tr>
<td>Depression</td>
<td>0.04</td>
<td>-0.14</td>
<td>-0.23</td>
<td>-0.09</td>
<td>0.13</td>
<td>-0.08</td>
</tr>
<tr>
<td>Kinesiophobia</td>
<td>0.13</td>
<td>-0.33*</td>
<td>-0.3*</td>
<td>-0.22</td>
<td>0.09</td>
<td>-0.38*</td>
</tr>
<tr>
<td>Catastrophizing</td>
<td>0.02</td>
<td>-0.24</td>
<td>-0.29</td>
<td>-0.06</td>
<td>0.02</td>
<td>-0.25</td>
</tr>
</tbody>
</table>

*p<0.05, **p<0.01, ***p<0.001, ROM: Range of Movement, FHP: Forward head posture, NDI: Neck Disability Index, FEV₁: Forced Expiratory Volume in one second, FVC: Forced Vital Capacity, PEF: Peak Expiratory Flow, PIF: Peak Inspiratory Flow, FEF₂₅%-₇₅%: Forced Expiratory Flow from the 25% to the 75% of the forced expiration, VC: Vital Capacity.
Table XIXb: Correlations between chronic neck pain deficits and respiratory parameters II (non-parametric). This table presents the Spearman correlation coefficient for each correlation between the chronic neck pain deficits and Maximal Voluntary Ventilation (MVV), Maximal Inspiratory (MIP) and Expiratory Pressure (MEP) and partial pressure of arterial carbon dioxide ($P_{tc}CO_2$) for the chronic neck pain group.

<table>
<thead>
<tr>
<th>Variables</th>
<th>MVV</th>
<th>MIP</th>
<th>MEP</th>
<th>$P_{tc}CO_2$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Flexion strength</td>
<td><strong>0.57</strong>*</td>
<td><strong>0.58</strong>*</td>
<td><strong>0.54</strong>*</td>
<td><strong>0.41</strong>*</td>
</tr>
<tr>
<td>Extension strength</td>
<td><strong>0.55</strong>*</td>
<td><strong>0.45</strong>*</td>
<td><strong>0.47</strong>*</td>
<td><strong>0.36</strong>*</td>
</tr>
<tr>
<td>Endurance</td>
<td>0.22</td>
<td>0.22</td>
<td>0.21</td>
<td><strong>0.31</strong>*</td>
</tr>
<tr>
<td>Sagittal ROM</td>
<td>0.01</td>
<td>0.07</td>
<td>0.05</td>
<td>-0.14</td>
</tr>
<tr>
<td>Transverse ROM</td>
<td>0.05</td>
<td>-0.05</td>
<td>-0.05</td>
<td>-0.02</td>
</tr>
<tr>
<td>FHP</td>
<td>0.17</td>
<td>0.08</td>
<td>-0.08</td>
<td>-0.21</td>
</tr>
<tr>
<td>Usual pain</td>
<td>-0.3*</td>
<td>-0.13</td>
<td>-0.24</td>
<td><strong>-0.33</strong>*</td>
</tr>
<tr>
<td>NDI</td>
<td>-0.17</td>
<td>-0.27</td>
<td>-0.25</td>
<td>-0.21</td>
</tr>
<tr>
<td>Anxiety</td>
<td>-0.21</td>
<td>-0.26</td>
<td>-0.18</td>
<td>-0.16</td>
</tr>
<tr>
<td>Depression</td>
<td>-0.1</td>
<td>-0.19</td>
<td>-0.11</td>
<td>-0.13</td>
</tr>
<tr>
<td>Kinesiophobia</td>
<td><strong>-0.39</strong>*</td>
<td><strong>-0.46</strong>*</td>
<td><strong>-0.4</strong>*</td>
<td><strong>-0.4</strong>*</td>
</tr>
<tr>
<td>Catastrophizing</td>
<td>-0.1</td>
<td>-0.26</td>
<td>-0.22</td>
<td><strong>-0.35</strong>*</td>
</tr>
</tbody>
</table>

*p<0.05, **p<0.01, ***p<0.001, ROM: Range of Movement, FHP: Forward Head Posture, NDI: Neck Disability Index.
Appendix XX

Standardized residuals-standardized predicted values plots

Figure XX: Plots of standardized residuals with standardized predicted values. These plots present the relationship between the standardized residuals with standardized predicted values in the regression analyses for the prediction of a) Forced expiratory flow, b) Vital capacity, c) Maximal voluntary ventilation, d) Maximal inspiratory pressure, e) Maximal expiratory pressure and f) Partial pressure of carbon dioxide.
Appendix XXI

Histograms of standardized residuals

Figure XXI: Histograms of standardized residuals. These histograms present the distribution of standardized residuals in the regression analyses for the prediction of a) Forced expiratory flow, b) Vital capacity, c) Maximal voluntary ventilation, d) Maximal inspiratory pressure, e) Maximal expiratory pressure and f) Partial pressure of carbon dioxide.
Appendix XXII

Diagnostics in regression models of more than 4 predictors

Figure XXII: Diagnostics in regression models of more than 4 predictors. This figures present a) the distribution of standardized residuals and b) the plot of standardized residuals against standardized predicted values for the prediction of i) Maximal inspiratory pressure, and ii) partial pressure of arterial carbon dioxide.