Pain Ratings Reflect Cognitive Context: A Range
Frequency Model of Relative Pain Judgements

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Abstract

This thesis presents an investigation into context-dependent evaluation of pain intensity. A literature review set out to explore different approaches to pain evaluation. It particularly looked for evidence of assumptions of absolute pain judgement (made in isolation about a current painful event) and also evidence of relative pain judgement, dependent upon circumstances or context. The review of approaches to relative pain evaluation was restricted to literature describing cognitive and emotional factors contributing to pain ratings and did not include any investigation of the sensory, physiological, neurological or genetic aspects of pain. The review identified that although some research and clinical practice has implicitly assumed pain judgements to be absolute and made in isolation, other research has investigated relative pain judgements which can vary depending on the context in which pain is experienced. Many researchers have suggested that pain evaluation involves cognitive and emotional as well as sensory and physiological factors. However, few have proposed a cognitive explanation for relative pain judgements, and there has been no quantitative model established to describe the cognitive mechanism underlying such judgements. Developments in general understanding of relative psychophysical and socioemotional judgements were explored, and Range Frequency Theory was identified as a potential quantitative model of the cognitive mechanisms underlying context-dependent pain evaluation. This was explored in two empirical studies presented in this thesis as a published article. The two studies used pressure pain stimulation to test the two principles of Range Frequency Theory against competing potential models of relative judgement. Study 1 tested the rank (or frequency) principle of Range Frequency Theory, and illustrated that the same objective painful stimulus was rated as more intense, the higher it ranked in the context of other painful stimuli. Study 2 tested the range principle of Range Frequency Theory, and illustrated that pain ratings were higher when most stimuli were relatively intense, despite the average of all stimuli in the context remaining constant. Together, these studies provided empirical evidence that pain judgements are made relative to other pain experienced, and that Range Frequency Theory provides a good model of the cognitive processes underlying such judgements. These results complement the existing body of research into context-dependent pain evaluation and suggestions are made for further research to better understand the interaction of these complementary approaches.
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.
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I would like to thank Prof. Alex Wood (University of Stirling) and Prof. Gordon Brown (University of Warwick) for their help and guidance during the design and the publication of the studies described in this thesis. I would also like to Prof. Wael el-Deredy (University of Manchester) and Dr. Donna Lloyd (University of Leeds) for their technical assistance in operating the pain stimulator used in these studies and for Dr. Lloyd’s contribution to the published work, Chris Dancer (Dancer Design, St. Helens, UK) for his technical advice and help with interpreting the pressure output from the pain stimulator system, and Dr. Andrew Stewart (University of Manchester) for his advice in preparing this thesis for submission. Finally, I would like to thank my partner and my two daughters for their love and support, and most of all for their patience when my study workload has been particularly demanding.

The Author

As the author of this thesis, Ann Patricia Watkinson, I graduated from the University of Manchester with a First Class Honours degree in Psychology. As a result of work on my final year dissertation, I co-authored an article on relative judgements of personality (Wood, Brown, Maltby, & Watkinson, 2012). I have worked as a research assistant on a variety of projects whilst also conducting and publishing my own studies described in the published article which forms the basis of this thesis.

There are co-authors of this article, and I would like to take this opportunity to confirm that the work to prepare, conduct and publish the studies, including designing the mathematical distributions of stimuli and programming the interface between the computer and the pain stimulation system, was entirely mine, although my co-authors were most helpful with advice and guidance at all stages. To avoid confusion I also wish to make clear that I publish under the name Pat Watkinson.
Alternative Thesis Format

This thesis has been prepared in alternative format. It consists of one empirical paper, enclosed by an introduction which presents the findings of a literature review and describes the methodology used in the paper, and a general discussion which places the results reported in the paper in the context of the extant literature and recommends possible directions for future research. The empirical paper is published in *Pain*.

The project supervisor, Prof. Alex Wood, oversaw the design and conduct of the studies described in the paper, and the process of preparing the paper for publication. Dr. Donna Lloyd gave additional guidance from the perspective of pain science and use of the pain stimulation system, and Prof. Gordon Brown (a colleague of Prof. Wood at another university) also gave advice and assistance from the field of relative judgement and decision-making and Range Frequency Theory. They are all therefore included as co-authors on the empirical paper.
Overview of Thesis

This thesis will argue that the intensity of current pain is judged relative to other pain experienced, and is the result of a cognitive appraisal mechanism. It will review prior literature on pain judgements, to demonstrate that although pain ratings are sometimes seen as absolute judgements based on the degree of injury or severity of a clinical condition, they are also widely believed to be made relative to other circumstances. It will demonstrate, by the inclusion of a published empirical paper, that momentary pain judgements, made in real time as the pain is experienced, operate as described by a particular psychological model known as Range Frequency Theory (Parducci, 1965; 1995).

This introduction will present evidence from a literature review on differing approaches to pain judgements, both absolute (dependent only on the information available from a painful stimulus at the time of experience) and relative (depending on the influence of other factors, or on comparison with other painful events). It will also describe the developments in approaches to relative judgements, from a psychophysical as well as a socioemotional perspective, to propose Range Frequency Theory as the potential cognitive model for relative pain judgements. The accepted methodology for testing the Range Frequency model will be described, as will the particular methodology for delivering painful stimuli used in the research presented in this thesis. The published article which describes two studies which tested Range Frequency Theory as a model for pain judgements follows. Finally, the results of these studies will be discussed in terms of clinical implications, and in the context of prior and recent research, with suggestions for future research.
Different Approaches to Pain Judgement

The management and treatment of pain involves clinical decisions based on patients’ self-reported pain severity. Self-reported pain is described as the “gold standard of pain management” (Strong, Sturgess, Unruh, & Vicenzino, 2002, p.126), and Tait, Chibnall, and Kalauokalani (2009) described its use as the “fifth vital sign” (p. 16) of medical assessment. As pain is by nature subjective, the individual must be considered the expert judge of how much pain he or she feels. As this judgement is interpreted by clinical professionals to decide upon, and assess the progress of, appropriate treatment, it is crucial to successful treatment that the individual’s judgement and communication of pain is clearly understood.

Much pain literature and clinical practice has implicitly treated self-reported pain as an absolute judgement, based upon the intensity of a current painful stimulus or condition. Some researchers have concentrated on the accuracy (or otherwise) of retrospective pain judgements, an approach which inherently assumes an absolute real-time judgement of current pain intensity as an accurate baseline against which to compare. Of those studies which have investigated how pain judgement can vary, some have looked to individual differences such as gender or age which might affect sensitivity to pain. Others have concentrated on summarised painful experiences after the event rather than real-time judgements during the painful episode. Pain is acknowledged to involve cognitive evaluation as well as a physiological response (Craig, 2009; Hadjistropolous, Hunter, & Dever Fitzgerald, 2009; Melzack, 2001; Melzack & Casey, 1968; Melzack, Taenzer, Feldman, & Kinch, 1981; Rollman, 1979, 1989, 1992). Many experimenters have investigated emotional and cognitive as well as sensory influences on pain response, but few have attempted a cognitive account of pain judgement. Of those who have concluded that pain judgement is subject to cognitive context, some have considered Adaptation-Level Theory (Helson, 1947) as a possible explanation (e.g. Rollman, 1979, 1989), but none have considered how current pain
ranks amongst an individual’s range of painful experiences to explain variations in reported pain, and until the publication of the studies presented in this thesis there has been no clear cognitive model about how context-dependant relative pain judgement occurs.

There follows a review of the extant literature which will present examples of research and practices that have made implicit (or explicit) assumptions of absolute pain judgements, work that has recognised cognitive and affective influences on pain evaluation, and studies that have recognised that pain judgements can be dependent on the context in which pain is experienced. This review will not consider in detail the neurological, physiological or genetic aspects of pain, as these would fall outside the overall purpose of this thesis, which is to explore the cognitive mechanisms underlying pain evaluation.

Assumptions of Absolute Pain Judgement

Pain rating scales. The routine use of verbal, visual or numeric pain rating scales to assess the progress of medical conditions in a clinical setting (Jensen, Caroly, & Braver, 1986; Strong et al., 2002; Williams, Davies, & Chadury, 2000) implies that self-report of pain can be regarded as an absolute judgement. If a patient’s reported pain can be compared at two different points in time, and a reduction in pain interpreted as successful treatment, then this implies that each of these judgements is an absolute reflection of the intensity of pain at that time. Much pain literature has made the same implicit assumption. For example, Fernandez (1989) proposed the use of an open-ended pain rating scale to improve test-retest reliability of artificially induced experimental pain. Levels of pain threshold and tolerance were compared within participants tested a week apart, implying that a similar absolute judgement of pain level could be expected at the retest session. However, Fernandez actually reported increased pain threshold and
tolerance in the second session, which suggests that pain was judged differently in the two contexts.

In a review of pain assessment, Katz and Melzack (2003) discussed the need to quantify pain, in order to overcome the difficulties involved in trying to describe it, and to assist in correct diagnosis and assessment of treatment effectiveness. They explicitly recommended that “… patients rate the absolute amount of pain at different points in time …” (p.718), evidently assuming that such absolute judgements are possible and can be compared. They referred to the need for accuracy of measurement, with an implicit assumption that the absolute magnitude of pain can be accurately captured.

Tait et al. (2009) considered whether clinicians’ judgements matched patients’ own judgements of their pain. These authors suggested that because patients’ self-reported pain is often unaccompanied by obvious physiological symptoms, chronic pain in particular can remain under-treated. They contrasted this with reports of acute pain which are often consistent with clear medical evidence and are perhaps more readily accepted by clinicians. This dichotomy carries an implicit assumption of a presumably ‘correct’ absolute level of pain, which ought to correspond to particular physical symptoms.

Jensen et al. (1986) considered the usefulness of different pain rating tools used by patients to report current pain and assess treatment progress, which would involve comparison of their pain over time, again assuming an absolute reflection of current pain at each point. Conversely, Williams et al. (2000) analysed patients’ responses to different pain rating scales, to investigate reasons for differences between individuals’ use of such scales. The authors found that many patients actively compared their present pain with their “usual” or “worst” pain (p.460); an explicit cognitive context-based judgement. They also found that people translated points on the scale into consequences for their lives, such as “incapacitation” or “dependence on others” (p. 461); again, a cognitive influence on the report of pain. Many of Williams et al.’s participants were
unwilling to use the high end of numeric scales; others ignored the bottom end of the scale, regarding it as out of their range of experience. Some reconceptualised “no pain” as “normal” or “manageable” (p. 461) so that they could use the full scale. These results suggest that people impose their own personal context of painful experience onto a rating scale, which might differ from that intended by its design, and judge their current pain relative to that context. Williams et al. criticised the routine clinical use of such scales, with their assumption that self-reports of pain can be consistent over time, and their aim of providing an absolute measure of pain magnitude, unaffected by context.

Pain is clearly a subjective experience and tolerance of and sensitivity to pain is known to vary between individuals (Diatchenko et al., 2005). It is evident to clinicians that pain is not simply judged on the absolute magnitude of a stimulus or injury alone, and use of pain-rating scales is now commonly believed to oversimplify the pain evaluation process (Craig, 2009; Williams et al., 2000). If pain ratings are not simply the result of judgements made about the absolute magnitude of injury, then pain judgements must depend on some other factor(s).

**Effect of Site of Stimulation**

One possible factor which could influence the perceived severity of pain might be the part of the body receiving the painful stimulus, and some researchers have looked for differing pain judgements depending on the site of stimulation. For example, Greenspan and McGillis (1994) measured the effect of laterality but found no difference in pain intensity reported from either hand. However, Özcan, Tulum, Pinar, and Başkurt (2004) found higher pain thresholds in the right hands of right-handed people (although no difference in left-handed people), suggesting that some individuals’ pain judgements might differ depending on the body site at which pain is applied. Taylor, McGillis, and Greenspan (1993) also found some evidence of this, although the only significant variation in pain was between sites with hairy versus glabrous skin, with higher
thresholds reported for pain applied to sites with glabrous skin. Taylor et al. offered a physiological explanation, outside the scope of this thesis, based on greater resistance of glabrous skin to pain. They found no difference in pain thresholds between the two glabrous sites tested (hand and foot) or between the two hairy sites (arm and leg), nor any overall effect of laterality. These results, which appear to offer no conclusive evidence for relative judgements of pain depending on body site, suggest that other factors influence evaluation of pain.

**Individual Differences in Pain Judgement**

Another possible influence on perception of pain might be differences between individuals, and much research has looked for variation in pain sensitivity and tolerance of pain based on individual differences such as gender and age. Some examples of such research follow. These investigations often carry an implicit assumption of absolute pain judgements, but the conclusions drawn suggest otherwise.

**Gender differences.** Sarlani, Farooq, and Greenspan (2003), recognising that much prior research has indicated that females are more sensitive to pain than males, investigated the emotional as well as the sensory aspects of gender differences in pain perception. They found that females rated stimuli of extreme low and high temperatures as more painful and more unpleasant (the emotional response) than did males. In the face of apparently conflicting and inconclusive evidence regarding gender differences in judgement of pain, Riley, Robinson, Wise, Myers, and Fillingim (1998) conducted a meta-analysis and found that threshold and tolerance for pain were both generally higher amongst males than females, although different effect sizes were found depending on the type of stimulus. These authors suggested social influence (such as the need to maintain bravado) as a possible factor, although causal mechanisms were assumed to be complex and remained unclear. However, underlying any such attempt to
find gender differences in pain judgement is the implicit assumption that individual females would always make similar absolute judgements, and that these would differ significantly from those made by males.

Lautenbacher and Rollman (1993) attempted to clarify the conflicting results of earlier research by applying different types of stimulus (thermal and electrical) to male and female participants and found that results varied according to the method of stimulation. Pain generated by applying heat was judged similarly by male and female participants, but women found electrical stimulation more painful than did men. The authors suggested that the same individuals would report pain differently depending upon the type of painful stimulus, and suggested that possible emotional or cognitive factors, such as women’s increased anxiety regarding short bursts of electric shock, might have contributed to the differences in reported pain.

More recent work has reported categorical claims that women suffer more from chronic pain than do men (Mogil, 2012; Thibodeau, Welch, Katz, & Asmundson, 2013). However, this has been attributed to cognitive and emotional factors such as fear and pain-related anxiety. Mogil suggested that factors other than pain sensitivity, such as a higher prevalence of depression in women, which can be associated with pain, might mediate the relationship between gender and pain sensitivity. Thibodeau et al. suggested anxiety as an influencing factor in sensitivity to pain, and that it might operate differently between the genders. Anxiety appears to be involved in judgement of pain intensity for men, but pain tolerance for women, suggesting that although pain perception varies between the genders this is influenced by more complex cognitive factors than simply gender. Furthermore, Mogil reported a lack of agreement amongst experts that women could actually be demonstrated to be more sensitive to laboratory-induced pain than men, and presented attempts to demonstrate any difference due to changing female hormones as inconclusive. Mogil concluded that it is still far from
clear whether gender differences in pain perception exist at all or are worth studying further.

All of these results and perspectives opinions not only question the notion of absolute pain judgements, but in these cases pain judgement appeared to depend upon situational factors, and on psychological states, rather than simply gender differences.

**Age differences.** In a review of pain assessment of the elderly, Hadjistavropoulos et al. (2009) discussed the scientific evidence for a higher pain threshold in older people, but argued that rather than feeling less pain than younger people, the elderly might experience it differently due to neurological degradation, and actually appear to have a lower pain tolerance than the young. Hadjistavropoulos et al. recognised the role of a cognitive mechanism when judging pain, which might account for a delay in registering pain and result in an apparently higher threshold. Investigating diminishing sensitivity to pain suggests a reduction in judgement of pain intensity in later life. Looking for changes in pain judgements over time implicitly assumes that an individual would make different absolute judgements of similar painful stimuli at different points in their life.

As an alternative explanation, if increasing age is often accompanied by more incidences of painful illness (Helme & Gibson, 1999), it seems possible that this could provide a changed context within which a given stimulus might appear less severe. Thus pain judgements made at various points in life would be made relative to the current context of the individual’s pain experience so far. Indeed, Helme and Gibson postulated many possible reasons for apparently reduced pain in the elderly, one of which was a cognitive bias during pain judgement, reducing the relative importance of some painful episodes in comparison to other more unpleasant experiences during a long life. Again, these studies suggest that pain judgements are not absolute, and that any individual differences in pain judgement due to age are likely to be dependent on the cognitive
context rather than physiological differences, and that this context might include pain remembered from the past. This suggestion that pain evaluation might involve memory for pain has been much explored in the literature.

**Memory for Pain**

In a review of memory for pain, Erskine, Morley, and Pearce (1990) referred to the accuracy or otherwise of recalled pain, which is often used in clinical settings to diagnose and to track response to treatment. Terry, Niven, and Brodie (2007) compared real-time numerical ratings of pain intensity and descriptions of pain sensations with recollections of these two weeks later, to conclude that memory for pain is an accurate reflection of the original sensation and not merely of the rating given to the original stimulus. Looking for an ‘accurate’ memory of previous pain in terms of correlation with the real-time rating implicitly assumes there was an accurate absolute pain judgement when the pain occurred.

In another example of this implicit assumption, Stone, Schwartz, Broderick, and Shiffman (2005) found that chronic pain patients’ recollection of pain was exaggerated (compared with their average pain reported in real-time during the recall period) if they had large variation in their real-time reports of pain, an effect which appeared to be due to an attentional bias toward the peak levels of pain experienced within the reporting period. Although this offered some cognitive explanation for the influence of context which might distort memory for pain, and also offered some support for Peak-End Theory (which is discussed in detail later), it offered no context-based explanation for the real-time judgement of current pain, which was simply rated as a numerical intensity.

Broderick et al. (2008) treated such real-time pain judgements as accurate reflections of a patient’s pain experience (and hence implicitly absolute judgements based only on the objective current pain intensity), and used these as a fixed baseline
against which to measure accuracy or otherwise of subsequent pain recollection, which they concluded became more exaggerated as periods of recollection increased. Broderick et al. explicitly stated that such baseline real-time pain ratings were neither composed from any combination of previous pain experiences, nor vulnerable to cognitive bias. On the contrary, Erskine et al. (1990) concluded with the suggestion that memory for previous pain might be involved in the immediate response to current pain, which instead suggests that memory might provide a context within which current pain is relatively judged.

These conflicting suggestions illustrate that there remains some debate over whether memory for pain can accurately reflect momentary real-time judgements of painful experiences and therefore whether it can be used as a measure to track clinical progress. There is also debate regarding the direction in which any cognitive bias might occur: whether memory for pain biases real-time judgements as the pain is experienced, or whether current pain introduces bias into retrospective evaluations based on memory. So far in this review it seems clear that cognitive processes influence the evaluation of pain, but there has been little evidence yet to suggest how the context in which pain is experienced can influence these cognitive judgement processes.

**Cognition and Emotion in Pain Judgement**

It has long been recognised that perception of pain is influenced by cognitive and emotional factors. Melzack and Casey (1968) conceptualised pain to acknowledge not only its sensory qualities, but also the cognitive evaluation and affective factors which contribute to, and influence the perception of, a painful experience. In a review of pain assessment, Katz and Melzack (2003) described the importance of cognitive evaluation of current pain against a background of previous painful experiences; clearly supporting the notion of context-dependent relative judgement of pain. Similarly, the McGill Pain Questionnaire, or MPQ (Melzack, 1975), commonly used in clinical and
experimental pain assessment, includes items from all three perspectives, termed “sensory, affective and evaluative” (p.1) which combine to create a full impression of an individual’s subjective pain experience. In particular, Melzack believed the “present pain intensity” (p.9) measured by the MPQ to be influenced by cognitive evaluative and emotional factors rather than being a simple response to the physical sensation of pain.

The importance of the cognitive and emotional aspects of pain judgement was further illustrated by Ahles, Blanchard, and Leventhal (1983). They separated participants into three groups; one described the physical sensation from experimental pain, another articulated the emotions elicited by the pain, and the third attended to another subject entirely. Those who articulated emotions reported the most distress, while those who expressed the physical sensations reported the least distress, and also displayed higher pain tolerance, demonstrating that response to pain can vary depending on the current cognitive emphasis.

**Context-Dependent Judgements**

From the evidence discussed so far, it appears that pain judgements include cognitive factors, and that evaluation of pain could vary depending on the context in which the individual experiences pain. One possible influence might be the desire to present a particular persona when pain is experienced in the presence of other people, or when comparing oneself with a particular reference group.

**Experimenter characteristics.** Kallai, Barke, and Voss (2004) examined the effects of experimenter characteristics on self-reported pain intensity, threshold and tolerance. Their participants received pain from an experimenter of the same or opposite gender, who was either a professional staff member or a fellow student. They found that participants displayed higher tolerance for pain from a member of the opposite gender, for both male and female experimenters. This was counter to their expectations that men
would behave stoically in the presence of a female experimenter, but that women would not, being more inclined to solicit protection from a male experimenter. Kallai et al. surmised that participants generally aimed to make a good impression on the opposite gender. This desire to impress also seemed a likely explanation for their finding that pain from professionals was tolerated for longer than that administered by fellow students, which they believed to be a result of the perceived authority of the experimenter. Kallai et al. noted that pain intensity ratings appeared not to depend on the professionalism of the experimenter; participants reported feeling the same pain intensity but were more inclined to tolerate it for a person in authority. They found no effect of participant gender, which calls into question Riley et al.’s (1998) conclusion that females appear less tolerant to pain than males, but an overall effect of experimenter gender, such that pain was reported to be more intense if the experimenter was female. Kallai et al. also noted that their participants’ pain intensity judgement was made after the painful stimulus ended, and suggested that participants might have exaggerated the pain intensity to impress the experimenter with their capacity for endurance. This latter might also be considered as a possible alternative explanation for findings such as those of Stone et al. (2005) whereby memory for pain appears exaggerated in retrospect. Overall, the implication of Kallai et al.’s results is that response to pain is not absolute but can vary depending on the person requesting the information, which provides more evidence that pain judgements can vary according to the cognitive context.

**Reference group comparison.** In an investigation of the effects of context on self-reported health, Stone, Broderick, Schwartz, and Schwartz (2008) found that participants reported more severe pain when asked to compare their own health with others of their own age than when comparing it with that of the entire population, or when no reference group was indicated. When asked to rate their health retrospectively
for the previous month, participants rated their pain as more severe than when asked to
make a real-time judgement of current pain, a finding which concurs with Stone et al.’s
(2005) exaggerated memory for pain. Whilst these results provided evidence of relative
pain judgements dependent on context, these judgements were made in the broad
contexts of the reference group and the pain reporting period. The results take into
account cognitive processes which influence pain judgements, and illustrate that self-
report of an individual’s pain is not absolute. However, an individual’s own experience
of pain would seem likely to provide a more specific personal context against which any
current pain might be compared.

**Chronic pain.** Those studies which compare groups of individuals for
differences in pain judgements (on the basis of gender or age, for example) often carry
an implicit assumption of absolute judgement by each ‘category’ of individual. A
different approach is taken by those studies which compare groups of healthy
participants with those enduring chronic pain, and often suggest instead that ongoing
pain provides a special context within which experimental or acute pain is judged.

For example, Petzke, Harris, Williams, Clauw, and Gracely (2005) explored
both sensory and affective aspects of pain judgements by comparing healthy
participants with fibromyalgia patients. Their participants rated the intensity and
unpleasantness of various pressure-pain stimuli, and fibromyalgia patients reported
higher pain intensity than healthy participants for the same objective magnitude of
stimuli. However, patients with fibromyalgia reported less relative unpleasantness (a
ratio of unpleasantness to pain intensity), and rated their usual ongoing pain as more
unpleasant than similar intensities of experimental pain. This again implies a context-
based judgement; that their immediate pain judgement of a painful experience was made
relative to their context of continual pain.
Chapman (1986) described a phenomenon which would appear to concur with Petzke et al.’s (2005) results. Chapman suggested that chronic pain patients learn from the responses that their pain elicits from other people, such as sympathy, special treatment and expressions of concern. These reinforce the patients’ attention to their pain, which can exaggerate its apparent severity. Thus chronic pain patients could become hypervigilant to additional extraneous painful stimuli, so that such stimuli appear more painful to pain patients than they do to healthy individuals, as Petzke et al.’s results suggested.

Petzke et al. (2005) suggested that the effects they found in fibromyalgia patients would generalise to other persistent painful illnesses. However, given that fibromyalgia generally involves increased sensitivity to pain of various kinds, such as pressure, heat and electrical stimulation (Gracely, Grant, & Giesecke, 2003), it seems plausible that fibromyalgia might be a special case. Perhaps other chronic pain conditions might instead provide a background context of higher intensity pain, against which additional painful stimuli would appear less intense, and would produce lower pain ratings (in a similar way to Petzke et al.’s lower unpleasantness rating).

**Adaptation-Level in pain judgement.** Rollman (1989) put forward just such a counter-argument, contrasting the idea that chronic pain patients’ hypervigilance can cause an exaggerated evaluation of additional pain with his own alternative suggestion. Rollman (1979, 1989) proposed that the theory of Adaptation-Level (Helson, 1947) could explain why chronic pain patients might instead judge additional unrelated stimuli to be less painful in comparison with their usual ongoing pain. Adaptation-Level Theory was originally proposed to describe how psychophysical judgements (of lengths of lines, duration of tones, etc.) are made not in isolation from information about a particular stimulus, but with reference to surrounding similar stimuli. According to Adaptation-Level Theory, judgement of a stimulus would depend on the apparent
difference between that stimulus and the central tendency (the Adaptation-Level) of the magnitudes of the other related stimuli in that context.

Rollman (1979) suggested that the Adaptation-Levels of patients with chronic or extreme pain would be different to those of healthy patients, so that they would respond differently to additional experimental pain. Pain patients’ cognitive mechanism for pain judgement would compare new current pain with their pre-existing internal Adaptation-Level, against which additional painful stimuli would appear less intense. Indeed, Petzke et al. (2005) put forward Rollman’s Adaptation-Level for pain as one possible explanation for their findings regarding unpleasantness, and recommended further research into the cognitive processes enabling such relative judgement. The results of the studies presented in this thesis contribute to that body of research.

Boureau, Luu, and Doubrére (1990) compared responses to induced pain from healthy participants with those from chronic pain sufferers (including some patients with fibromyalgia as well as a variety of other conditions). Contrary to expectations they found little overall difference between the groups. They attributed this in part to a potentially unrepresentative sample of pain patients (on a low level of medication and therefore possibly with a relatively low level of chronic pain) and to the loss of data for some highly painful stimuli which were above some pain patients’ tolerance levels. Nevertheless, in a result somewhat similar to that of Petzke et al. (2005), Boureau et al. did report that pain patients found the same magnitude of stimuli less unpleasant than did the healthy participants. However, unlike Petzke et al., their healthy participants found the higher magnitudes of stimuli (though not the lower) significantly more unpleasant and more intensely painful than did the pain patients, which suggests that a background context of ongoing pain can indeed make experimental stimuli appear less painful, as Rollman’s (1979, 1989) work proposed.

There would seem to be much evidence that patients with ongoing pain respond differently to additional unrelated painful stimuli than do healthy participants. However,
the mechanism for this has not yet been clearly established. Similarly, it is not yet understood how pain already experienced might affect real-time evaluation of pain at the time it is experienced. It is possible that painful stimuli already experienced might influence the perception of subsequent stimuli, and some researchers have investigated whether the order in which painful stimuli are experienced might contribute to this effect. Others have looked for effects of repeated stimulation, or for the influence of expectations of a stimulus yet to be experienced, on the evaluation of subsequent stimuli. Examples of these studies follow.

**Stimulus presentation order.** In their study comparing healthy individuals and fibromyalgia patients (discussed earlier), Petzke et al. (2005) found that relative unpleasantness was only greater in their patient group when the painful stimuli were presented in a random order. They also reported that pain intensity judgements were higher when stimuli were presented randomly, apparently demonstrating a cognitive dimension to the pain judgement process. Petzke et al. suggested that a stimulus would appear more painful if the participant felt unable to anticipate its intensity. Gracely et al. (2003) described the problematic “stimulus-independent bias” (p. 597) which can occur when a participant receives painful stimuli in ascending order, and can anticipate that each subsequent stimulus will be more painful and choose a response accordingly. In this way individuals are able to rate the pain intensity of stimuli in a credible manner, even when under anaesthetic and unable to discriminate between stimuli. Thus individual pain judgements can differ depending on the context of the order of stimulus presentation.

Kyle, McNeil, Weinstein, and Mark (2009) also demonstrated presentation order effects. When they presented the more intense of two painful stimuli last, that stimulus was rated more painful than when it was presented first. Conversely, when the less intense stimulus was presented first, it was rated as more painful than when it was
presented last. Kyle et al. acknowledged that learning effects from recent exposure to the stimuli would influence later pain reports, which suggests a changing context within which each new stimulus would be judged, although they suggested that their results would lend support to the Adaptation-Level pain hypothesis.

**Repeated stimulation.** Nie, Graven-Nielsen, and Arendt-Nielsen (2009) described two mechanisms whereby repeated painful stimuli can lead to a lowered pain threshold and greater apparent pain intensity. When painful stimuli are applied to various or large areas of the body, spatial summation can increase apparent pain intensity, as can temporal summation as a result of repeated stimuli. Nie at al. administered repeated application of the same magnitude of stimulus and found an increase in reported pain intensity (an effect of temporal summation involving increased activation of individual neurons). They also found that pain thresholds were lowered when a larger area of the body was stimulated (an effect of spatial summation involving an increase in the number of neurons activated). The authors concluded that the two summation mechanisms combine to increase sensitivity to pain. Nie et al. concentrated on physiological explanations for these effects, outside the scope of this thesis. Nevertheless their results provided more evidence that the same magnitude of painful stimulus can be judged to be more painful depending on the circumstances in which it is experienced.

Conversely, Greenspan, and McGillis (1994) looked for evidence of habituation (increased pain threshold suggesting higher tolerance and reduced sensitivity to pain) from repeated pressure-pain testing over several days. Whilst they found no overall effect of diminishing sensitivity to the repeated painful stimuli, they did identify that trend in some individuals, which they suggested might have occurred because participants who were initially apprehensive and over-reported early pain became less concerned later in the experimental process as their expectations of severe pain
diminished. This would imply that one’s psychological state could influence pain judgements. Bohus et al. (2000) further illustrated this by comparing reported pain in healthy individuals with that in self-harming patients with borderline personality disorder. They found that healthy individuals found the same stimulus more painful, and also that the patients reported less pain when in a distressed state than when calm, thus demonstrating that the same person can judge the same pain differently depending on his or her psychological state.

**Anticipation and expectation.** Brown, Seymour, Boyle, El-Deredy, and Jones (2008) measured the effect of anticipation of the magnitude of painful stimuli on pain intensity ratings. They gave participants an accurate warning in advance of each stimulus that the following sensation would either be of low, medium or high intensity (to generate expectation with certainty) or that its intensity was not yet known (to create a state of uncertainty). They found that when participants were certain of a high intensity stimulus to come, they rated the ensuing stimulus as more painful, and when they were expecting a certain low intensity stimulus, they rated that stimulus as less painful, than when they had no certain expectation. Certainty of anticipation exaggerated the pain rating in the appropriate direction (higher or lower), indicating that the same magnitude of stimulus would be rated differently depending on the expectations of the recipient. Brown et al. suggested that the judgement of each stimulus was made from a combination of the expectation and the actual physical sensation, recognising that cognitive mechanisms influence the response to the sensory experience of pain. As well as recording pain intensity ratings, Brown et al. measured neurological reactions using EEG (electroencephalographic) recordings and found results suggesting memory activity when participants were certain in their expectation of the next stimulus. This might suggest reference, prompted by the low, medium and high intensity warnings, to an establishing pain context which includes events sampled from
memory as Stewart, Chater, & Brown’s (2006) Decision by Sampling model would suggest (this model is discussed in more detail later).

Leknes et al. (2013) provided participants with a cue to set expectations of a stimulus to deliver pain-free warmth, moderate pain or severe pain. They demonstrated context effects in pain judgements from the perspective of relative pain relief. They administered the same magnitude of moderate pain in two contexts. In one context the stimulus delivering moderate pain offered the most favourable outcome (in comparison with another stimulus which delivered severe pain). In the other, the moderate pain offered the least favourable outcome (in comparison with another stimulus which delivered warmth but no pain). Participants gave ratings of their hedonic response (how painful or pleasant they found each stimulus) and their physiological responses were recorded using skin conductance measures and brain activation imaging. Leknes et al. found that physiological measures corroborated self-reports of hedonic responses, and also reported a “hedonic flip” (p. 407), whereby the stimulus delivering moderate pain was judged to be painful in comparison with painless warmth, but pleasant in comparison with the severely painful stimulus. Contrasting with prior research (including that of Brown et al., 2008), Leknes et al.’s participants reported lower pain from the same stimulus when expectations were set for high pain, and higher pain when expectations were set for low pain (Jepma & Wager, 2013).

To measure the effect of setting expectations in a clinical setting, Melzack et al. (1981) investigated the use of preparatory training during pregnancy, an initiative designed to reduce fear of the unknown and to reduce distress and pain during labour. They found that women who had been trained for labour reported lower pain intensity during labour, although this was a relatively small effect. This appears to suggest the opposite of Brown et al.’s (2008) findings, in that knowing what to expect from the experience lowers the pain intensity when it occurs. They also found that women who had experienced medical difficulties during their pregnancy reported less pain during
labour. This might appear counter-intuitive, but Melzack et al. suggested that these women expected the labour to be as complicated as the pregnancy, and reported less pain when this did not happen. Melzack et al. also found that those women who had given birth before reported less pain during their most recent labour, and suggested that these women were better prepared as their expectations were set before labour commenced so would be less distressed by the experience.

**Behavioural Measures Illustrating Relative Pain Judgement.**

Although the above studies into the effect of anticipation on pain evaluation might appear somewhat contradictory, they do suggest that people judge pain differently depending on their expectations. Further evidence of relative pain judgement comes from research that has used behavioural measures to show that people act on their context-dependent pain evaluation by choosing to repeat or avoid painful stimuli.

**Peak-End Theory.** So far, it seems clear that the context in which pain is experienced has an effect on the cognitive evaluation process which must take place to rate the intensity of the painful event. There has been a substantial body of research into the effects of this process on the overall judgement of an aversive experience, depending on the context in which stimuli are presented, demonstrating a heuristic which has become known as the Peak-End rule (Kahneman, Fredrickson, Schreiber, & Redelmeier, 1993). Kahneman et al. provided the first behavioural measure of the Peak-End rule as applied to physiological pain judgements. The authors had already demonstrated the Peak-End effect for other aversive experiences such as judging other people’s discomfort, or watching a distressing film. The Peak-End rule suggests that the overall judgement of an experience after the event depends upon the peak, or most intense stimulus during the episode, and the end, or final stimulus of the episode, and that the duration of the episode has little effect. Kahneman et al. gave participants two
painful cold-water trials, one of which was longer than the other. The longer trial ended with extra time during which the temperature was raised, to reduce pain at the end. During the trials, participants made continual real-time judgements of the pain they felt, and then judged each overall experience after the event. When asked which trial to repeat, most chose the longer trial which they had retrospectively judged less aversive, even though their real-time judgements of the two trials (apart from the end of the longer trial) were identical. A few did not register the reduction in pain at the end of the longer trial, and so chose in equal measure to repeat either the shorter or the longer trial. Kahneman et al. took these findings as support for Peak-End Theory as the additional duration of the longer trial was ignored in favour of the more pleasant end.

There is much evidence that the Peak-End rule applies not just to induced pain in the laboratory but also to patients suffering natural pain. For example, Redelmeier and Kahneman (1996) took real-time pain ratings every minute from people undergoing surgical procedures, then asked for a summation of the procedure after an hour, and found that the peak momentary pain and the level of pain at the very end (but not the length of the procedure) had an impact on the overall judgement of the painfulness of the procedure. The authors concluded that this bias took effect not by forgetting how the experience felt, but at the point of encoding the judgement. As well as rating the overall experience they asked patients to rank it relative to other common painful procedures (such as dental treatment), thus introducing the notion of judgement within a wider pre-existing pain context.

Similarly, Stone, Broderick, Kaell, DelesPaul, & Porter (2000) measured rheumatoid arthritis patients’ memory for pain intensity. The authors concluded that a combination of the peak and end severity of the pain experienced during the recall period was a good predictor of the severity of pain remembered; a significantly better predictor than the average of momentary pain ratings collected at random intervals during the same period. They drew attention to the fact that pain ratings would be
affected by Peak-End effects, and that clinicians should consider this when assessing patients’ pain levels. They also recommended that research into the effectiveness of specific treatments should not rely on recalled pain to assess the outcome.

Expanding upon prior evidence of the Peak-End heuristic amongst clinical patients, mostly gathered using between-participant studies, Schneider, Stone, Schwartz and Broderick (2011) used a within-participants design to eliminate individual differences from any apparent Peak-End effects on recall of pain. They collected momentary pain ratings from rheumatology patients at random intervals during each day, then asked for a summarised recall of the day’s pain at the end of the day. The authors found that people gave a more exaggerated daily recall of pain (above the actual average of momentary ratings) on days when they had experienced a more intense peak and end pain. Schneider et al. found that people individuals appeared to differ in their susceptibility to the Peak-End heuristic, and accepted that the effect they found was small. They concluded on the basis of their results that the use of daily recall of pain would be an adequate assessment of clinical progress, but warned that Peak-End effects might become more pronounced over longer recall periods.

Kahneman et al. (1993) saw the Peak-End heuristic as an example of the way people sample particular moments amongst an extended event and use these to build a “snapshot” of the whole experience (Kahneman, 2000, p. 6). The entire experience is then judged relative to this “snapshot” rather than as an amalgamation of all the moments in the entire experience. Kahneman et al. proposed that people hold cognitive representations of an entire painful experience in terms of these selective “snapshots”, but offered no mechanism for how these cognitive representations might be produced. Kahneman also considered the real-time evaluation of individual moments, which can never be instantaneous but must instead comprise judgements about information from the very recent past (he suggested at least the few seconds preceding the judgement). This would seem to suggest that a changing context of pain might affect each
subsequent real-time, momentary judgement. However, the Peak-End heuristic is limited to retrospective, summarised judgements of pain after the painful episode has ended, and offers no explanation for real-time judgements of pain when it is experienced.

**Attaching a monetary value to pain.** In another behavioural measure of relative pain evaluation, Vlaev, Seymour, Dolan and Chater (2009) compared participants’ willingness to pay to avoid pain from electric shock and found that people were prepared to pay more to avoid medium intensity stimuli when experienced amongst lower intensity stimuli than when they were accompanied by higher intensity stimuli. Vlaev at al. concluded that people would place a higher value on avoidance of the same pain if it was more painful than other recent stimuli, demonstrating a context of recent pain against which each momentary painful stimulus is judged.

Kurniawan et al. (2010) followed up Vlaev et al.’s findings with a further behavioural measure, whereby participants pointed to a computer screen in order to receive a monetary reward, with the intention of aiming for the reward area and avoiding an adjacent penalty area on screen. If they pointed to the penalty area they were penalised with an electric shock. Shocks were grouped in intensity pairs of low-medium, medium-high and low-high, and participants were warned which intensity to expect for each trial. The dependant measure was the distance between the central starting point and the final pointing position, a measure of avoidance of the threat of pain. If pain judgements were absolute, then Kurniawan et al. would have expected the avoidance measure to be greater for higher intensity stimuli across all combinations of intensity pairs. However, they found instead that the avoidance measure for a given intensity varied according to the intensity of the other stimulus in the pair. So, for example, the avoidance movement was further away from the medium intensity penalty area when it was paired with a low intensity stimulus than when it was paired with high
intensity. Kurniawan et al. concluded that recent relatively high-intensity pain influenced avoidance action more than relatively low-intensity pain, and that this avoidance appeared to be actioned at the level of physiological motor-control. However, their results could also suggest that the medium intensity stimulus appeared more painful in comparison with low than high intensity pain, so that participants made more attempt to avoid it in the medium-low condition. All these behavioural measures have provided more evidence that current pain is judged relative to a context of other recent pain.

**The State of Research into Relative Pain Judgement**

Whilst by no means exhaustive, the preceding review of pain literature is intended to give a broad overview, with examples, of the historical assumptions of absolute pain judgement, and the different approaches to research into relative pain judgement. As such, it did not set out to consider the many proposed neurobiological bases of pain evaluation, nor those studies based on genetics, both topics which were outside the remit of this cognitive approach to relative judgements of pain. After considering the variety of approaches to pain evaluation, it seems that some challenges remain in the pursuit of understanding of the cognitive processes involved in pain judgements.

To summarise, some studies (and clinical practices) have carried an implicit assumption of absolute judgement, whereas others have explicitly examined variable pain judgements relative to a changing context. Some have viewed pain in terms of sensory and emotional processing, and many have recognised cognitive influences on pain judgement. A number have examined immediate real-time responses to pain; others have considered impressions of pain after the event, as a memory for, or retrospective summation of, painful experiences.
One aspect mostly absent from the literature is an attempt to explain the cognitive mechanisms which might underpin real-time judgements of current pain made relative to a wider context of painful experience, although some researchers have acknowledged the need for such understanding (e.g. Schwartz, 2007) and others have suggested that relative pain judgements might be governed by similar mechanisms to those put forward to explain psychophysical judgements (e.g. Rollman, 1979, 1989). This relative absence might seem surprising considering the early proposal by Melzack and Casey (1968) of a three-dimensional conceptualisation of pain in terms of sensory, emotional and cognitive factors, which acknowledged the importance of past experience of pain during the evaluation of current pain. Clearly, cognition is involved in evaluation of pain, and understanding the cognitive mechanism underlying the judgement process which produces pain ratings will be helpful in the interpretation of self-reported pain.

**Developments in Context-Dependent Judgement Research**

Evaluation of pain is a response to a physical sensation, which is evidently susceptible to cognitive influences. It therefore seems logical to look towards research into the cognitive processes involved in psychophysical judgements for a cohesive explanation of the mechanism for pain judgements. The understanding of cognitive judgement processes has evolved from the concept that judgements of the size of psychophysical stimuli which share a common property (lengths of lines, duration of tones, etc.) is possible using only the information available from a particular stimulus (Wever & Zener, 1928). It has since been accepted that people are much better at judging stimuli relative to other stimuli (Stewart, Brown, & Chater, 2005) and that such judgements are made not in isolation from information about a particular stimulus, but with reference to a wider context of other similar stimuli.
Adaptation-Level Theory (Helson, 1947) was an early explanation proposed for such context-dependent relative judgement. According to this theory, relative judgements of psychophysical stimuli involve adaptation to the Adaptation-Level, a perceived central tendency of stimulus magnitude. As new stimuli are encountered, they are judged relative to that central tendency (such as the mean or median) of all stimuli in the context for judgement. Adaptation-Level Theory has been offered as an explanation of socioemotional judgements such as job satisfaction (Bowling, Beehr, Wagner, & Libkuman, 2005) and personality (Wilson & Gilbert, 2008), as well as for evaluation of intensity (Rollman, 1979, 1989, 1992; Kyle et al., 2009) and unpleasantness (Petzke et al., 2005) of current pain against a context of chronic pain, as described earlier.

**Range Frequency Theory**

Parducci (1965) offered Range Frequency Theory as an alternative explanation to Adaptation-Level Theory for context-based relative judgement, initially for psychophysical judgements. Although Adaptation-Level Theory appears to intuitively explain relative judgement of differently-sized stimuli, in that as one is exposed to more new stimuli, one would adjust one’s Adaptation-Level to reflect the new central tendency of all stimuli experienced, it assumes that people only use the information available from the stimulus itself and the perceived central tendency to make a comparative judgement. However, there are other useful pieces of information available during evaluation: how the target stimulus compares with the lowest and highest in the context, and at what position it ranks among other stimuli (Wood, Brown, Maltby, & Watkinson, 2012).

Parducci (1965) originally proposed that people make judgements about the physical properties of stimuli by a process of dividing the available evidence (the stimuli in the presented context) into a series of categories. People place a stimulus to be judged into the appropriate category based on their perception of the range of stimuli,
a representation constructed using the lowest and highest magnitude of stimuli (referred to as the range principle). In Parducci’s example, making a category judgement of ‘large’ or small’ about a series of stimuli would involve placing half of the stimuli into the ‘large’ category and the other half into the ‘small’ category. Changing the stimuli themselves would not affect this even category division. In apparent contradiction of the range principle, Parducci also proposed the frequency principle, later known as the rank principle. According to this principle, in Parducci’s simple example above, if people perceive more ‘large’ than ‘small’ stimuli, they choose the appropriate category differently; the boundary for what is judged to be ‘large’ is set higher, and fewer stimuli would be judged to be ‘large’. Thus people construct the rank of a particular stimulus in terms of relative magnitude amongst the available context, based on how many of the other stimuli are smaller, or larger, than the stimulus to be judged. Range Frequency Theory proposes that a balance between these two apparently conflicting principles is the cognitive mechanism for relative judgements.

Range Frequency Theory incorporates all of this available information, and states that a stimulus is judged higher in any property, the closer it resides towards the top of the range of related stimuli (according to the range principle), and the higher it ranks among other related stimuli (according to the rank principle). This overall judgement can be expressed algebraically as:

\[ J_i = wR_i + (1-w)F_i \]

where \( J_i \) is the judgement of magnitude of stimulus \( S_i \), \( R_i \) is the judgement based on the position of stimulus \( S_i \) within the overall range of stimuli, \( F_i \) is the judgement based on the ranked position of stimulus \( S_i \), and \( w \) is a weighting parameter between 0 and 1, derived empirically by modelling responses to tests of the two principles.

According to the range principle, the higher a stimulus lies along the range of stimuli, the higher it appears in the given quality:

\[ R_i = (S_i - S_{\text{min}}) / (S_{\text{max}} - S_{\text{min}}) \]
where $S_{\text{min}}$ is the lowest and $S_{\text{max}}$ the highest magnitude of stimulus in the context.

According to the rank principle, the higher a stimulus ranks amongst other stimuli, the higher it appears in the given quality:

$$F_i = (r_i - 1)/(N - 1)$$

where stimulus $S_i$ is ranked at position $r_i$ in a context of $N$ stimuli (Wood, Brown, & Maltby, 2011).

Later work has extended Range Frequency Theory by further exploring the lower-level cognitive comparisons which appear to operate when making these judgements. Decision by Sampling (Stewart et al., 2006) suggests that when people make relative judgements they construct their context for judgement from immediately available information, along with sampled information from their experience and knowledge of the real world. When making a judgement about a particular stimulus, people make a series of pairwise comparisons between the stimulus to be judged and each of these sampled pieces of information, in order to construct its rank position within that composite sample.

Range Frequency Theory has been shown to be a good model of psychophysical judgements of magnitude (Parducci, 1965) as well as more complex psychophysical judgements such as pleasantness of odour (Sandusky & Parducci, 1965) and sweetness of taste (Riskey, Parducci, & Beauchamp, 1979) which result in reports of subjective personal experience. It has also been shown to be a good model of how people make personal and emotional judgements, such as happiness (Parducci, 1995; Smith, Diener & Wedell, 1989), wellbeing (Brown, Gardner, Oswald & Qian, 2008) and gratitude (Wood et al., 2011). Range frequency theory has been applied to a variety of social judgements, such as those of other people’s attractiveness (Wedell, Parducci, & Geiselman, 1987), likeability (Wedell, 1994), psychopathology (Wedell, Parducci, & Lane, 1990), and personality (Wood, Brown, Maltby, & Watkinson, 2012). It is emerging as a unified theory of relative judgement (Wood, Brown, Maltby, &
Watkinson) and provides a cognitive explanation of how such judgements are made. This body of research demonstrates that not only evaluation of psychophysical stimuli, but also socioemotional judgements are better explained by psychological accounts of context-based relative judgement than by the assumption of absolute judgement in isolation. Pain is believed to be a combination of sensory, emotional and cognitive responses to a physical sensation (Melzack & Casey, 1968). As Range Frequency Theory has been shown to provide a cognitive explanation for self-judgements of psychophysical and emotional stimuli, it seems plausible that Range Frequency Theory might similarly apply to pain judgements, to offer a cognitive mechanism for judgements of current pain made relative to other pain experienced. The enclosed article describes two studies which tested the rank and range principles of range frequency theory against the two competing explanations for pain judgement: Adaptation-Level Theory and absolute judgement of each stimulus in isolation.

Methodology

Methodology for Testing the Range Frequency Model

There is a well-accepted method for testing each of the rank and range principles of Range Frequency Theory. To test the rank principle, two contexts of stimuli are constructed, one in a unimodal distribution and one in a bimodal distribution (Brown et al., 2008; Maltby, Wood, Vlaev, Taylor, & Brown, 2012; Wood et al., 2011; Wood, Brown, & Maltby, 2012; Wood, Brown, Maltby, & Watkinson, 2012). These stimuli might be in the form of verbal or numerical information, or might have a psychophysical quality such as varying lengths of lines, drinks with varying degrees of sweetness, or in the case of the studies described in this thesis, varying levels of pressure pain. Examples of these distributions are given in Figure 1. There are typically three stimuli common to both distributions. The first common point is ranked at a higher
position in the bimodal distribution than in the unimodal distribution. The second common point is ranked at the same position in both distributions (at the central tendency, in this case at the mean). The third common point is ranked higher in the unimodal distribution than in the bimodal distribution.

\[\begin{array}{c|c}
\text{Stimulus Magnitude} & \text{Unimodal} \\
0 & \bullet \\
10 & \bullet \\
20 & \bullet \\
30 & \bullet \\
40 & \bullet \\
50 & \bullet \\
60 & \bullet \\
70 & \bullet \\
80 & \bullet \\
90 & \bullet \\
\end{array}\]

\[\begin{array}{c|c}
\text{Stimulus Magnitude} & \text{Bimodal} \\
0 & \bullet \\
10 & \bullet \\
20 & \bullet \\
30 & \bullet \\
40 & \bullet \\
50 & \bullet \\
60 & \bullet \\
70 & \bullet \\
80 & \bullet \\
90 & \bullet \\
\end{array}\]

Figure 1. Examples of unimodal and bimodal distributions of stimuli.

(Numbers for distributions are from Wood et al., 2011.)

The first common point is the stimulus of magnitude 23, with rank = 2 in the unimodal distribution and rank = 5 in the bimodal distribution. The second common point is the stimulus of magnitude 36, with rank = 6 in both distributions. The third common point is the stimulus of magnitude 49, with rank = 10 in the unimodal distribution and rank = 7 in the bimodal distribution.

Participants are exposed to one set of stimuli, and provide a rating for each stimulus. Participants in the bimodal group are predicted to rate the first common point higher than those in the unimodal group (where it ranks lower). Both groups are expected to rate the second common point as the same (at the same rank in both distributions). Participants in the bimodal group are expected to rate the third common point lower than those in the unimodal group (where it ranks higher). This manifests as a significant crossover interaction of group X common point from an ANOVA, with the
intersection around the second common point. Both distributions have the same mean, range and total magnitude of stimuli. Because the relative distance from the mean of each common point is kept constant in both distributions, this relative judgement can be attributed to the different rank positions and not to Adaptation-Level Theory.

To test the range principle, two more contexts of stimuli are constructed, one positively skewed, with most stimuli clustered toward the lower end of its range, and one negatively skewed, with most stimuli clustered toward the higher end of its range (Smith et al., 1989; Wood et al., 2011; Wood, Brown, Maltby, & Watkinson, 2012), as illustrated in Figure 2.

![Figure 2. Examples of positively and negatively skewed distributions of stimuli](image)

(Numbers for distributions are from Wood et al., 2011.)

Both distributions have the same mean, range and total magnitude of stimuli. Participants in the negatively skewed group (where most stimuli appear relatively high) are predicted to rate stimuli higher than those in the positively skewed group (where most stimuli appear relatively low). This is tested by averaging (or totalling) ratings and comparing these overall ratings from the two groups using an independent t-test or ANOVA. The average rating from the negatively skewed group is predicted to be
significantly higher than that from the positively skewed group, despite the actual mean magnitude being the same for both.

Methodology for Administering Painful Stimuli

Pain was administered using a custom-built pneumatic pain stimulator system designed by Dancer Design (St. Helens, UK). The system includes a pneumatic force controller which uses compressed air to lower a 1cm$^2$ circular rubber probe at variable force, designed to be delivered to the finger, as shown in the image in Figure 3. The circular probe is designed to be lowered onto the finger at the junction with the fingernail bed, centrally placed to cover an equal area of nail and skin.

Figure 3. The pain stimulator system, showing the compressor (on the right), the pressure generator (on the left), and the probe lowered onto the finger of a (model) participant, holding the emergency pressure release switch.

The pain stimulator has been used in the past by researchers at the University of Manchester, in studies that allowed participants to manually adjust the pressure applied
to their finger, using the dials on the pressure generator shown in the image in Figure 3, in order to establish their pain threshold and tolerance limits. The studies presented in this thesis made novel use of the stimulator by passing specific voltages into the stimulator system in order to produce specific magnitudes of pressure, and thus objective stimuli, out of the control of the participant.

This was achieved by passing a specific voltage into the pressure generator, which translates this into pressure at the probe in a range from 0.00 kg/cm\(^2\) generated from 0.00v input, to 7.28kg/cm\(^2\) generated from 1.00v input. The pain stimulation system is capped by the manufacturer at this maximum pressure delivery for safety reasons. Voltages were generated in the required distributions of pressure magnitude required for the established Range Frequency tests described above, enabling painful stimuli to be precisely delivered in one of the required distributions (unimodal, bimodal, positively skewed or negatively skewed). These specific voltages were generated by a bespoke computer program written in MATLAB 7.5.0 (Mathworks Inc., Sherborn, MA, USA) and passed into the pain stimulator via a LabJack U12 device (LabJack Corp., Lakewood, CO, USA). As the magnitude of pressure was not under the control of the participant, an emergency pressure release switch was accessible at all times, and it was made clear to participants that they could release the pressure and withdraw their finger immediately should they find the experience too painful. As pain is well-known to be subjective, and tolerance to pain varies between individuals (Diatchenko et al., 2005), when embarking on an experiment of this type there was an inevitable concern that the stimuli chosen might have proved to be too painful for some participants. However, this basic methodology was carried out 91 times and only two people chose to abort the process in this manner. Whilst a finger was under the probe, each complete painful stimulus comprised a three-second depression time, followed by maintenance of full pressure for a further three seconds, after which pressure was released immediately.
All participants received three sequences each containing 11 painful stimuli to a finger from the pain stimulation system, as shown in Figure 3. To avoid the potential problem of order effects raised by Gracely et al.’s (2003) description of the “stimulus-independent bias”, the painful stimuli were delivered in a double-blind random order. This order was generated by the bespoke MATLAB program at the time of delivery, and not disclosed to the experimenter until after all three sequences of stimuli had been delivered and the experiment was over, to avoid any experimenter cues which might come from knowledge of the magnitude of the next stimulus to be delivered.

A further potential problem could have been introduced by Petzke et al.’s (2005) suggestion that a stimulus appears to be more painful when a participant has no knowledge of its expected severity. However, in order to allow the participant to establish the context of pain, the first sequence of 11 stimuli constituted practice trials, which also meant that any possibly exaggerated responses in this first sequence were not analysed. After the practice trials, participants were aware of the maximum severity of any stimulus to come, although not the order in which the stimuli would be delivered.

As Nie et al. (2009) described, temporal summation of repeated painful stimuli can cause sensitisation to pain, so that later pain judgements might be exaggerated, although it has been reported that this is only likely when painful stimuli are inflicted fewer than three seconds apart (Hollins, Harper, & Maixner, 2011). Also, Greenspan, and McGillis (1994) reported no evidence of habituation (which might have led to later stimuli being judged less painful), and it appears to occur only when pain is repeatedly inflicted on the same site (Hollins et al.). Nevertheless, precautions were taken to ensure that such effects were unlikely to occur using this particular methodology, by ensuring that participants changed, and therefore rested, fingers for every subsequent stimulus, and that the time taken to change fingers and re-site the probe appropriately on the next finger was longer than three seconds. Participants changed fingers in the following sequence:
repeating this sequence throughout the three blocks to avoid repetition of a particular stimulus on the same finger with repeated blocks. Along with the delivery of the stimuli in random order, this allowed confidence that the risk of order effects leading to the potential effects described above was minimised, and the additional analyses described in the enclosed article confirmed that order effects did not distort the results.
There follows an empirical paper which describes two studies which tested Range Frequency Theory as applied to pain judgements, published as:


The citations for the introduction and general discussion sections of this thesis, and all references for the entire thesis (including the following article) at the end of this document, are given in the standard format of the American Psychological Association. However, the citations and references included in the article itself are given in the format required for publication in the journal *Pain*. The article was published in American English, but for consistency within the thesis all spellings have been converted to British English. Heading styles have been changed to be consistent with those in the rest of the thesis, and figures and tables are repositioned for efficient use of page space.
Pain Ratings Reflect Cognitive Context: A Range Frequency Model of Pain Perception

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Abstract

When painful stimuli are evaluated at the time they are experienced, judgements are made not in isolation but with reference to other experienced stimuli. We tested a specific quantitative model of how such context effects occur. Participants experienced three blocks of 11 different pressure pain stimuli, and rated each stimulus on a 0-10 scale of intensity. Stimulus distribution was varied between participants. Study 1 found that the rating of a stimulus of a particular pressure was higher in the context in which it ranked highest. Study 2 found that pain ratings were higher in a context where most stimuli were relatively intense, even when the mean stimulus was constant. It is suggested that pain judgements are relative, involve the same cognitive processes as are used in other psychophysical and socioemotional judgements, and are well described by Range Frequency Theory. This approach can further inform the existing body of research on context-dependent pain evaluation.

Keywords: context, judgement, pain, range, range frequency, rank.
Introduction

Self-reported pain is understood to involve cognitive evaluation as well as neurological response [7,10,24,25,33,34,35], and can be conceptualised as involving three stages: (1) neurological detection of the stimulus, (2) cognitive evaluation of the stimulus, followed by production of a response (a subjective opinion of how painful the stimulus feels) and (3) encoding of that particular experience in memory. Whilst much research focuses on neurological response [5,23,24,26,47], and pain memory [2,3,8,16,30,41,45] including tests of Peak-End Theory [14,15,31,36,40,42], there is much less research on (and currently no quantitative model of) judgements made at the time pain occurs.

Some researchers assume that pain can be evaluated in isolation without reference to prior experience [2]; indeed, the assumption of context-independence is implicit in the existence of pain rating scales [13,43,53], although use of these is now commonly believed to oversimplify the pain evaluation process [7,53]. Such an assumption would be consistent with an “absolute” account of pain judgement, according to which pain is predicted solely by the magnitude of the painful stimulus. Alternatively, as with other psychophysical judgements, real-time pain judgements could be relative and depend on how a stimulus compares with other painful experiences. The basic understanding of self-reported pain depends on understanding how such relative judgements are made.

We hypothesise that ratings of current pain can be influenced by other recent pain. How might such context effects occur? According to Adaptation-Level Theory [11,18,33,34,35], pain might be evaluated relative to a perceived mean stimulus in the recent context. Alternatively, people might use the same judgement processes as they have been shown to use for other psychophysical stimuli. Such judgements are typically well-described by Range Frequency theory (RFT) [27,28]. A demonstration that RFT characterises pain judgements could link pain research with the study of other...
psychophysical [27,29,32] and socioemotional judgements [6,20,22,38,49,50,51,52,54,55,56,57].

RFT states that judgement of a stimulus depends on a combination of its rank amongst other stimuli (the rank principle), and its position along the range of stimuli (the range principle). As applied to judgement of pain (a new domain for the application of RFT) the principles would operate as follows.

Under the rank principle, the higher a stimulus ranks amongst other stimuli, the more painful it seems:

\[ F_i = (r_i - 1)/(N - 1) \]

where \( F_i \) is the judgement by rank of stimulus \( i \), ranked at position \( r_i \) in a context of \( N \) stimuli.

Under the range principle, the higher a stimulus lies along the range of stimuli, the more painful it seems:

\[ R_i = (S_i - S_{\text{min}}) / (S_{\text{max}} - S_{\text{min}}) \]

where \( R_i \) is the judgement by range of stimulus \( i \), of magnitude \( S_i \), \( S_{\text{min}} \) is the lowest and \( S_{\text{max}} \) the highest stimulus in the context.

Overall judgement of a stimulus is expressed as:

\[ J_i = wR_i + (1-w)F_i \]

where \( w \) is a weighting parameter [55].

The studies reported below tested whether relative pain ratings are governed by the rank principle (Study 1) and the range principle (Study 2). Both studies tested RFT against the two rival accounts, absolute judgement and Adaptation-Level Theory.

**Study 1**

**Method**

Study 1 examined whether pain ratings were influenced by the ranked position of painful stimuli within different contexts. Using a methodology well-established in
research into rank-dependent judgement [6,20,55,56,57], we manipulated the rank position of painful stimuli, while holding constant their distance from the mean, and from the highest and lowest stimulus in both contexts. We predicted that particular stimuli would be judged more painful in the context in which they ranked highest.

**Participants.** We recruited an opportunity sample of 51 participants (35 female) from the University of Manchester; 70.6% were first- and second-year undergraduates who received course credits for taking part, with the remainder consisting of postgraduate students and staff who took part voluntarily. All participants were blind to the objectives of the study and none were involved in pain research. Participants gave their informed written consent, and the study was approved by the University of Manchester School of Psychological Sciences Ethics Committee. Participants were aged between 18 and 49 years (82.4% under 25) and 21.56% were left-handed. The majority of participants described themselves as White (78.4%); the next most represented ethnicity was Pakistani (9.8%). Participants were tested individually with an experimenter present.

**Design and procedure.** All participants experienced three blocks each comprising 11 painful stimuli. Each stimulus was a pressure applied to the fingers by a pneumatic pain stimulator. We asked participants to judge the severity of pain from each stimulus at the point of experience, without explicit reference to previous responses. Participants’ fingers were placed under the pain stimulator probe as described below, beginning with the ring finger of the left hand. In order to control for order effects, which might result in sensitisation or habituation of receptors at the site of stimulation, participants changed finger for each stimulus, in the following sequence:

*Left Ring; Left Middle; Left Index; Right Index; Right Middle; Right Ring...*
repeating this sequence throughout the three blocks to avoid repetition of a particular stimulus on the same finger with repeated blocks.

**Pain stimulation.** We delivered pressure pain using a pneumatic pain stimulator system designed by Dancer Design (St. Helens, UK). The system included a pneumatic force controller which uses compressed air to lower a 1cm² circular rubber probe at variable force. The circular probe was lowered onto the finger at the junction with the fingernail bed, centrally placed to cover an equal area of nail and skin. Each stimulus was delivered by passing a specific voltage into the pain stimulator, which translates this into pressure at the probe in a range from 0.00 kg/cm² (generated from 0.00v input) to 7.28kg/cm² (generated from 1.00v input). Specific voltages were generated by a bespoke computer program written in MATLAB 7.5.0 (Mathworks Inc., Sherborn, MA, USA) and passed into the pain stimulator via a LabJack U12 device (LabJack Corp., Lakewood, CO, USA). With a finger placed under the probe, each complete stimulus comprised a three-second depression time, followed by maintenance of full pressure for a further three seconds, after which pressure was released immediately. An emergency pressure release switch was accessible at all times, and we made clear to participants that they could abort the process and withdraw their finger immediately should the pain become too uncomfortable.

**Self-report measure.** The intensity of each pressure pain stimulus was rated on the 0-10 Numeric Pain Rating Scale [21], anchored by “No pain” (0) “Moderate pain” (5) and “Worst possible pain” (10). Participants made their response on a paper copy of the scale immediately after each stimulus, using only the whole integers on the scale.

We allocated odd-numbered participants to one group of 25 participants, and even-numbered participants to another group of 26 participants. All participants underwent three blocks, each of which consisted of 11 different pressure pain stimuli to
the finger. The 11 stimuli were presented in random order, as generated by the MATLAB computer program. Participants were not aware of the division into three separate blocks, but were presented with 33 stimuli as a single sequence. The first block was not intended for analysis, being the context-establishing block. This was followed by experimental blocks 1 and 2 (each identical to the context-setting block, in the same random order), results of which were averaged for analysis.

The two groups received different series of 11 stimuli. One group \((n = 25)\) received stimuli in a unimodal distribution and the other group \((n = 26)\) received stimuli in a bimodal distribution. These distributions are illustrated in Figure 1.

![Unimodal and Bimodal Distributions](image)

Figure 1. Illustration of unimodal and bimodal distributions of stimuli, Study 1.

Three target stimuli were common to both groups, but differed in rank position between the groups. The stimuli presented to each group are shown in Table 1. Both groups received stimuli ranging from 1.53 kg/cm\(^2\) to 7.28 kg/cm\(^2\), and the mean stimulus was the same for both groups \((4.41\text{kg/cm}^2)\). Means were based on the average pressure delivered to each group, which is appropriate as pain ratings from pressure stimuli have been shown to increase in a linear fashion as pressure increases [1].
To explicitly test the RFT rank principle against Adaptation-Level Theory, the magnitude of each of the three target stimuli relative to the mean was kept constant between the two distributions. If pain judgements were not dependent on context, but were based on the intensity of each stimulus alone, then the three target stimuli, being of equal pressure between the two groups, should elicit the same pain rating from both groups. If pain ratings were based on comparison with the mean, as Adaptation-Level Theory might suggest, again, the target stimuli should each produce the same pain rating from both groups, as the magnitude of each target stimulus relative to the mean was the same for both groups. However, if pain judgements are dependent on rank within context, then the same stimulus should be judged more painful in the context in which it ranks higher, so target stimulus 1 (2.97kg/cm$^2$) should be judged more painful by the bimodal group (where rank = 5) than by the unimodal group (where rank = 2). Target stimulus 2 (4.41kg/cm$^2$), ranked in sixth place in both distributions, should be
judged equally painful by both groups. Target stimulus 3 (5.84kg/cm²) should be judged more painful by the unimodal group (where rank = 10) than by the bimodal group (where rank = 7). Thus a cross-over interaction was expected, whereby the unimodal group would report less pain from target stimulus 1 but more pain from target stimulus 3, with the cross-over occurring at target stimulus 2.

**Results and Brief Discussion**

Two participants chose to abort the test and withdrew. A further three cases were excluded due to restricted use of the scale; those participants did not report even moderate pain during the experimental blocks. Table 2 shows mean reported pain for the three target stimuli. The differences in pain intensity rating between the groups appeared as predicted. As Table 2 illustrates, target stimulus 1 appeared to be judged to be more painful by the bimodal group (where rank = 5) than by the unimodal group (where rank = 2). Target stimulus 2 (which occupied the same ranked position in each condition) appeared to be judged similarly by both groups (occupying the same rank in both), and target stimulus 3 appeared to be judged more painful by the unimodal group (where rank = 10) than by the bimodal group (where rank = 7).

**Table 2**

<table>
<thead>
<tr>
<th>Stimulus</th>
<th>Pressure (kg/cm²)</th>
<th>Group</th>
<th>Unimodal (n = 21)</th>
<th>Bimodal (n = 25)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>M</td>
<td>SD</td>
</tr>
<tr>
<td>Target stimulus 1</td>
<td>2.97</td>
<td>Unimodal</td>
<td>2.76</td>
<td>1.10</td>
</tr>
<tr>
<td>Target stimulus 2</td>
<td>4.41</td>
<td>Unimodal</td>
<td>5.83</td>
<td>1.68</td>
</tr>
<tr>
<td>Target stimulus 3</td>
<td>5.84</td>
<td>Unimodal</td>
<td>8.12</td>
<td>1.22</td>
</tr>
</tbody>
</table>

A 2 (between: group) x 3 (within: target stimulus) mixed-model ANOVA revealed a main effect of target stimulus, $F(2, 88) = 257.02, p < .001$, confirming that
higher pressure was judged more painful, and no main effect of group. As expected, there was a significant interaction effect of target stimulus X group, $F(2, 88) = 3.69, p = .03$, which suggests that the rank position of a given stimulus amongst other painful stimuli influences judgement of how painful it appears. This interaction is shown in Figure 2, which illustrates that the intersection occurs around target stimulus 2, the mean pressure applied, with rank = 6 for both groups. (See Footnote 1.)

![Figure 2. Interaction between the unimodal and bimodal groups’ pain intensity ratings of the three target stimuli, Study 1.](image)

As the target stimuli for Study 1 were of the same absolute magnitude, and were at the same distance from the mean (4.41 kg/cm$^2$) in both distributions, differences in evaluation of these stimuli between the two groups must be wholly attributable to rank
effects, and not due to differences in absolute magnitude, nor to comparison with a
central tendency as would be suggested by Adaptation-Level Theory. As noted in other
literature on RFT [6,20,55,56,57], the true test of the theory is whether there is a
significant and symmetrical interaction effect, indicating that the results are based on
relative rank position of stimuli. Effect sizes, calculated from the differences between
mean responses from the two groups to target stimulus 1 and target stimulus 3, were
moderate ($d = 0.40$ and $d = 0.43$ respectively).

It is possible that the order of presentation might influence lower-level processes
such as sensitisation or habituation, which could contribute to the context effect.
Following the logic of previous RFT work on sensory judgements of taste [32], it seems
likely that such effects would manifest as an influence of a preceding stimulus on
judgement of the following stimulus. We tested this by analysing the effect of the
preceding stimulus on the ratings of each of the three target stimuli, common to both
groups. For each of the three target stimuli, we calculated whether the preceding
stimulus had been higher or lower in each of the two experimental blocks, and
conducted six (between: group) x (between: high/low predecessor) two-way
independent ANOVAs. These revealed no significant main effect of high/low
predecessor on the pain ratings given to any of the target stimuli with statistics ranging
from $F (3, 42) = .68, p = .41$ to $F (3, 42) = 2.45, p = .13$. There was no significant
interaction effect of group X high/low predecessor on any of these pain ratings, with
statistics ranging from $F (3,42) = .02, p = .89$ to $F (3, 42) = .68, p = .41$ (see Footnote
2). These results suggest that there was no systematic effect of the previous stimulus on
judgement of the current stimulus, and therefore no evidence of sensitisation or
habituation, and that this is equally true of both distributions.
Study 2

Method

Study 2 again used an established methodology [38,55,57], this time to test the range principle, according to which a stimulus appears more painful the higher it lies within the range bounded by other stimuli. The range principle suggests that if someone’s painful experiences were negatively skewed, with most pain tending toward the top of their range of experience, they would report more pain than someone whose painful experiences were positively skewed, with pain clustered toward the bottom of their range, even if both suffered equal physical trauma. We predicted that stimuli would appear on average to be more painful when experienced in the context where the stimuli were negatively skewed.

Participants. We recruited an opportunity sample of 40 participants (23 female) from the University of Manchester; 80% were third-year undergraduates, postgraduate students and staff who took part voluntarily, with the remainder consisting of first- and second-year undergraduates who received course credits for taking part. All participants were blind to the objectives of the study and none were familiar with pain research. Participants gave their informed written consent, and the study was approved by the University Of Manchester School of Psychological Sciences Ethics Committee. Participants were aged between 19 and 35 years (77.5% under 27) and 15% were left-handed. The majority of participants described themselves as White (90%); the next most represented ethnicity was Chinese (5%). Participants were tested individually with an experimenter present.

Design and procedure. We allocated odd-numbered participants to one group and even-numbered participants to another group, with 20 participants in each group.
All participants underwent three blocks, each of which consisted of 11 different pressure pain stimuli to the finger, as described in Study 1. The 11 stimuli were presented in random order, as generated by the MATLAB computer program. The first block was not intended for analysis, being the context-establishing block. It was made clear to participants that the first block would be a practice block, and that two further blocks would be presented containing the same number and range of stimuli but not necessarily in the same order. The 11 stimuli were re-randomised before each of experimental blocks 1 and 2, results of which were averaged for analysis.

The two groups received different series of 11 stimuli. One group received a positively skewed distribution of stimuli (where most stimuli clustered toward the lower end of the range of stimuli) and the other a negatively skewed distribution (where most stimuli clustered toward the higher end of the range of stimuli). These distributions are illustrated in Figure 3.

![Picture of positively skewed and negatively skewed distributions]

**Figure 3. Illustration of positively skewed and negatively skewed distributions of stimuli, respectively showing stimuli clustered toward the low and high end of the range, Study 2.**
Both distributions had a range of 4.18 kg/cm$^2$, both had aggregate pressure of 48.4 kg/cm$^2$, and the average pressure was 4.4 kg/cm$^2$ in both distributions.

Construction of averages is appropriate as pain ratings from pressure stimuli have been shown to increase in a linear fashion as pressure increases [1]. The stimuli presented to each group are shown in Table 3.

**Table 3**

*Pressure Pain Stimuli Presented to Positive and Negative Skew Groups, Study 2*

<table>
<thead>
<tr>
<th>Voltage into System</th>
<th>Pressure under probe (kg/cm$^2$)</th>
<th>Position within range of distribution</th>
</tr>
</thead>
<tbody>
<tr>
<td>Positive skew</td>
<td>Negative skew</td>
<td></td>
</tr>
<tr>
<td>0.45</td>
<td>1.53</td>
<td>1</td>
</tr>
<tr>
<td>0.55</td>
<td>2.58</td>
<td>2</td>
</tr>
<tr>
<td>0.60</td>
<td>3.10</td>
<td>1</td>
</tr>
<tr>
<td>0.61</td>
<td>3.20</td>
<td>2</td>
</tr>
<tr>
<td>0.62</td>
<td>3.31</td>
<td>3</td>
</tr>
<tr>
<td>0.63</td>
<td>3.41</td>
<td>4</td>
</tr>
<tr>
<td>0.65</td>
<td>3.62</td>
<td>5</td>
</tr>
<tr>
<td>0.68</td>
<td>3.94</td>
<td>6</td>
</tr>
<tr>
<td>0.69</td>
<td>4.04</td>
<td>4</td>
</tr>
<tr>
<td>0.71</td>
<td>4.25</td>
<td>7</td>
</tr>
<tr>
<td>0.74</td>
<td>4.56</td>
<td>5</td>
</tr>
<tr>
<td>0.76</td>
<td>4.77</td>
<td>8</td>
</tr>
<tr>
<td>0.77</td>
<td>4.88</td>
<td>6</td>
</tr>
<tr>
<td>0.80</td>
<td>5.19</td>
<td>7</td>
</tr>
<tr>
<td>0.82</td>
<td>5.40</td>
<td>9</td>
</tr>
<tr>
<td>0.83</td>
<td>5.50</td>
<td>8</td>
</tr>
<tr>
<td>0.84</td>
<td>5.61</td>
<td>10</td>
</tr>
<tr>
<td>0.85</td>
<td>5.71</td>
<td>11</td>
</tr>
<tr>
<td>0.90</td>
<td>6.24</td>
<td>10</td>
</tr>
<tr>
<td>1.00</td>
<td>7.28</td>
<td>11</td>
</tr>
</tbody>
</table>

Because both groups received the same average pressure, absolute judgement of each stimulus in isolation, using only the magnitude of each stimulus for evaluation, would result in both groups reporting the same average severity of pain. Such a result would also be consistent with Adaptation-Level Theory. The two distributions consisted of stimuli with the same mean and aggregate magnitude which were symmetrical
around that common mean. Comparison with the mean, as might be suggested by Adaptation-Level Theory, should result in a net zero difference in judgement between the two groups. However, according to the range principle, people in the negative skew group should judge the experience more painful because most of the painful stimuli clustered toward the higher end of the range of pain they experienced. In this case, ‘relatively-more-painful’ stimuli would occur more frequently, and each of these should be judged more painful than if they were at the lower end of the range. We therefore tested the range principle against both Adaptation-Level Theory and the absolute judgement account, and predicted that the negative skew group would report a higher average intensity of pain.

Results and Brief Discussion

The usual method of analysis of RFT range effects is to compare the average response from the two groups of stimuli [38,55,57]. As expected, the mean pain intensity reported on the 0 through 10 scale by the negative skew group ($M = 5.60$, $SD = 0.93$) appeared to be higher than that reported by the positive skew group ($M = 4.54$, $SD = 1.51$).

We analysed all responses (after averaging across experimental blocks 1 and 2) from the two groups with a 2 (between: group) x 11 (within: stimulus) mixed-model ANOVA, which revealed a main effect of stimulus, $F\left(5,190\right) = 155.46$, $p < .001$ (Greenhouse-Geisser), confirming that higher pressure was indeed judged to be more painful, and also a main effect of group, $F\left(1,38\right) = 7.14$, $p=.01$, indicating that the negatively skewed group generally reported more pain than the positively skewed group. The results of the ANOVA suggest that people found the stimuli in the negative skew distribution (where most stimuli were at the higher end of the range) more painful, despite the mean and aggregate pressure being the same for both groups. Although the individual judgement of each stimulus would be influenced by both range and rank
principles, the average relative rank of the stimuli was exactly the same in both distributions, eliminating rank effects from the result. Because we administered the same aggregate and mean magnitude of stimuli to both groups, neither absolute judgement nor Adaptation-Level comparisons can explain the results, which we can therefore attribute to the range effect. The effect size, calculated from the difference between overall means of the responses from the two groups was large, $d = 0.96$. (See Footnote 3.)

As described in Study 1, we tested whether low-level processes such as sensitisation or habituation could have contributed to the context effect. We analysed the effect of the preceding stimulus on the ratings of each of the two stimuli common to both groups. We conducted four (between: group) x (between: high/low predecessor) two-way independent ANOVAs. These revealed no significant main effect of high/low predecessor on the pain ratings given to either of the two stimuli common to both groups, with statistics ranging from $F(3,36) = .02, \ p = .89$ to $F(3, 36) = 2.87, \ p = .10$. There was no significant interaction effect of group X high/low predecessor on any of these pain ratings, with statistics ranging from $F(3, 36) = .07, \ p = .80$ to $F(3, 36) = 3.22, \ p = .08$. Again, the results suggest that there was no systematic effect of the previous stimulus on judgement of the current stimulus, and therefore no evidence of sensitisation or habituation, and that this is equally true of both distributions.

**Discussion**

The combined results of the studies show that evaluation of pain is a cognitive judgement process which takes into account the rank position of a painful stimulus and its proximity to the high or low extreme of the range of stimuli. Prior research has suggested that pain ratings are influenced by the context of other pain [5,18,33,34,35,46], and clinicians are aware of psychological factors in pain evaluation. Our results add to this literature by providing a quantitative model of how these context
effects occur. They also complement prior work which has suggested that people impose their own context on their use of scales, comparing present pain with their “usual” or “worst” pain [53]. Furthermore, clinicians’ judgements that do not match patients’ own pain evaluation [7,19,44] might suggest that the clinician and patient make assessments relative to different contexts. Previously it was unclear which of the three potential models (absolute judgement, Adaptation-Level Theory, or RFT) might best describe these processes. Our research can assist in the interpretation of this existing literature by proposing RFT, and not Adaptation-Level Theory, as the model for the cognitive processes underlying relative pain judgements.

We can be sure that RFT is the explanation for our results as we explicitly tested RFT against both Adaptation-Level Theory and absolute judgement. We achieved moderate effect sizes for Study 1, likely to be due to the size of the manipulation, there being a difference of only three positions in the rank of target stimuli 1 and 3 between the two distributions. The indication that the rank manipulation was responsible for the results is the resulting symmetrical interaction (illustrated in Figure 2), this being the well-established method of testing rank effects in RFT research [6,20,55,56,57]. If judgements had been based on the absolute magnitude of stimuli, one would expect similar responses to target stimuli 1 and 3, as was the case for target stimulus 2, which ranked at the same position in both distributions. A similar result might be expected if judgements had been made relative to the Adaptation-Level, as the distances from the mean of target stimuli 1 and 3 were kept constant in the two distributions.

The effect size from Study 2 was large, which can only be attributed to the range manipulation, as the average relative rank of stimuli was the same for both groups, eliminating rank effects from the results. We can be sure that absolute judgements were not made as this should have resulted in similar responses from both groups as the aggregate and average pressure were the same for both. The same result would be expected if judgements had been made relative to the Adaptation-Level, as the
symmetrical distributions around equal means should have resulted in a net difference of zero between the two groups.

It is important that the correct model for judgement is understood. Although it is most important to manage and minimise pain, it is also a warning mechanism to register illness or injury [24], described as “the fifth vital sign” [44]. Imagine a person whose pain is measured regularly to track progress of a medical condition. An absolute account of judgement would suggest that increased or decreased pain ratings would respectively correspond to worsening or improvement of their condition. An account based on Adaptation-Level Theory would suggest that their Adaptation-Level would shift to reflect the new mean, and pain ratings would remain fixed, despite changes in the underlying cause. According to an RFT account, under the rank principle, pain ratings would similarly remain fixed, as the relative rank positions of painful episodes would remain the same even if the overall range of pain became more or less severe, thus potentially masking any deterioration or improvement in their condition.

However, the RFT range principle could create something of a paradox. If an individual’s experienced range of painful events becomes more positively skewed, with occasionally more extreme pain extending the overall range, pain ratings could be generally lower as most painful episodes cluster toward the lower end of the range of experience. This might at first appear beneficial; pain is generally felt to be intrinsically a bad thing which should be avoided or reduced [4]. Yet under-reporting of pain could mask any worsening of the underlying cause, and obscure that “vital sign”.

Conversely, if an individual’s pain becomes more negatively skewed, with fewer episodes of low-intensity pain, most painful episodes would cluster toward the top end of their range of experience. Ratings could be generally higher even if their worst pain remains the same, as the more painful episodes would be relatively more frequent. This introduces implications which could inform future research into pain-reduction. If analgesia is successful for low levels of pain but not for more severe episodes, the
context might become negatively skewed, and these unimproved episodes could appear more painful. Reported pain could potentially increase rather than decrease.

Our study focused on testing the processes underlying momentary pain judgements, although we believe our results also complement Peak-End Theory [14,15,31,36,40,42] and other work on memory for pain [2,3,8,16,30,41,45]. A recent extension to RFT, Decision by Sampling (DbS) [39] has suggested that when making judgements from memory, people construct a mental sample which is populated from selected memories, as well as the immediate context. Evaluation of a particular stimulus is derived from its rank position within this constructed sample. It is possible that particularly salient stimuli from memory would be more likely to contribute to this sample, for example the peak and end of an experience [14,15,31,36,40,42]. If the stimuli sampled from memory are representative of momentary painful experiences on a daily basis, we would expect a high correlation between the daily judgements and retrospective evaluation. However, should the sampled stimuli not be entirely representative of the experiences on a daily basis, possibly due to displacement by other more salient stimuli, we would expect less correlation. This might go some way toward explaining the debate about the accuracy or otherwise of memory for pain [2,8,16,30,45].

**Potential Limitations**

All results were based on self-report. However, self-report was our required outcome in order to understand how individuals evaluate their current pain in real-time, during the second stage of self-reporting, using a pain rating scale of the kind used in clinical assessment.

We used evoked pressure pain in the laboratory. One concern with such research is that participants can anticipate increasing pressure and simply produce successive higher pain ratings accordingly. Participants have been shown to respond with such an
ascending pattern of ratings even when anaesthetised [9]. Our presentation of stimuli in double-blind random order removed the potential for such stimulus-independent bias.

Our results were achieved using only acute pain, and with the participants’ knowledge that they could terminate the source of pain instantly. This context is very different to that of clinical and especially chronic pain and it may not be possible to generalise these results to that context. A background context of chronic pain was not examined during these initial studies but could be considered for future studies into RFT effects of pain evaluation.

A particular concern regarding the RFT paradigm is that participants might simply rate the size of the stimuli presented in each context, rather than properly judge how painful each stimulus is at that moment [55,57]. If participants were simply labelling each stimulus according to the scale presented, one might expect them to use the full range of the scale, including the lowest and highest points. However, of 86 final participants in total, across all four conditions in two studies, only three participants averaged ‘0’ as their lowest response and ‘10’ as their highest, therefore participants clearly did not simply rate the stimuli from ‘0’ through ‘10’ without engaging with the task.

It is possible that order effects might have led to increased or decreased ratings over the course of the experiment, due to low-level processes such as sensitisation or habituation. We took precautions to control for order effects, by changing and resting fingers between stimuli, and randomising stimuli to avoid repeated pressure of similar magnitude at the same site. Habituation to pain is rarely reported, and seems to be associated with repeated stimuli to the same site [12]. Sensitisation appears not to occur with inter-stimulus intervals of more than three seconds [12], and our participants took longer than this to write their responses and change fingers. The additional analyses of the effect of preceding stimuli found no evidence that the context effects might have occurred because of such low-level sensory processes.
Conclusion

This research is the first to quantitatively model the mechanism by which current pain is evaluated in real-time with reference to other painful experiences, as described by RFT. It is the first to apply RFT effects to judgements of physiological (as opposed to hedonic [28]) pain, and supports both rank and range principles as the cognitive processes which underpin such judgements. These results contribute to existing literature on context-dependent pain evaluation, and forge a link between pain research and other psychophysical and socioemotional judgements.
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Footnotes

1 To confirm that the responses from undergraduates did not differ substantially from those from postgraduates and staff in Study 1, we conducted a 2 (between: group) x 3 (within: target stimulus) mixed-model ANCOVA (covariate: student/staff status). After controlling for possible effects of student/staff status, the main effect of target stimulus remained, $F(2, 86) = 37.61, p < .001$. The interaction effect of group X target stimulus was also retained, $F(2, 86) = 3.47, p = .04$.

2 Amongst the results of tests of the effect of the preceding stimuli on the target stimuli in Study 1, one extremely non-significant interaction of group X high/low predecessor ($F(3, 42) = 0.00, p =1.00$) was disregarded, as only one participant in the unimodal group had received a higher predecessor to that stimulus.

3 To confirm that the responses from undergraduates did not differ substantially from those from postgraduates and staff in Study 2, we conducted a 2 (between: group) x 11 (within: stimulus) x 2 mixed-model ANCOVA (covariate: student/staff status). After controlling for possible effects of student/staff status, the main effect of stimulus remained, $F(5, 185) = 10.38, p < .001$ (Greenhouse-Geisser). The main effect of group was also retained, $F(1, 37) = 6.36, p = .02$. 


Contribution to Knowledge

The combined results of the two studies presented in this thesis show that evaluation of pain is not an absolute, isolated response to the intensity of a painful stimulus, but a cognitive judgement process which takes into account not only the relative ranked position of a painful stimulus but also its proximity to the high or low extreme of the range of stimuli in an individual’s context. This is in accordance with, and adds a quantitative model to, prior work which has illustrated that pain judgements are made relative to the context of other recent pain (e.g. Brown, Seymour, Boyle, El-Deredy, & Jones, 2008; Kyle, et al., 2009; Kurniawan et al., 2010; Vlaev et al., 2009). This new cognitive explanation complements Peak-End Theory (e.g. Kahneman et al., 1993; Redelmeier, & Kahneman, 1996; Schneider et al., 2011; Stone et al., 2000; Stone et al., 2005) and other work on memory for pain (e.g. Broderick et al., 2008; Erskine et al., 1990; Stone, Broderick, Schwartz, & Schwartz, 2008; Terry et al., 2007), by outlining the processes by which momentary pain judgements are made.

The results also identify Range Frequency Theory as an alternative to the Adaptation-Level Theory explanation of relative pain judgement (Rollman, 1979, 1989), in accordance with the shift in emphasis of psychophysical research discussed in the introduction to this thesis. It is most important to understand which model of relative judgement operates for pain evaluation. Not only is it important to manage and treat pain, especially in chronic pain patients, but pain also provides an indication of the extent of illness or injury (Melzack, 2001) and serves as that “fifth vital sign” (Tait et al., 2009) in medical practice. Although clinicians understand that pain ratings are clearly not simply physiological responses, but also involve psychological factors, and prior research has acknowledged that pain ratings are made relative to a context of other
pain experienced, there has not until now been a quantitative model of how such relative pain judgements occur.

**Clinical and Theoretical Implications**

A clinical implication of the work presented in this thesis is on assessment of treatment progress using comparison of repeated self-reports of pain, which take no account of other painful experiences in the interim which might have changed the individual’s pain context, and hence might influence their latest judgement. This is in accordance with Williams et al.’s (2000) qualitative observations of idiosyncratic use of pain rating scales, whereby people appear to use previous pain still in their context for judgement, against which to judge current pain.

The Range Frequency explanation of pain judgement highlights important practical implications for the use of pain rating scales to measure progress of medical conditions and treatment. Such use of pain rating scales in clinical assessment (e.g. Jensen et al., 1986; Strong et al., 2002; Williams et al., 2000) implies that self-reported pain is an objective response to the severity of an underlying condition, so that altered pain ratings might indicate change in the physiological cause, or successful analgesia. However, the results presented in this thesis suggest that this is not the case; pain ratings are opinions formed relative to the patient’s pain context, rather than simple reports of their current level of discomfort. It is known that people impose their own context on use of scales, comparing present pain with their “usual” or “worst” pain (Williams et al., 2000). Use of scales to report pain intensity makes the implicit assumption that a reported ‘10’ on a pain rating scale actually reflects, for example, “worst possible pain” (McCaffery & Pasero, 1999) and not merely the worst, or something greater than the worst, pain that the patient has so far experienced. Conversely a low score on the same scale, interpreted as little or no pain, might simply be less painful than another painful condition which the patient is also experiencing, or has experienced in the past.
Schwartz (2007) reviewed patients’ retrospective and real-time self-reports of their health, and recommended asking for current rather than retrospective information, as memory for the latter can be unreliable and subject to bias. However, Schwartz also warned of the need to explore the cognitive mechanisms underlying real-time self-reporting, to avoid replacing a flawed methodology with new and different limitations. Whilst the results presented in this thesis results have advanced that process of exploration, they also suggest that Schwartz’s recommended real-time data capture is not a simple solution to the problems of unreliable memory for pain, as real-time judgements are themselves context-dependent variable reports.

It is also known that clinicians’ judgements do not always agree with the pain severity reported by patients (Craig, 2009; Lander, 1990; Tait et al., 2009), and have been shown to generally underestimate the patient’s pain (Prkachin, Solomon, & Ross, 2007). A Range Frequency explanation of pain judgements would suggest that clinicians and patients make their assessments relative to different contexts. Prkachin et al.’s review presented as a paradox the suggestion that the more experience a clinician has, the more he or she will underestimate pain in comparison with the patient’s own judgement. However, this could also be seen as a naturally occurring change in the judgement process as the clinician’s context for judgement changes with more exposure to people with varying levels of pain. Prkachin et al. also questioned whether this mismatch was indeed an underestimation on the part of the clinician, suggesting instead that the concept of self-report as the “gold standard” of pain diagnosis might itself be flawed.

Schwartz (2007) recommended the use of real-time pain ratings, to address supposed problems of bias in memory for pain, but warned that real-time ratings might themselves be susceptible to bias, and Erskine et al. (1990) suggested that they might be influenced by pain memories. However, the three-stage model of self-reported pain judgements proposed in this thesis suggests not that there is cognitive bias on real-time
pain judgements, but that each judgement is a mechanism of cognitive comparison between painful stimuli and depends on which stimuli are in the context at the time of judging. By extension, this suggests that current pain cannot be translated into a subjective opinion at all without some existing context within which to judge. With no prior experience of pain one might imagine ratings corresponding to the anchors of ‘0’ or ‘no pain’ (which could be interpreted as “what is pain anyway?”), ‘10’ or ‘worst pain’ (which could be interpreted as “the only pain I have ever felt”) or even ‘5’ or ‘moderate pain’ (which could be interpreted as “I have nothing against which to judge this pain”), but certainly not the finely graded responses demanded by pain rating scales.

If the patient’s self-report is susceptible not only to the patient’s own context effects, but also potentially to the clinician’s own experience of pain, self-report may well not be the “gold standard” it is generally believed to be. If the practitioner simply accepts the patient’s self-report, then over-reliance on analgesia and pain treatment might result. Prkachin et al. (2007) suggested that this supposed underestimation of pain might even have a positive effect, by placing emphasis on the recovery process rather than pain control. However, pain has to be treated. A definition used in clinical practice states that pain is what the patient says it is, and exists whenever the patients says it exists (McCaffery & Pasero, 1999), and clinicians have to act on this information. The results presented in this thesis add to the current understanding of how current pain is evaluated, but the debate on exactly how reliable this information can be will surely continue.

Of particular interest in the interpretation of the results presented here is a potential paradoxical effect of a changing context of pain. If a patient regularly gives self-reports of pain severity using a rating scale, these might be used for comparison in order to measure progress of a medical condition. Indeed, an absolute account of judgement would suggest that changing pain-ratings would indicate an improvement or
decline in health, as pain-ratings could be expected to be wholly based on the extent of illness or injury. An account based on Adaptation-Level Theory as suggested by Rollman (1979, 1989) would predict that even if the medical condition improved or worsened, their pain ratings would not change to reflect this, as the patient would adapt to the changing central tendency.

If only the rank principle of Range Frequency Theory were applicable to pain evaluation, this would predict a similar effect to that described for Adaptation-Level Theory. Pain ratings would not necessarily reflect any medical changes, as the relative rank positions of painful episodes would remain intact even if the overall range of pain increased or decreased in severity. The cognitive mechanism of comparison underlying the rank principle of Range Frequency Theory could therefore potentially mask any change in a medical condition.

However, judgements operating as described by the range principle could give rise to a paradoxical situation. The patient’s range of painful experiences could become more positively skewed, such that most painful events cluster at the lower end of their overall range of experience, but they experience occasional more extreme pain that would extend their overall range. Despite this more severe pain, the range principle of Range Frequency Theory predicts that their pain-ratings would be generally reduced. This at first would seem to be a positive outcome, as the patient appears to be feeling less pain, and pain should be reduced wherever possible (Broome, 1996). However, this reduction in pain ratings could be interpreted as under-reporting of pain, which could obscure any worsening of the medical condition manifesting as more extreme but relatively less frequent pain.

Conversely, if the patient’s range of painful events were to become more negatively skewed, with few episodes of low-intensity pain, most painful episodes would cluster toward the top end of their range of experience. Even though their most severe pain might not change, their pain ratings could become generally higher, as their
more painful episodes would now be relatively more frequent. Such a negatively skewed pain context might arise from pain-relief treatment if the analgesia were effective for lower-intensity pain but less so for more severe pain. This could result in the unimproved episodes appearing more painful, and pain ratings increasing, despite the partially-successful treatment.

This potential paradox is in accordance with a prediction from the earlier Range Frequency work of Brown, Wood, Ogden, and Maltby (2012) who measured student satisfaction based on the time taken to provide feedback on submitted coursework. The authors manipulated distributions of feedback times for assignments and found both rank and range effects. Specifically their participants reported higher overall dissatisfaction when the times to return coursework were presented in a negatively skewed distribution than when they were given in a positively skewed distribution. The authors advised that improving feedback time for a small proportion of marked work in order to improve the average feedback time could paradoxically cause the overall distribution of feedback times to become more negatively skewed, with most clustering toward the high end of the range, and student satisfaction regarding feedback could reduce rather than increase in these circumstances.

**Interpretation of Prior Research**

Interpretation of the results of earlier pain research can be reconsidered with rank and range effects in mind. As the introduction shows, there has been much conflicting evidence and many attempts to investigate relative pain judgements from various perspectives. Perhaps the Range Frequency explanation of momentary pain evaluation could help to eliminate some of the noise from the field of pain research.

For example, the results of the research presented in this thesis might have some bearing on the conflicting evidence for the accuracy, or inaccuracy, of memory for pain. Terry et al. (2007) reported that memory for pain does recall the actual original painful
sensation rather than the momentary judgement itself. Even if this is the case, it is possible that an individual’s context could have changed in the meantime, as a result of other painful experiences which might reduce the rank of the remembered pain. Similarly a long period with little or no pain might place the remembered pain higher in rank in that individual’s pain experience. In either situation a different relative judgement of the accurately remembered pain intensity could be made on recall, based on the new context.

Stone et al.’s (2005) attribution of exaggerated remembered weekly pain intensity to peak effects could be re-examined in terms of the relative position of painful episodes within the patients’ latest pain context at recall time. Those with high pain variability (and hence a broader range of pain intensities) exaggerated their recalled pain most. Stone et al. successfully replicated their findings with a second week of recall. From a Range Frequency perspective it could be argued that an individual’s pain context would have changed to include both trial weeks (and indeed painful episodes prior to the study) so that replication ought to be difficult to achieve; however the selective context against which recalled pain was to be judged was made explicit to patients (the previous week). Stone et al. concluded with the suggestion that another factor might influence both real-time and retrospective pain judgements. As weekly pain recall would include the full context of that week’s painful episodes at the time of recall, and real-time judgements during the week could only be made with reference to the context so far established, Range Frequency rank and/or range effects might possibly be that influencing factor.

There is clearly some debate about whether memory for pain accurately represents pain as it was experienced at the time (e.g. Broderick et al., 2008; Erskine et al., 1990; Stone et al., 2005; Terry et al., 2007), as discussed in the introduction to this thesis. If memory for pain is examined in Range Frequency terms, including the lower-level comparison process proposed by Decision by Sampling (Stewart et al., 2006), it is
likely that memory for pain depends entirely on what remains in the context for judgement when the memory is recalled. As suggested in the enclosed article, the mental sample constructed from the immediate context plus other information available from memory, knowledge and experience forms the context for relative judgement (according to Decision by Sampling), and judgement of any painful stimulus is based on its rank position within that constructed sample. Stone et al. (2005) identified the particular salience of the peak of a painful experience in memory, and it is possible that such salient events as the peak and end of an experience would be more likely to remain in, or re-enter the context for judgement, including judgements from memory. If the stimuli in this constructed sample are representative only of painful events that occurred during the real-time reporting period, then it would be expected that momentary ratings of pain and remembered pain would be closely related. However, if the events rated in real-time were displaced by other, highly salient stimuli, the remembered pain might correlate less with the momentary judgements. Schneider et al.’s (2011) conclusion that higher peaks and ends were related to the same individuals exaggerating their subsequent recall of daily pain would seem to lend support to this idea.

With regard to the debate about whether real-time pain judgements are biased (Schwartz, 2007) or influenced (Erskine et al., 1990) by memory for pain, or whether memory for pain is affected by current momentary pain (Schwartz, 2007), the results presented in this thesis suggest that the former is more likely, but that the real-time judgement is not biased, but is instead a result of comparison with the most salient remembered painful experiences. This Range Frequency interpretation of memory for pain also appears to contribute to Helme and Gibson’s (1999) suggestions about pain in older people, in that particularly salient memories of pain experienced during a long life might remain in the context for judgement and influence how subsequent pain is judged.

Kyle et al.’s (2009) attribution of their order effects to Adaptation-Level Theory could also be re-examined from a Range Frequency perspective. It could be argued that
the rank position of each of their stimuli changed as the full pain context emerged. Their participants received the lower intensity stimulus in a pre-experimental trial, then either the lower or the higher intensity in a first experimental trial, followed by the remaining stimulus in a second experimental trial. If the more intense stimulus were presented last, its rank would be 3 in the recent pain context, and hence be judged more painful than if it were presented first, in which case its rank would only be 2 at the time of judging.

Vlaev et al.’s (2009) results could also be explained using Range Frequency principles. If a given stimulus (medium intensity pain, in this case) were experienced alongside higher intensity stimuli then it would occupy a relatively low rank and sit at the lower end of the range of recent similar stimuli, and therefore would appear relatively less painful. However, if the same stimulus were experienced amongst lower level pain, then it would rank relatively higher in intensity and be at the high end of the range, and hence would appear more painful. Vlaev et al. actually claimed that their findings contradicted Range Frequency Theory on the grounds that the theory demands a long-standing historical perspective of previous pain. However, Parducci (1965) developed the theory from psychophysical judgements against an immediate context of very recent stimuli, and described quite clearly that every new related stimulus becomes part of the current context (Parducci, 1995).

Melzack et al.’s (1981) suggestion that a previous experience of pregnancy and labour reduces the pain experienced in subsequent labour due to altered expectations might also suggest a possible context-based pain judgement whereby the pain of the first labour changes a woman’s pain context from that point to include severely painful experiences against which new pain will be judged. Indeed, as part of an explanation of why gender differences in pain perception might be an artefact, and not an effect in itself, Mogil (2012) suggested that when women who have given birth subsequently use pain rating scales, the high end of the scale as they perceive it represents a higher intensity of pain than for most other women and men. As Mogil suggested, a ‘moderate’
pain of ‘5’ on a scale from ‘1’ to ‘10’ might well represent more pain for women who have given birth than for other people. This would be consistent with a Range Frequency explanation whereby the high end of the range is extended by this particularly intense experience, so that the pain context could become more positively skewed. Women who have given birth might actually under-report pain in comparison with other people experiencing less intense pain, as after childbirth a woman’s overall range of experienced pain would be extended to incorporate the pain of giving birth. Subsequent pain judgements could then be made against a context in which this high level of pain remains salient and available in the sample for comparison, in Decision by Sampling terms.

Melzack et al.’s (1981) results, which suggested that childbirth training or a difficult pregnancy can lead to a less painful labour, might also support a Range Frequency explanation. Parducci (1995) suggested that imagined as well as actual experiences could enter an individual’s pleasure context. If that could also be applied to imagined painful experiences, then in Decision by Sampling terms, people might sample imagined as well as remembered experiences in order to construct their context for judgement. Perhaps those women who underwent childbirth training and those who had experienced medical complications during pregnancy had allowed imagined severe pain to enter their pain context and judged the reality of their labour pain relative to that.

It seems likely that a Range Frequency explanation of momentary pain judgements will be shown to complement the Peak-End heuristic (see future research recommended below). However, at present it would also seem to raise new questions about how people make the momentary judgements from which Kahneman’s (2000) “snapshots” are built. For example, perhaps the peak stimulus might be judged differently depending on where it appears in the overall experience. If the peak comes at the end, the full context of pain is not known until then. Earlier moments would have appeared at the high end of the range so far experienced, and might have already been
judged to be more painful than they would have been in comparison with the peak. A late peak would rank even higher in the final context and would be judged in comparison with these exaggerated earlier moments, so the peak might be judged to be more painful than it would if it had been experienced earlier. Conversely, if the peak were to come early, perhaps later moments would be judged to be less painful than they would otherwise have appeared. Perhaps Peak-End effects can vary depending on where in the full context the peak appears. One might also question what constitutes a ‘painful experience’, with a ‘peak’ and an ‘end’. Range Frequency Theory would suggest that a wider context of previous pain could influence how every subsequent experience would be judged, and Decision by Sampling itself would suggest that selective additional stimuli from memory and experience can enter the context for momentary “snapshot” judgements.

**Potential Limitations**

The results of the studies presented in this thesis were based on participants’ self-reported pain. However, given that the intention was to investigate whether self-reported pain ratings might differ depending on the context in which they were administered, self-report was the required measure, using the type of pain rating scale that is used in clinical practice and in prior research. All participants were tested with only a female experimenter present which, as Kallai, Barke, and Voss (2004) suggested, could possibly have influenced the participants’ reactions to the painful stimuli. Only evoked laboratory pain was experienced by the participants, which means that the results were evident only for acute pain in a short-term contrived context, and cannot yet be generalised to a background context of chronic pain. The participants were always aware they could instantly terminate the painful stimulus by using the emergency pressure release switch, which is clearly a very different context from that of
clinical pain experienced naturally, so it is not yet possible to generalise the results to a clinical context on the basis of these two artificial laboratory studies.

It is possible that order effects might have led to ratings being inflated or diminished over the course of the experiment, due to low-level processes such as sensitisation or habituation, although precautions were taken to ensure that such risks were minimal, as described in the methodology section. Analysis of any possible effect of the preceding stimulus on the current stimulus suggested that no distortion of results occurred due to order effects. A related concern sometimes levelled at the Range Frequency paradigm (Wood et al., 2011; Wood, Brown, Maltby, & Watkinson, 2012) is that participants do not necessarily engage with the task, but might instead rate the relative size of the stimuli in each context according to the scale provided. In this case, this seems unlikely, as the stimuli provided no verbal or visual clues about the magnitude of each stimulus, unlike visual psychophysical trials (e.g. Parducci, 1965) or vignette-based hypothetical situations (e.g. Wood et al., 2011; Wood, Brown, Maltby, & Watkinson, 2012). Further evidence that this was not a feature of the results presented in this thesis is the fact that over the course of the two studies, only three participants gave an average low response of ‘0’ (“no pain”) and ‘10’ as their average highest response (“worst possible pain”). This shows that participants did not simply rate the stimuli from ‘0’ through ‘10’ but did attempt to properly judge the painful stimuli as they occurred, and responded to the context established by the manipulation. It also suggests that participants employed their own interpretation of the scale, as Williams et al.’s (2000) investigation into the use of rating scales might suggest.

Directions for Future Research

As noted in the limitations above, the results presented in this thesis alone cannot be generalised to apply to pain judgements of patients who have chronic pain or are enduring a clinical pain as a result of injury or medical condition. It would be
beneficial in future to test for Range Frequency effects on pain judgements against a background context of chronic pain. This would be likely to begin by administering evoked pain in the laboratory, using a similar method to that described in the enclosed article, to patients who have chronic pain, and compare their ratings with people without chronic pain. The challenge for any such research is first to establish a measurement of the chronic pain context, with its reliance on remembered pain for comparison with current pain.

A precursor to this might be to investigate how memory for pain enters the context for current judgement. Again using evoked laboratory pain, people could be asked to concentrate on a particular painful experience to reactivate a pain memory. Their pain ratings of current pain with and without the painful memory could be compared in a within-participants design with some days in between the repeated tests, to see whether identical current painful stimuli are rated differently after activating a particularly painful memory.

The evidence for Peak-End effects can be particularly compelling because researchers have conducted tests not only in the laboratory but in clinical settings (e.g. Redelmeier & Kahneman, 1996; Schneider et al., 2011; Stone et al., 2000). It would be useful to conduct a similar test of Range Frequency effects on people in acute pain but without the ability to terminate the pain at will, which was always possible during the experiments described in this thesis. However, the huge challenge for any such research would be to construct appropriate distributions of pain from different people’s momentary pain ratings during clinical procedures.

Perhaps more immediately promising is an exploration of a potential interaction between Range Frequency and Peak-End effects. It is expected that Range Frequency Theory will be found to complement Peak-End Theory. Whilst Peak-End Theory appears to explain retrospective judgements after the event, Range Frequency Theory can explain each momentary real-time pain judgement as the pain is experienced, which
then contributes to those retrospective judgements. A potential future study could use a similar behavioural measure to that used in the early Peak-End experiments already described (Kahneman et al., 1993), whereby participants chose which sequence of stimuli to repeat. The range principle manipulation for Range Frequency testing lends itself well to such experiments, as the negatively skewed distribution contains a lower peak stimulus than does the positively skewed distribution (see Figure 2 in the thesis introduction). It would be possible to manipulate the order of the negatively skewed context of pain stimuli so that the least painful stimulus is always presented last, to ensure a relatively less-painful end. The order of presentation of the positively skewed context could be manipulated to always present the most painful stimulus last. The peak stimulus would also be the end in the positively skewed context, and that would be higher than any stimulus in the negatively skewed context.

Peak-End Theory would predict that a retrospective evaluation of each sequence would find the positively skewed context more unpleasant (it having a higher peak and end than the alternative). Participants would experience both contexts (counterbalanced) and would be asked which they would choose to repeat. The hypothesis would be that, as in the standard range principle manipulation (Smith et al., 1989; Wood et al., 2011; Wood, Brown, Maltby, & Watkinson, 2012), people would judge the negatively skewed stimuli to be more painful during momentary real-time pain ratings of each stimulus, but despite this, they would retrospectively judge the positively skewed context to be more painful and choose to repeat the negatively skewed context, as Peak-End Theory would suggest.

Encouragement for such a design comes from an associate from the University of Warwick, UK (S. Aldrovandi, personal communication, July 18, 2013), who has conducted a similar experiment, using annoying sound tones as the noxious stimuli. This experiment used positively and negatively skewed contexts as described above, and results suggest that Peak-End Theory does indeed explain the retrospective
assessment of the overall sequence (demonstrated by participants’ preference to repeat the negatively skewed sequence, with a less noxious peak and end). Participants also rated the individual stimuli in the negatively skewed context as more unpleasant, as the Range Frequency Theory range principle would predict. Given this encouraging result, it is recommended that future research into relative pain evaluation should pursue the prediction that for a given set of painful stimuli, Range Frequency Theory can explain the momentary pain judgements, and complements Peak-End Theory which can explain the retrospective evaluation of the overall experience.

However, a possible confound in this design might be memory for pain, as people might choose to avoid the sequence most recent in memory and opt to repeat the first sequence they experienced, which is what occurred during a brief study to pilot the interaction of Range Frequency and Peak-End effects as described above. It also seems possible that their context could become contaminated by exposure to both negatively and positively skewed conditions within a very short period. To avoid such difficulties, a break would be needed between presentation of the positively and negatively skewed contexts (to avoid context contamination) and between the presentation of the second context and the decision on which to repeat (to avoid recency effects of memory for pain). Also, the sequence of stimuli should be repeated several times in each context to help to firmly establish the context before asking for momentary judgements.

Possible assistance for this design might come from the work of Leknes et al. (2013), who demonstrated the “hedonic flip” as discussed in the introduction to this thesis. Firstly, Leknes et al.’s results could be interpreted in the light of Range Frequency effects. The two contexts employed by Leknes et al. each involved two stimuli in which the higher intensity stimuli in each context would always be placed in a more painful category, and the lower intensity stimuli would always be placed in a more pleasant category. Range Frequency Theory would predict that moderate pain would appear less painful and more pleasant in comparison with severe pain, and more painful
in comparison with pain-free warmth. Secondly, despite each participant experiencing both contexts in the same session, Leknes et al. clearly regarded these as having established two distinct contexts for judgement. They appear to have achieved separation of contexts by leaving a 10-minute break between the two sets of stimuli, so this would be recommended as the minimum length of the break between the presentation of the positively and negatively skewed distributions to avoid context-contamination in the study suggested above.

A further direction for future research could take inspiration from Vlaev et al.’s (2009) paradigm which tested people’s willingness to avoid pain. Such a design would obviously present ethical challenges if participants were expected to endure pain unless they were prepared to pay to avoid it. However, it would provide a behavioural measure of Range Frequency Effects and provide further robust support for the Range Frequency model of pain evaluation if, for example, people are willing to pay more to avoid a repetition of the same objective pain when it is presented in a context in which it ranks higher.

**Conclusion**

The research presented in this thesis is the first to quantitatively model the cognitive mechanism by which momentary judgements of current pain are made against a context of other pain experienced. It is the first to test Range Frequency Theory as a model of relative judgements of physiological pain, as opposed to the hedonic pain discussed by Parducci (1995). It eliminates Adaptation-Level, and absolute judgement in isolation, as possible competing models of relative pain evaluation, and clearly establishes Range Frequency Theory as a good explanation of the cognitive processes underlying pain judgement. The results presented in this thesis demonstrate that both the rank and the range principles of Range Frequency Theory contribute to such
judgements. This work strengthens the link between pain research and current understanding of relative evaluation processes in other psychophysical and socioemotional judgements, and contributes to the emerging unified Range Frequency model of psychophysical, social and personal judgements.
References


