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A Potential New Fabric Evaluation Approach by Capturing the Brain Perception under Fabric Contact Pressure

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Abstract:	<p>The problem of the transmission mechanism of textile perception and the barrier to express textile cognition directly were the two major issues in the field of textile evaluation. In this study, an advanced biomedical imaging technology, functional magnetic resonance imaging (fMRI), which was non-invasive and had a higher temporal resolution and spatial resolution, was utilized to describe the features of brain perception in the brain mask areas under increased fabric contact pressures, and thus in an attempt to provide a new approach to express fabric comfort perception. As a result, we found that: (1) When fabric contact pressure increased from 0.5kpa to 1.5kpa, both of maximum activation intensity TZ and activation proportion K of peak points were transferred from postcentral gyrus in SI to amygdala, and were negative activations. Therefore, we drew the conclusion that: both of a lower and a higher fabric contact pressure (about 1kpa of proper comfort fabric pressure) would produce brain signal inhibitory effect on the SI and amygdala. The difference was the fact that the inhibition role on SI was more obvious under a lower pressure, while inhibition role on amygdala was more remarkable under a higher pressure, which meant that SI, particularly postcentral gyrus in SI, was likely to play a significant role on surface tactile perception of fabrics, while amygdala might be related to fabric oppressing sensation.</p>

A Potential New Fabric Evaluation Approach by Capturing the Brain Perception under Fabric Contact Pressure

Abstract

The problem of the transmission mechanism of textile perception and the barrier to express textile cognition directly were the two major issues in the field of textile evaluation. In this study, an advanced biomedical imaging technology, functional magnetic resonance imaging (fMRI), which was non-invasive and had a higher temporal resolution and spatial resolution, was utilized to describe the features of brain perception in the brain mask areas under increased fabric contact pressures, and thus in an attempt to provide a new approach to express fabric comfort perception. As a result, we found that: (1) When fabric contact pressure increased from 0.5kpa to 1.5kpa, both of maximum activation intensity T_z and activation proportion K of peak points were transferred from postcentral gyrus in SI to amygdala, and were negative activations. Therefore, we drew the conclusion that: both of a lower and a higher fabric contact pressure (about 1kpa of proper comfort fabric pressure) would produce brain signal inhibitory effect on the SI and amygdala. The difference was the fact that the inhibition role on SI was more obvious under a lower pressure, while inhibition role on amygdala was more remarkable under a higher pressure, which meant that SI, particularly postcentral gyrus in SI, was likely to play a significant role on surface tactile perception of fabrics, while amygdala might be related to fabric oppressing sensation.

Keywords

Fabric comfort, fabric contact pressure, brain perception, functional magnetic resonance imaging

1. Introduction

1.1 Background

In this era of too much emphasis on industrialization, textile comfort perception

problem was a major issue which had always been ignored by textile industry, the fabric comfort issue of the contact pressure was not only one of the most basic problems of the transmission mechanism of fabric comfort perception and a non-indirect representational problem in the textile evaluation area, but also a significant problem that should not be ignored in the actual application process of many industrial textiles, such as: various functional textiles, protective textiles, and especially for biomedical textiles which were utilized in the human body, body-shape textiles having a high elasticity and high fabric pressure, and so on. However, various traditional evaluation methods of fabric comfort were just limited to the textiles themselves, but ignored this important fact: the main body of comfortable expression was human themselves, not fabric. Therefore, the best method to get to a standard expression fitting for all groups was to start with the origin of perception, the brain.

Since the beginning of the 20th century, thousands of textile scholars have been trying to make full use of various psychological evaluation methods¹⁻⁴ (also named subjective evaluation methods); physical evaluation methods⁵, which combined fabric tactile perception with textile pressure; psychophysical evaluation methods⁶ by connecting psychological touch sensations with physical mechanical properties of textiles; and physiological evaluation methods⁷, such as: EEG (Electroencephalogram)⁸⁻¹², ERP (Event Related Potentials)^{13, 14}, HRV (Heart Rate Variability)¹⁵, ECG (Electrocardio-gram)¹⁶, EMG (Electromyography)^{17, 18}, et al. These four mainstream evaluation systems to quantitatively describe the contact pressure comfort from the fabric.

In the past few decades, for the sake of simplicity and convenience, people always utilized the most original subjective evaluation on the wearing comfort of some new textiles, such as smart clothing³ and functional textiles¹. What was more objective was to use the psychophysical evaluation method, thus a series of mechanical measurement systems based on various measuring instrument for physical and mechanical properties of textiles, such as KES-FB (Kawabata Evaluation System -

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Fabric) test methods, were developed to objectively characterize the tactile properties of miscellaneous textiles, even porous polymeric materials, by simulating the dynamic contact processes during human skin contact with the materials and in consideration of different aspects of tactile sensations¹⁹. These measurement systems could measure the compression, bending, friction, and thermal transfer properties in one apparatus, like Fabric Touch Tester (FTT)²⁰, based on 13 fabric indices including bending performance, surface friction, surface roughness, compression and thermal conductivity five aspects, which was exploited to measure fabric handle properties. But all of them ignored the essence of fabric comfort perception was human body themselves, therefore, physiological evaluation methods emerged at the right moment. What we needed to do was to explore and capture the most authentic fabric sensory origins accurately and quickly with advanced physiological instruments. No matter of EEG, HRV or ERP, all of them were trying to do that. But in this topic, we set foot in a more advanced field of science and technology, that was fMRI (functional Magnetic Resonance Imaging) due to its higher spatial resolution than them²¹ and the mechanism superiority of the origin of fabric perception itself. Besides, some of the subtle sensory information, such as: light pressure to the forearm, which ERP could not capture, could also be picked up with the fMRI²². Thereby, an exploration extremely closed to the origin of fabric perception had begun.

In recent years, more and more researches²³⁻²⁶ about human perception of fabric texture contact proved that the brain areas associated with perception of fabric contact were mainly located in the somatosensory cortex (including the primary somatosensory cortex SI and the secondary somatosensory cortex SII) and the insular cortex. In particular, a happy comfortable fabric contact perception was likely in the brain's high level process area of SII, while a uncomfortable perception might be in the frontal lobe. Moreover, compared with comfort perception, uncomfortable perception was stronger. Another study²⁷ believed that rolandic operculum in SII was closely related to fabric surface texture perception, such as roughness. But the present findings were consistent with the hypothesis that activation points at hairless skin

stimulated by fabric occurred more in the somatosensory area, especially in SI, which was associated with the primary rough touch perception of human body itself. A pleasant touch from glabrous skin, mediated by A-beta afferents, was processed in the somatosensory cortex and represented an analytical process dependent on previous tactile experiences. However, activation points, when fabric stimulation was applied to hairy skin, occurred more in the insula cortex, which was connected to human emotions processing^{28, 29}. A pleasant touch from hairy skin, mediated by **C-tactile afferents (also named CT afferents)**, was processed in the limbic-related cortex (including orbitofrontal cortex and posterior insula) and represented an innate non-learned process^{30, 31}. Besides, studies have shown that rational perceptions were associated with contralateral cortex activation areas, while emotional imagination and emotion were associated with ipsilateral cortex³². Moreover, precuneus region which positively be related to happiness³³ should also be considered in this subject because it might also be associated with a good sense stimulated by contacting with textiles, such as a comfortable tactile impression. As for human uncomfortable sensory, the largest research results showed that activation response was appeared in bilateral amygdala when human skin was accepted fabric contact pain stimulations^{34, 35}.

Therefore, in order to avoid interferences from external factors such as all kinds of noises and psychological effects on the brain analysis of perception, the five brain regions mentioned above, including SI, SII, amygdala, precuneus and insula, which were considered to be may related to the perception of fabric touch pressure, were ultimately selected as a brain mask, and we only analyzed in the brain mask areas. Functional brain regions in Brodmann areas (BA) and anatomical structural brain regions in Anatomical Automatic Labeling (AAL) corresponding to each brain mask region were shown in Fig.1 and Table 1.

Fig.1 Brain Mask Areas

Table 1 Locations in Functional Brain Regions and Anatomical Brain Regions corresponding to Brain Mask Regions

Brain Mask Areas Associated with the Perception of Tactile	Functional Brain Region Localization (BA)	Anatomical Structural Localization(AAL)
Primary Somatosensory Cortex (SI)	BA3a, BA3b, BA2, BA1 ³⁶⁻³⁸	Postcentral Gyrus
Secondary Somatosensory Cortex (SII)	BA5, BA40, BA43	Parietal Operculum(OP 1 – OP 4) ^{39, 40} ;
Amyglada	BA28, BA34, BA35	Deep and medially within the temporal lobes, including Amyglada Stria terminalis (AStr), Superficial group (SF), Centro medial group (CM) and Laterobasal group (LB) ⁴¹ ;
Precuneus	BA7A, BA7M, BA 7P ^{42, 43}	Part of the superior parietal lobule;

Insula BA13, BA21, BA22, BA41 Folded deep within the lateral sulcus,
including Insular lobe granular areas (Ig1,Ig2)
and Insular lobe granular area(Id1)⁴⁴

Materials and Methods

Subjects

Six healthy female volunteers with similar age (mean=25.3± 2yrs old, SD=1.75) and BMI (mean=20.6±2Kg/m², SD=1.29) were recruited. They were inquired and examined to ensure having no any mental illness, neurological diseases, psychiatric history, and injury of brain tissue structure, with normal neural responses and conduction system, each part of the body had no metal implants, not pregnant, no space phobia, without heart disease, epilepsy, restlessness, renal insufficiency or any other psychological and physiological diseases. They were asked not taking any medication, and keeping a normal sleep and diet normal in the first three days. Besides, due to a lot of cosmetics containing heavy metals, so before fMRI experiment, all subjects were not allowed to make up, and all of jewelry, tattoo (eyebrow tattoo), hair dye, etc, which might cause burns, were removed in advance.

Before the experiment, the subjects were aware of the principle of fMRI and the possible physiological reactions during the scanning process, the test could be terminated at any time if the subjects raised leg to signal any physical discomfort. Furthermore, they were trained simply about the scanning procedure and signed the informed consent. The study was approved by the ethics committee of Donghua University.

Materials and Instruments

One widely used corset on the market was selected as the experimental sample, whose effective area was 24.5cm×50cm with the widths of hook face and loop face 2.5cm, 10cm respectively.

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Clothing pressure test using AMI3037 Air-pack Type Contact Pressure Measurement System, ranged from 0 ~ 34kpa, output voltage 0 ~ 3.4V, accuracy $\pm 0.2 \sim 0.45$ kpa, manufactured by AMI TECHNO Co., Ltd in 2006.

FMRI experiments were conducted in collaboration with Ruijin Hospital of Shanghai Jiaotong University. Neuroimaging data was obtained from Ingenia 3.0T medical fMRI equipment manufactured by Philips Investment co., LTD, provided and supported by Ruijin Hospital. After locating the scanning position, the 3D scrambling GRE T1WI sequence structure image scanning was used to determine the high-resolution lateral anatomical structure diagram of each subject's entire brain from left to right, so as to prepare the individual brain to be standardized into standard space in subsequent data preprocessing.

The scanning parameters of structural images were: the scanning interval TR (Inter-scan Interval)=3s, which referred to the time interval between acquiring a plane of one volume and the same plane in the next volume. TE (Time of Echo)=30s, double Angle of FA (Flip Angle)=8°, View FOV (Field of View)=256 x 256mm, gathering matrix of every level was 256 x 227mm, layer thickness was 3 mm, and there was no interval between layers, 180 layers in total, and the total scanning time was 300s.

The scanning parameters of functional images were: using gradient echo and single excitation echo planar imaging technology, with TR=3s, TE=30s, FA=90°, FOV=192 x 192mm, gathering matrix of every level was 96 x 96mm, 3mm with a thick layer of no layer interval, a total of 47 sagittal slices, slicing direction was horizontal. The pre-scanning time was 9s, the actual scanning time of each sequence was 189s, and the time for data analysis was 180s.

Fabric Contact Pressure Testing

Fabric contact pressure testing was performed in constant temperature and humidity laboratory in Donghua University. Environmental temperature and humidity were about $\pm 20^{\circ}\text{C}$, $\pm 65\%$ RH, respectively. Each subject was tested after entering the laboratory 30 minutes to ensure that they had been adapted to temperature and humidity. As a result of the pressure of sample was mainly in the distributed in the chest, waist and abdomen, and according to the garment pressure comfort threshold tested and calculated on lateral abdomen, middle shoulder, scapula, armpit, where waistline and scapular line cross, abdomen, lateral empire line, anterior center of waistline and underbust nine measuring points by psychophysical limit-step method, the underbust of 0.937kpa tended to be the minimal value in comfort threshold⁴⁵. Combined with the fact that cardiac indicators such as heart rate and heart rate variability could be used as evaluation indicators of fabric comfort⁴⁶⁻⁴⁸. Finally, the left liver point near the heart which was located in underbust was selected as the characteristic measurement point to measure the clothing pressure. Considering that the comfort pressure of the fabric at that point was about 1kpa, we chose the pressure values of 0.5kpa and 1.5kpa close to it as the measurements. The experimenter marked each subject's body measurement point, then pasted pressure sensor film in the point, participants were asked to put on sample in turn and still natural relaxation, and the pressures were measured by adjusting the length of the magic tape. Each pressure test lasted 1 min and averaged the pressures.

fMRI experiments

A block design⁴⁹ experiment was adopted. There were three same blocks in each time course sequence, the former 30s in one block, subject was in a rest state, which had no any fabric pressure applied, while in the latter 30s in each block, clothing pressure was conducted. Repeating the block for three times and averaging the brain data for further analysis. fMRI experiments were proceeded with fabric pressure of 0.5kpa and 1.5kpa, respectively.

Before entering the scanning room, it was required to wear loose-fitting clothes

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without metal, magnetic or significant wearing pressure. During the whole procedure of the experiment, the subjects closed their eyes and remained awake. They were required to concentrate in the experiment and not to think of other things which was not related to the stimulation of fabric pressure.

Results and Discussion

After a series of brain imaging preprocessing operations, individual analysis and group analysis operated in SPM12⁵⁰ (Statistical Parametric Mapping 12), two indicators were of significance in the results: activation intensity T_z and activation proportion K (%), which could represent the perception of stimulation of fabric quantitatively²⁴. T_z was β value generated by GLM (general linear model) in SPM 12 which had no units, so we could use T_z to made comparisons between groups. Its actual meaning represented the difference between the average BOLD (Blood Oxygenation Level Dependent) signal in the pressure block and rest block. The higher the absolute value of T_z was, the stronger the relative activation signal was. Positive T_z values represented positive activations, which indicated fabric touch pressure increased the cerebral blood flow and neural activity in the local brain region. In other words, when the fabric stimulus was applied, oxygen uptake was far less than the increase in blood flow, which caused the concentration of paramagnetic deoxyhemoglobin was reduced. On the contrary, negative T_z values represent negative activations. K referred to the number of activated voxels in this brain area accounts for the proportion of total number of activated voxels in whole mask brain areas. The larger the K value, the greater the range of activated voxels in the brain region were.

In the results, we conducted the most rigorous FWE (Family Wise Error) correction on the results of group analysis to ensure the probability of any false positive was within 5% by combining with the research practice of spatial perception information of healthy human brain based on fMRI^{51, 52} and research cases of contact thermal pain

stimulation⁵³. Besides, in view of this subject was an exploratory study, therefore, in the case of low error rate, all activated brain areas also should be included as far as possible, we finally put the threshold of activated brain area cluster as zero, even a single activation point would also be shown in the results. Data with no stimulus activation point and data with significant artifacts were discarded in analysis⁵⁴. Eventually, positive activation maps under fabric contact pressure of 0.5kpa and 1.5kpa were shown in the Table 3, Fig.2 and Fig.3 by using SPM12 (Statistical Parametric Mapping), AAL (Anatomical Automatic Labeling), Xjview and other brain imaging analysis software.

Fig.2 Positive Activation Maps under Fabric Contact Pressure of 0.5kpa (a) and 1.5kpa (b), Negative Activation Maps under Fabric Contact Pressure of 0.5kpa (c) and 1.5kpa (d).
(The colored slices were in the mask, the slices in black and white were corresponding to color slices)

Fig. 3 Histogram of Activation Intensity under Fabric Contact Pressure of 0.5kpa (a) and 1.5kpa (b), Pie Chart of Activation Proportion under Fabric Contact Pressure of 0.5kpa (c) and 1.5kpa (d) (The blue font indicates the maximum negative activation, while the red font indicates the maximum positive activation)

Table 2 Positive Activation Information Table in the Brain Mask Regions under the Stimulations of Fabric Contact Pressure of 0.5kpa and 1.5kpa

Peak Point	0.5kpa		1.5kpa	
Brain Area	(MNI), Tz, E	K (%)	(MNI), Tz, E	K (%)
IPO	(-45,-12,30), 2.98,1	22.73	NONE	0
	(54,-21,54), 2.86, 1			
	(48,-21,39), 2.86, 1			
	(-36,-21,36), 2.76,2			
IIPO	NONE	0.00	(63,-9,15),3.22,2	3.77
IIRO	NONE	0.00	(51,-12,15),3.13,1	1.89
IVPS	NONE	0.00	(-30,-66,51),2.72,1	1.89

*E was the number of continuous linked activators in the activated cluster. IPO: Postcentral in SI; IIPO: Postcentral in SII; IIRO: Rolandic Operculum in SII; IVPS: Superior Parietal Gyrus in Precuneus; NONE: significant activations.

Table 3 Negative Activation Information Table in the Brain Mask Regions under the Stimulations of Fabric Contact Pressure of 0.5kpa and 1.5kpa

Peak Point Brain Area	0.5kpa		1.5kpa	
	(MNI), Tz, E	K (%)	(MNI), Tz, E	K (%)
IPO	(39,-39,66),-3.73,2	31.82	(-48,-33,60),-3.34,1	15.09
	(24,-42,66),-3.51,2		(39,-39,63),-3.16,2	
	(36,-30,42),-3.22,1		(-54,-18,54),-2.97,1	
	(33,39,51),-2.81,1		(-54,-24,51), -2.86,2	
	(-42,30,54),-2.73,1		(-51,-36.57), -2.74,1	
			(42,-33,63),-2.65,1	
ISM	(36,-36,42),-2.92,3	13.64	NONE	0.00
IIRO	NONE	0.00	(-42,-18,18),-3.31,6	13.21
			(-39,-24,18),-2.82,1	
IIIAG		4.55	(-21,0,-21),-3.47,12	26.42
	(-27,-3,-21),-3.62,1		(33,0-30),-3.14,1	
			(-24,-6,-12),-2.66,1	
IIIIHI	(27,-6,-21),-3.3,2	9.09	(27,-6,-24),-3.41,10	22.64
			(-27,-6,-21),-2.74,1	
			(-33,-3,-27),-2.67,1	
IIIPHI	NONE	0.00	(-27,0,-30),2.92,2	5.66
			(18,-6,-18),2.75,1	
IVPS	NONE	0.00	(24,-63,60), -3.04,2	9.43
			(21,-72,57),-2.8,1	
			(-24,-54,69),-2.79,1	
			(-36,-54,63),-2.66,1	
IVPC	(12,-72,57),-3.55,1	9.09	NONE	0.00
	(-3,-78,48),-3.28,1			
VHI	(42,-18,-9),-3.15,1	9.09	NONE	0.00
	(39,-12,12),-2.72,1			

*E was the number of continuous linked activators in the activated cluster. IPO: Postcentral in SI; ISM:

SupraMarginal Gyrus in SI; IPO: Postcentral in SII; IIRO: Rolandic Operculum in SII; IIIAG: Central Amygdala

in Amygdala; IIIHI: Hippocampus in Amygdala; IIPHI: ParaHippocampal in Amygdala; IVPS: Superior Parietal Gyrus in Precuneus; IVPC: Central Precuneus in Precuneus; NONE: significant activations.

Activation results under fabric pressure of 0.5kpa

As could be seen from activation results of the brain mask areas (SI, SII, amygdala, precuneus and insula) under the action of 0.5kpa fabric pressure, as shown in Figure 2(a), Figure 2(b), Figure 3(a), Figure 3(b), Table 2 and Table 3, compared with maximum negative activation peak point intensity T_z (-3.73) and maximum negative activation proportion (31.82%) located in IPO (belonged to SI), a small amount of positive activations in the IPO ($T_z=2.98$, $K=22.73\%$) were almost negligible. That was, under the surface texture sensory contact with low pressure, the SI brain area was significantly activated, and the degree of negative activation (including T_z and K) was more significant than that of positive activation.

Activation results under fabric pressure of 1.5kpa

As we could seen from Figure 2(c), Figure 2(d), Figure 3(c), Figure 3(d), Table 2 and Table 3, when the fabric contact pressure increased to 1.5kpa, very few positive activations were found, but large areas of negative activation were found in amygdala, SI, SII, precuneus, the intensity and proportion of negative activation decreased successively. Both of the maximum negative activation intensity peak point ($T_z = -3.47$) and maximum proportion of negative activation ($K = 26.42\%$) were located in IIIAG, which was belonged to amygdala), while IPO whose maximum positive activation intensity was 3.22 and maximum positive activation proportion was just 3.77%.

Comparison of activation results between fabric contact pressure of 0.5kpa and 1.5kpa

From the perspective of T_z and K , under the effect of 0.5kpa fabric stimulation, the maximum negative T_z was -3.73, the maximum negative K was 31.82%, and under the effect of 1.5kpa, the maximum negative T_z and K decreased to -3.47 and 26.42%,

respectively. That was, compared with 0.5kpa, under pressure stimulation of 1.5kpa, both of the maximum activation points were negative, while the difference was that the maximum activation degree was reduced.

According to the activation location, the brain area where the maximum negative activation intensity was located transferred from IPO to the brain area of amygdala. That was: when the pressure increased, the negative activation in SI area had a down, instead, the maximum negative activation was obtained in amygdala area.

Discussion

Under the effect of 0.5kpa fabric stimulation, why was the maximum activation point located in SI region?

In the early 1990s, many researches proved that in contact with electrical stimulation⁵⁵⁻⁵⁷ and thermal pain stimulation⁵⁸⁻⁶⁰, SI would appear different degrees of meaningful activation responses, and with the increase of repetitions, SI brain regions activated will gradually weaken. The first time we found inhibitory effects of noxious stimuli in SI activity was in monkey's brain. Afterwards, Apkarian et al⁵⁹ showed that blood flow in the human SI also decreases when the human skin was stimulated by heat, because the presence of pain reduced tactile perception. However, another explanation was inhibition of SI tactile activity by noxious stimuli might happen at lower levels of the neuraxis rather than through a direct inhibitory influence at the level of SI. The inhibition was related to the stimulation of C fiber^{60, 61}. Light touch-sensitive c-fibres (also known as c-low-threshold mechanosensitive nerves) were first discovered in rodents in 1939 by Zotterman⁶², a third class of C-fibre afferents that code for the pleasurable properties of touch – c-tactile afferents or CTs. CTs only existed in human hairy skin^{30, 63}, played a critical role on tactile emotional response, especially for signal pleasant aspects of gentle touch^{64,65}. If the c-fibres were inhibited, it may represent a bad feeling or discomfort feeling. Garzon T. R.Y used fMRI to observe the influence of the tactile stimulus intensity in SI cortical responses,

which also found that SI cortical representation of a tactile stimulus with fMRI was modulated for the intensity of the stimulus applied⁶⁶. All of these researches acknowledged somatotopic organization of SI pain responses, and SI had a downward-modulating effect on tactile perception, described as a “touch gate” by Apkarian et al⁶⁷. In this project, under the fabric pressure of 0.5kpa, high levels of negative activation in SI reflected that a too mild fabric contact pressure could also produce a discomfort feeling in the brain, and this discomfort might well be caused by macrogeometric properties of fabric surface. Because functional brain regions involved in the macrogeometric properties of fabric (such as pliability) was located in SI, and the perception of microgeometry of fabric surface (such as roughness and glutinousness) in SII⁶⁸.

Why did the maximum point transfer from SI to AG when the pressure increased to 1.5kpa?

From the view of the neural physiological mechanism, transmission routes of nociceptive information and somatosensory information were different, serial information from somatosensory were integrated automatically after transmitting from somatosensory area SI to the posterior parietal cortex SII (posterior parietal cortical areas) and insula (insular cortex), again by the insula to the amygdala (including amygdala, perirhinal cortex, and hippocampus)²⁶, while nociceptive information in SI and SII were parallel processing⁶⁹, but all of them were ended at amygdala, there was no doubt that amygdala was a very important brain area in reaction of tactile perception. A large number of studies in molecular biology, imaging and pharmacology had provided evidence for the involvement of the amygdala in pain perception⁷⁰. In acupuncture stimulations^{71, 72}, nonverbal sad auditory stimulations^{73, 74}, terrible visual stimulations^{75, 76}, contact thermal pain stimulations^{34, 35} and other pain sensory stimulations, the human amygdala all showed stronger and extensive negative active regions. Many studies⁷⁷ had shown that the brain areas involved in pain information processing and included contralateral SI, bilateral SII, bilateral insula and amygdala, et al, touch intensity ratings correlated significantly with BOLD

response in the right hemisphere (contralateral) SI, right insula, and bilateral SII, especially for the right SI, while ACC (anterior cingulate cortex) activity, who innervated mostly the basolateral and central amygdala nucleus⁷⁸, was correlated with emotions⁷⁹. Neugebauer⁸⁰ believed that there were three types of neurons in the central amygdala which may be related to the emotional response of pain. The first type of neurons were nociceptive specific neurons (NS) which were excitatory to injurious stimuli. The second category of neurons were inhibited neurons (INH), which had an inhibition performance to noxious stimulation, the third type of neuron were low threshold neurons (LT), they responded to both harmful and non-harmful stimuli, but more stronger to harmful stimuli. In this study, the amygdala area was strongly inhibited under fabric pressure of 1.5kpa, which might be related to INH.

Why was there a significant increase in the negative activation range of the amygdala but a slight decrease in activation intensity as fabric pressure increased?

According to Nakagawa et al⁸¹, the central amygdala was directly connected to the spinal cord and brain stem through the spinal cord - (trigeminal) - brachial nucleus – amygdala pathway, which was involved in the transmission of visceral pain. Visceral sensory information could also be passed on to the nucleus of the lone bundle, which had a fibrous connection to the central amygdala, So the central amygdala was quite possibly to respond to physical noxious stimulation. That was, neurons in the central amygdala might respond to damaging mechanical or thermal stimulation on the surface or deep tissue of the skin, especially on the deep tissue, the response would be stronger. That was why negative activation scope in amygdala under 1.5kpa was much larger than under 0.5kpa, the relatively slight decrease in activation intensity might just because excessive increase of activation areas caused average activation intensity decreased slightly. Meanwhile, the negative activation of amygdala under 1.5kpa also suggested that the amygdala was associated with the uncomfortable perception of the compression of the fabric on the deep skin tissue.

Why was the maximum negative activation under both kinds of pressure, and the

maximum negative activation intensity and negative activation ratio decrease with the increase of pressure?

The so-called negative activation referred to that the BOLD signal under pressure was smaller than that under static state⁸², which was caused by imbalance of oxygen supply and oxygen consumption⁸³. Under the pressure of excessive fabric pressure, the local cerebral blood flow decreases and the rate of oxygen consumption was higher than the rate of oxygen supply, which would inevitably lead to the reduction of neural activity and negative activation in brain imaging. Under the effect of too small fabric pressure, the speed of cerebral blood flow increased slowly, but the oxygen consumption of nerve activity was too large, resulting in the oxygen consumption was greater than the oxygen supply, which also inhibited the nerve activity and presented negative activation. Under the effect of the two kinds of contact pressure in this subject, the maximum activation point was located at the negative activation point, which indicated that in these two cases, the brain areas of the mask were mainly dominated by inhibition of neural activity. What's more, negative neural activities always represented negative induced emotions, such as: depression⁸⁴, loneliness⁸⁵ unpleasantness⁸⁶, visual discomfort/pain⁸⁷, thermal uncomfortable⁸⁸, etc. The difference was that the negative feeling under a too little fabric pressure was due to excessive oxygen consumption, while the one under a too high fabric pressure was due to insufficient oxygen supply. But all of these told us that these two fabric pressure caused discomfort contact. However, the decreases of both of negative activation intensity and negative activation proportion were only because the decrease of oxygen supply caused by the increase of pressure was not as large as the increase of oxygen consumption caused by the increase of neural activity. That was, the degree of pressure increase was too small, and the inhibiting effect of fabric compression on amygdala was not strong, which was not as strong as inhibiting effect in SI caused by fabric surface discomfort. As the fact proven before, the human body was only beginning to feel a little discomfort under the 1.5kpa of fabric pressure⁸⁹.

Conclusion

Both of fabric contact pressure of 0.5kpa and 1.5kpa, which were slightly lower and higher than comfort fabric touch pressure (about 1kpa) respectively, would produce negative activation on SI and amygdala, the difference was that neuroinhibition role on SI was more obvious under the former pressure, while neuroinhibition effect on amygdala was more remarkable under the latter pressure, which meant that SI might play a significant modulating role related to macroscopic surface tactile perception of fabrics, while amygdala was probably the characteristic brain region associated with fabric oppressing perception. It is not only of great theoretical significance for ascending the origin of fabric comfort perception, but also of practical significance in the evaluation and perception of biomedical textiles and body sculpting clothing with high elasticity and touch pressure.

Future research

In the future, SI and amygdala may be viewed as regions of interest to furtherly quantitative analyze the correlations among physical and mechanical properties of fabrics, the fabric pressures and the brain signals of characteristic brain areas. By observing the response of the characteristic brain regions to judge the human body's true perception of fabric sense of touch quantitatively, a new and more realistic evaluation system of fabric perception will be derived based on the connection between fabric performances and brain perceptions to replace the existing indirect textile evaluation system. Futhermore, a model of textile exposure pressure-comfort fitting for various crows with different ages and genders could also be established to popularize the technology by plenty of fabric physical and mechanical properties tests and fMRI tests. Similarly, this advanced technology may also be extended to the thermal and wet comfort evaluation system of textiles.

Funding

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Dear Editor and Reviewers,

Thank you for your efficient work in processing our manuscript entitled “The Brain Response to Fabric Contact Pressure : A Study of fMRI” (Manuscript ID TRJ-18-0331.R1).

We have revise the manuscript, according to the comments and suggestions of reviewers and editor, and responded point by point to the comments as listed below. And the paper has been revised by using red font to highlight the changes. Looking forward to hearing from you soon.

With kindest regards,

Yours Sincerely

Replies to Reviewers and Editor

First of all, we thank both reviewers and editor for their positive and constructive comments and suggestions.

Replies to Reviewer #1

Comments to the Author

I have given all my concerns. I still think the paper is not suitable for publication in TRJ.

Answer: Thank you for your efficient work in processing our manuscript entitled “The Brain Response to Fabric Contact Pressure: A Study of fMRI” (Manuscript ID TRJ-18-0331.R1).

After we have carefully read the comments from the reviewer, we realize that we do

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have a lack of clarity, which cause the major merits of our work not fully identified or recognized by the reviewer. Here we would emphasize that the most notable merits of our manuscript.

Firstly, in order to make the research topic more obvious, we changed the original title "The Brain Response to Fabric Contact Pressure: A Study of fMRI" into "A potential new fabric evaluation approach by capturing the brain perception under fabric contact pressure". This manuscript uses an advanced biomedical imaging technology, fMRI technology, to explore the physiological evaluation perception from textile contact pressure. The main purpose of this manuscript is to try to clarify the transfer mechanism of fabric perception, and thus establish a new physiological evaluation system for textile comfort perception. As early as 2007, Bhatia A and Dr. Hugh Gong began using fMRI technology to explore the hand sensation of fabrics(named "*Investigation of the perception of fabric hand using functional magnetic resonance imaging*"). Therefore, there is a foundation and precedent for this approach. But it is only at the stage of exploration due to the difficulty of interdisciplinary integration, so the innovation and difficulty of this study are indisputable. (In the revised paper, we have added the following in the abstract and bacground part to explain the theme:

Abstract

The problem of the transmission mechanism of textile perception and the barrier to express textile cognition directly were the two major issues in the field of textile evaluation. In this study, an advanced biomedical imaging technology, functional magnetic resonance imaging (fMRI), which was non-invasive and had a higher temporal resolution and spatial resolution, was utilized to describe the features of brain perception in the brain mask areas under increased fabric contact pressures, and thus in an attempt to provide a new approach to express fabric comfort perception. As a result, we found that: (1) When fabric contact pressure increased from 0.5kpa to 1.5kpa, both of maximum activation intensity T_z and activation proportion K of peak points were transferred from postcentral gyrus in SI to amygdala, and were negative

activations. Therefore, we drew the conclusion that: both of a lower and a higher fabric contact pressure (about 1kpa of proper comfort fabric pressure) would produce brain signal inhibitory effect on the SI and amygdala. The difference was the fact that the inhibition role on SI was more obvious under a lower pressure, while inhibition role on amygdala was more remarkable under a higher pressure, which meant that SI, particularly postcentral gyrus in SI, was likely to play a significant role on surface tactile perception of fabrics, while amygdala might be related to fabric oppressing sensation.

Keywords

Fabric comfort; fabric contact pressure; brain perception; functional magnetic resonance imaging

1. Introduction

1.1 Background

In this era of too much emphasis on industrialization, textile comfort perception problem was a major issue which had always been ignored by textile industry, the fabric comfort issue of the contact pressure was not only one of the most basic problems of the transmission mechanism of fabric comfort perception and a non-indirect representational problem in the textile evaluation area, but also a significant problem that should not be ignored in the actual application process of many industrial textiles, such as: various functional textiles, protective textiles, and especially for biomedical textiles which were utilized in the human body, body-shape textiles having a high elasticity and high fabric pressure, and so on. However, various traditional evaluation methods of fabric comfort were just limited to the textiles themselves, but ignored this important fact: the main body of comfortable expression was human themselves, not fabric. Therefore, the best method to get to a standard expression fitting for all groups was to start with the origin of perception, the brain.)

Secondly, there are two advantages in applying this advanced technology to

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textile comfort evaluation. On the one hand, from the fabric comfort perception mechanism, perception begins in the cerebral cortex and passes by neuroelectrical signals, through brainstem and spinal cord, eventually translated into speech. The evaluation systems of textile comfort are mainly divided into three types: subjective evaluation system, physical evaluation system and physiological evaluation system. Apparently, the psychological evaluation is at the end of the neural circuits, it must has a great interference and disparity to evaluate our perception. Besides, it's more indirect and uncredible to express human perception just according to the physical characteristics of fabric, because the subject of perception is human, not fabric. If we want to explore the nature of fabric perception, we must begin from its source--the cerebral cortex. On the other hand, from the view of performance of the instrument, the best method to show cerebral cortex is the functional Magnetic Resonance Imaging(fMRI) technology due to its higher temporal resolution (< 1s) and spatial resolution (< 1mm). Further more, only fMRI can visually see which brain regions are responding, that is other technologies cannot reach. (In paper, you can find these changes in background part: No matter of EEG, HRV or ERP, all of them were trying to do that. But in this topic, we setted foot in a more advanced field of science and technology, that was fMRI (functional Magnetic Resonance Imaging) due to its higher spatial resolution than them¹ and the mechanism superiority of the origin of fabric perception itself . Besides, some of the subtle sensory information, such as: light pressure to the forearm, which ERP could not capture, could also be picked up with the fMRI². Thereby, an exploration extremely closed to the origin of fabric perception had begun.)

1. Huettel SA, Song AW and McCarthy G. *Functional magnetic resonance imaging*. Massachusetts U.S.A.: Sinauer Associates 2004.

2. Schirmer A and Adolphs R. Emotion perception from face, voice, and touch: comparisons and convergence. *Trends in cognitive sciences* 2017; 21: 216-228.

Thirdly, this paper not only explores the theoretical basis of fabric perception, but also provides a new potential evaluation method of non-indirect fabric comfort, which is of great practical significance, especially for the fabric comfort

evaluation of some biomedical textiles used by patients. In future studies, we can find main textile factors which influence textile comfort characteristic brain regions through a lot of fabric physical and mechanical properties tests, we can also obtain different comfort perception thresholds of various crowds. Eventually, a model of textile exposure pressure-comfort for people of different ages and genders could be established to popularize the technology. (In paper, we have added the following in the conclusion part part and future reserch part:

conclusion

...It is not only of great theoretical significance for ascending the origin of fabric comfort perception, but also of practical significance in the evaluation and perception of biomedical textiles and body sculpting clothing with high elasticity and touch pressure.

Future research

In the future, SI and amygdala may be viewed as regions of interest to furtherly quantitative analyze the correlations among physical and mechanical properties of fabrics, the fabric pressures and the brain signals of characteristic brain areas. By observing the response of the characteristic brain regions to judge the human body's true perception of fabric sense of touch quantitatively, a new and more realistic evaluation system of fabric perception will be derived based on the connection between fabric performances and brain perceptions to replace the existing indirect textile evaluation system. Futhermore, a model of textile exposure pressure-comfort fitting for various crows with different ages and genders could also be established to popularize the technology by plenty of fabric physical and mechanical properties tests and fMRI tests. Similarly, this advanced technology may also be extended to the thermal and wet comfort evaluation system of textiles.)

Fourthly, the results in this manuscript are accurate and reliable due to the fact that this manuscript is written in collaboration with a number of medical

professionals. The experiment part is also proceeded in a university affiliated school of medicine, in the aspect of image analysis, we learn a lot of professional knowledge from them. In addition, before submitting the manuscript, they have reviewed it repeatedly. So the problem of authenticity of the results across disciplines has been well solved. (In the revised version, you can see these changes in experiment part:

...Before the experiment, the subjects were aware of the principle of fMRI and the possible physiological reactions during the scanning process, the test could be terminated at any time if the subjects raised leg to signal any physical discomfort. Furthermore, they were trained simply about the scanning procedure and signed the informed consent. The study was approved by the ethics committee of Donghua University.

Besides, we have added a large number of test instrument parameters, indicators and image processing analysis methods, which you can find the detail in experiment part.)

Finally, I have opportunities to talk to Dr. Qicai Wang (Shandong University of Technology) and Dr. Qiaoli Xu (University of Georgia), both of whom read the manuscript and encourage me to write to you to ask if you could consider the revised version of the manuscript.

We will be most grateful if you could offer us a opportunity to revise.

Look forward to hearing from you soon.

Replies to Reviewer #2

-The study of the human brain reaction under fabric pressure simulation is useful for which domain? textile?

Answer: There are two aims of this study of the human brain reaction under fabric pressure simulation. The one is to expore the nature and transporting

mechanism of touch perception from fabric pressure. The other is to attempt to establish a new evaluation system of fabric brain perception based on this study. The dominant of both purposes are all in textile area.

The main purpose of this manuscript is to explore the nature of the comfort of fabric contact pressure. Just like the existing EEG and ERP technologies in the field of textile contact comfort evaluation, the final indicators generated by these technologies, such as α wave, β wave and P300 wave, will be used to evaluate the perceived evaluation of textile contact comfort. FMRI is a kind of more advanced biological imaging technology, compared with the existing biological evaluation of textile technology, it can not only more visually through brain imaging section figure to see real perception of the brain, and on the spatial and temporal resolution is higher, more can break through the existing technical bottlenecks, to express more evaluation of fabric. In future studies, a new and more realistic evaluation system of fabric perception could be established based on the connection between fabric performances and brain perceptions. Therefore, it is indisputable that the subject of this manuscript remains textile. (We have supplement this part in the abstract part and the background part in the revised version and thank you for your kind remind:

Abstract

The problem of the transmission mechanism of textile perception and the barrier to express textile cognition directly were the two major issues in the field of textile evaluation. In this study, an advanced biomedical imaging technology, functional magnetic resonance imaging (fMRI), which was non-invasive and had a higher temporal resolution and spatial resolution, was utilized to describe the features of brain perception in the brain mask areas under increased fabric contact pressures, and thus in an attempt to provide a new approach to express fabric comfort perception. As a result, we found that: (1) When fabric contact pressure increased from 0.5kpa to 1.5kpa, both of maximum activation intensity T_z and activation proportion K of peak points were transferred from postcentral gyrus in SI to amygdala, and were negative activations. Therefore, we drew the conclusion that: both of a lower and a higher

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fabric contact pressure (about 1kpa of proper comfort fabric pressure) would produce brain signal inhibitory effect on the SI and amygdala. The difference was the fact that the inhibition role on SI was more obvious under a lower pressure, while inhibition role on amygdala was more remarkable under a higher pressure, which meant that SI, particularly postcentral gyrus in SI, was likely to play a significant role on surface tactile perception of fabrics, while amygdala might be related to fabric oppressing sensation.

Keywords

Fabric comfort; fabric contact pressure; brain perception; functional magnetic resonance imaging

Background

In this era of too much emphasis on industrialization, textile comfort perception problem was a major issue which had always been ignored by textile industry, the fabric comfort issue of the contact pressure was not only one of the most basic problems of the transmission mechanism of fabric comfort perception and a non-indirect representational problem in the textile evaluation area, but also a significant problem that should not be ignored in the actual application process of many industrial textiles, such as: various functional textiles, protective textiles, and especially for biomedical textiles which were utilized in the human body, body-shape textiles having a high elasticity and high fabric pressure, and so on. However, various traditional evaluation methods of fabric comfort were just limited to the textiles themselves, but ignored this important fact: the main body of comfortable expression was human themselves, not fabric. Therefore, the best method to get to a standard expression fitting for all groups was to start with the origin of perception, the brain.

...No matter of EEG, HRV or ERP, all of them were trying to do that. But in this topic, we setted foot in a more advanced field of science and technology, that was fMRI (functional Magnetic Resonance Imaging) due to its higher spatial resolution than them¹ and the mechanism superiority of the origin of fabric perception itself . Besides,

some of the subtle sensory information, such as: light pressure to the forearm, which ERP could not capture, could also be picked up with the fMRI². Thereby, an exploration extremely closed to the origin of fabric perception had begun.)

1. Huettel SA, Song AW and McCarthy G. *Functional magnetic resonance imaging*. Massachusetts U.S.A.: Sinauer Associates 2004.
2. Schirmer A and Adolphs R. Emotion perception from face, voice, and touch: comparisons and convergence. *Trends in cognitive sciences* 2017; 21: 216-228.

-This type of study is easy to achieve and available for any wearer?

Answer: Of course, in terms of safety performance, fMRI is a non-invasive biological imaging scanning technology, which is safer than radiation CT scanning technology, and is suitable for all kinds of people, even children. **In terms of time,** it takes only a few minutes to complete a human body scan, which is relatively short. **In terms of operation steps,** the scanning operation is also very convenient. **So this type of study is easy to you and available for any wearer.** The only drawback is the problem of cost, but we believe that with the rapid development of the echoes, the popularization of fMRI technology in the field of textile is not a problem.

-Which is the usefulness of this study?

Answer: As mentioned above, the purpose of this manuscript is to explore a new evaluation system of textile contact pressure comfort, which will play an important role in the evaluation field of various functional textile, protective textiles, and especially for biomedical textiles which were utilized in the human body, body-shape textiles having a high elasticity and high fabric pressure, and so on. Furthermore, this advanced technology may also be extended to the thermal and wet comfort evaluation system of textiles. (We have supplement this content in future research part in the revised version, the following is in detail:

Future research

In the future, SI and amygdala may be viewed as regions of interest to furtherly quantitative analyze the correlations among physical and mechanical properties of

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fabrics, the fabric pressures and the brain signals of characteristic brain areas. By observing the response of the characteristic brain regions to judge the human body's true perception of fabric sense of touch quantitatively, a new and more realistic evaluation system of fabric perception will be derived based on the connection between fabric performances and brain perceptions to replace the existing indirect textile evaluation system. Furthermore, a model of textile exposure pressure-comfort fitting for various crowds with different ages and genders could also be established to popularize the technology by plenty of fabric physical and mechanical properties tests and fMRI tests. Similarly, this advanced technology may also be extended to the thermal and wet comfort evaluation system of textiles.)

Thank you for your carefully reading of our manuscript. According to your meaningful suggestions, we have made some revisions and supplyments, and I hope to get your comments and reply next time.

Replies to Reviewer #3

Comments to the Author

The present manuscript presents fabric brain perception via fMRI method. The work is interesting and inspiring to the field of textile evaluation. I therefore recmmend this paper to be publicated. And it is better if the authors consider the following mentioned remarks and further improve the manuscript before submitting the final version.

1. Page 1 line 50, "...Brain perception; functional magnetic resonance imaging; fabric contact pressure..." should be changed into "...Brain perception, functional magnetic resonance imaging, fabric contact pressure..."

Answer: Thank you for your comments, we have correctec it.

2. Page 5 line 50, "...Table1 Locations..", one space is missed.

Answer: Thank you for your comments, we have added it.

3. Page 8 line 42, "...of 937pa tended to be...", page 9 line 13 and line 14, "...fMRI experiments were proceeded with fabric pressure of 0.5Kpa and 1.5Kpa, respectively...", you'd better use a uniform unit of measure for the full text. It can be changed into "...of 0.937kpa tended to be...", "...fMRI experiments were proceeded with fabric pressure of 0.5kpa and 1.5kpa, respectively..."

Answer: Thank you for your careful comments, we have unified them.

Replies to Reviewer #4

Comments to the Author

The manuscript is improved after revision and the fMRI is a good method to investigate the fabric handle characteristics essentially; however, most parts of the draft are closely related to the fMRI and brain image analysis. Thus it would be better to review those parts by a Medical imaging researcher.

Answer: Thank you very much for your advice, but as a matter of fact, we have to tell you that this study is done in cooperation with medical professionals, the experiment part is also proceeded in a university affiliated school of medicine, in the aspect of image analysis, we learn a lot of professional knowledge from them. (You can read the detail in the experiment parts and the first half of result part). In addition, before submitting the manuscript, they have reviewed it repeatedly. For reasons of anonymous submission, we cannot tell you their names. But to some extent, we think we have done with your recommendation, in the meantime, we still accept all the reviews from any other medical imaging researchers.