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Autonomic responses to pressure sensitivity of head, face and neck: Heart rate and skin conductance

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ABSTRACT

Subjective scales are frequently used in the design process of head-related products to assess pressure discomfort. Nevertheless, some users lack fundamental cognitive and motor abilities (e.g., paralyzed patients). Therefore, it is vital to find non-verbal measurements of pressure discomfort and pressure pain. This study gathered the autonomic response data (heart rate and skin conductance) of 30 landmarks in head, neck and face from 31 participants experiencing pressure discomfort and pressure pain. The results indicate that pressure stimulation can change heart rate (HR) and skin conductance (SC). SC can be more useful in assessing pressure discomfort than HR for specific landmarks, and SC also possesses a faster arousal rate than HR. Moreover, HR decreased in response to pressure stimulation, while SC decreased followed by an increase. In comparisons between genders, the subjective pressure discomfort threshold (PDT) and pressure pain threshold (PPT) of women were lower than those of men, but men's autonomic responses (HR and SC) were more intense. Furthermore, there was no linear correlation between subjective pressure thresholds (PDT and PPT) and autonomic response intensity. This study has significant implications for resolving ergonomic issues (pressure discomfort and pain) associated with head-related products.

1. Introduction

Safety equipment, medical equipment, entertainment products, and even military supplies contain multiple head-related products. Pressure applied on the skin is one of the critical factors in the discomfort caused by products (Zemp et al., 2015; Pang et al., 2018). Researchers have demonstrated that constant pressure on a specific area can cause skin spots, rashes, irritations, and ultimately ulcers (Ebe and Griffin, 2001). Furthermore, Zhuang's research amongst others also revealed that higher pressure increases discomfort (Dai et al., 2011). In order to reduce the pressure discomfort of head-related products, it is crucial to evaluate the pressure discomfort of the corresponding product.

In general, the evaluation methods for comfort and discomfort can be classified into subjective and objective evaluation methods (Pearson, 2009). The subjective evaluation is based on the subjective feedback of the target user regarding the product while in use. In subjective evaluation, scales are the primary evaluative methods. In various investigations, Agodoa (Agodoa et al., 2002), Aota (Aota et al., 2007), and Gadge (Gadge and Innes, 2007) used the Visual Analog Scale (VAS) to assess discomfort. In the studies of Jacobson (Jacobson et al., 2004) and Matthias (Matthias et al., 2021), visual Likert-type rating scales were utilized. The Numerical Rating Scale (NRS) was applied by Parent (Parent et al., 2000), Sharifi (Sharifi et al., 2021), and Papas (Papas et al., 2011). Objective assessment methods tend to measure objective indicators such as body posture (Drury et al., 2008; Noro et al., 2012; Van Veen et al., 2014), pressure distribution (Kyung and Nussbaum, 2008; Mergl, 2006), and EMG measured muscle condition (Sancibrian et al., 2020; Kong et al., 2022). Human comfort and discomfort are jointly determined by physiological and psychological elements (Pearson, 2009). Subjective evaluations (questionnaires, scales, etc.) are time-consuming and heavily impacted by personal preferences (Che et al., 1994). In addition, objective measurement methods can only gather a portion of the human body's indicators and cannot fully reflect how the user feels while the product is used. Therefore, in most previous studies, a combination of subjective evaluation and objective measurement is widely utilized.

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Measuring the contact interface pressure distribution and pressure area are the most common assessment methods of objective pressure discomfort in the evaluation of pressure discomfort, particularly in the study of seat-related discomfort (Zemp et al., 2016; Paul et al., 2012; Vincent et al., 2012; Kyung and Nussbaum, 2013). The main body parts involved in the study of seat-related pressure discomfort are relatively simple morphological structures, such as the buttocks and back, and it is relatively simple to assess the pressure distribution. However, the morphological structures of the head and face involved in head-related products are more complicated, particularly the face, making it challenging to perform pressure distribution measurement and muscle state identification for a particular product. Therefore, the current research on the pressure of head-related products is mainly separated into two categories: (a) Subjective evaluation of pressure discomfort, including the detection of pressure discomfort in virtual reality helmets (Kyung and Nussbaum, 2013; Yan et al., 2018), cycling helmets (Song et al., 2018), and safety helmets (Hao et al., 2019). (b) Simulation experiments of pressure distribution utilizing head models, including finite element simulation studies of helmets (Subic et al., 2005), respirators (Dai et al., 2011; Lei et al., 2012), and goggles (Yang et al., 2022). Nonetheless, the pressure simulation experiment can only determine the pressure distribution of a specific head-related product instead of the user's real feeling. Therefore, the current measurement of pressure discomfort in head-related products relies primarily on subjective scales. However, although the majority of participants had little difficulty learning how to evaluate their discomfort or pain, this is not always the case. Basic cognitive and motor skills may be lacking in some individuals, because they have not yet developed (e.g., in prelinguistic toddlers) or as they have changed with age or disease (e.g., in older patients with motor difficulties, or in patients with dementia or paralysis) (Werner et al., 2022; Lopez-Martinez and Picard, 2017; Cowen et al., 2015).

Due to the importance of pain detection in the medical field, many researchers have evaluated the autonomic response of people to pain. According to studies, painful stimuli activate the sympathetic nervous system, resulting in an increased heart rate (HR) (Lavigne et al., 2001; Tousignant-Laflamme et al., 2005; Möltner et al., 1990) and skin conductance (SC) (Dubé et al., 2009; Eriksson et al., 2008; Harrison et al., 2006). Therefore, skin conductance and heart rate can be used as pain evaluation indicators (Lopez-Martinez and Picard, 2017; Arbour et al., 2014; Gjerstad et al., 2008; Storm, 2008; Geuter et al., 2014). In this type of experiment, short-term electrical stimulation (Bari et al., 2018a, 2018b) and thermal stimulation at varying temperatures (Gouverneur et al., 2021) are the typical methods for externally applying pain. However, our main concern in the field of ergonomics is the discomfort and pain caused by the product's pressure on the skin. But the authors could not find a study on the effects of physical pressure discomfort and pain on heart rate and skin conductance.

Based on the knowledge gap mentioned above, this study aims to investigate the autonomic responses (heart rate and skin conductance) of the head, face, and neck to pressure discomfort and pain. With the final goal to help individuals with impaired speech or motor abilities reduce pressure discomfort and pain from head-related products and to provide an objective method for assessing pressure discomfort in the head, face, and neck for regular subjects. To achieve this purpose, this study mainly addresses the following questions:

1. What is the influence on pressure discomfort and pressure pain have on heart rate and skin conductance?
2. What is the relationship between subjective pressure threshold and heart rate and skin conductance?
3. What are the differences in autonomic responses between genders?

2. Methodology

2.1. Participants

Thirty-one (18 females and 13 males) Chinese subjects, aged 18–30 years were recruited for the study. Subjects with self-reported chronic and acute pain, neurological disease, severe cardiovascular disease (i.e., any disease of the heart or blood vessels that could result in a life-threatening medical emergency, such as arrhythmia, infarction, or stroke), and current medication use were excluded from the study.

2.2. Equipment and procedure

Pressure probes were used to measure local PPT (Jayaseelan et al., 2021; Spano et al., 2021). In this experiment, an Advanced Force Gauge (AFG) meter (Mecmesin AFG 500 N) with a flat tip with diameter of 10 mm was used to apply pressure. Several previous studies have applied pressure to various body parts using the same type of pressure gauge (Buso and Shitoot, 2019; Vink and Lips, 2017; Yang et al., 2023; Smulders et al., 2023). Moreover, skin conductance and heart rate were continuously recorded using Bitalino and OpenSignals software V2.2.0 for the experiment (Páris et al., 2017). From an ECG (electrocardiogram) that we recorded, we derived the heart rate. Two circular electrodes (24 mm in diameter) located on the palmar side of the proximal phalanx of the left index and middle fingers were used to record skin conductance in micro siemens (μS; sampling rate: 32 Hz). The heart rate was recorded in beats per minute (BPM; sampling rate: 4 Hz) by placing one electrode in the center of each clavicle and one electrode on the superior border of the left hip bone (Fig. 1).

In addition, to accurately record the pressure discomfort and pain thresholds at different landmarks, the pressure gauge is connected with Bitalino and OpenSignals to form a synchronous data collection system (Fig. 2) . Participants can press a button when they feel discomfort and (with increasing pressure) pain, and the program could record the initial discomfort and pain pressure values for subsequent calculations.

The process of the experiment consists of two phases: first, the preparation stage. At this stage, basic information such as age, gender, height, and weight of the subjects was collected through questionnaires. Following that, subjects were required to wear a hair cap to fix their hair. After initial preparation, circular self-adhesive patches with landmark numbers were placed on the heads, faces, and necks of the individuals. Second, physiological signals were collected. Throughout the experiment, subjects sat in comfortable chairs in a recording studio that excludes external signal interference. The temperature in the laboratory is between 20 and 24 °C. Before the experiment began, the participants were required to remain seated for 5 min in order to achieve a physical and emotional baseline. After that, an experienced researcher consecutively applied a pressure stimulus at each landmark. For each stimulus, the pressure was gradually increased at with a rate between 30 and 40 kPa/s. When participants began to experience discomfort, they were instructed to press a button that recorded the pressure discomfort threshold (PDT). To record the pressure pain threshold (PPT) of the landmarks, the researcher would then continue to apply increasing pressure, and individuals would press the button again until they began to experience pain. During pressure application, the pressure stimulus for each landmark lasted 10 s after the second button press (PPT).

Between stimuli there was a 40s resting interval. The duration of 40 s includes the following: 1.5 s of stillness. Because there is a 1–2 s latency in skin conductance and heart rate following the start of stimulation (Cacioppo et al., 2007), participants were required to stay immobile for 5 s after the pressure stimulation was terminated. 2. Relax for 35 s to obtain a baseline for skin conductance and heart rate. During the relaxation period, participants were advised to stay awake, avoid physical movement, and refrain from speaking.

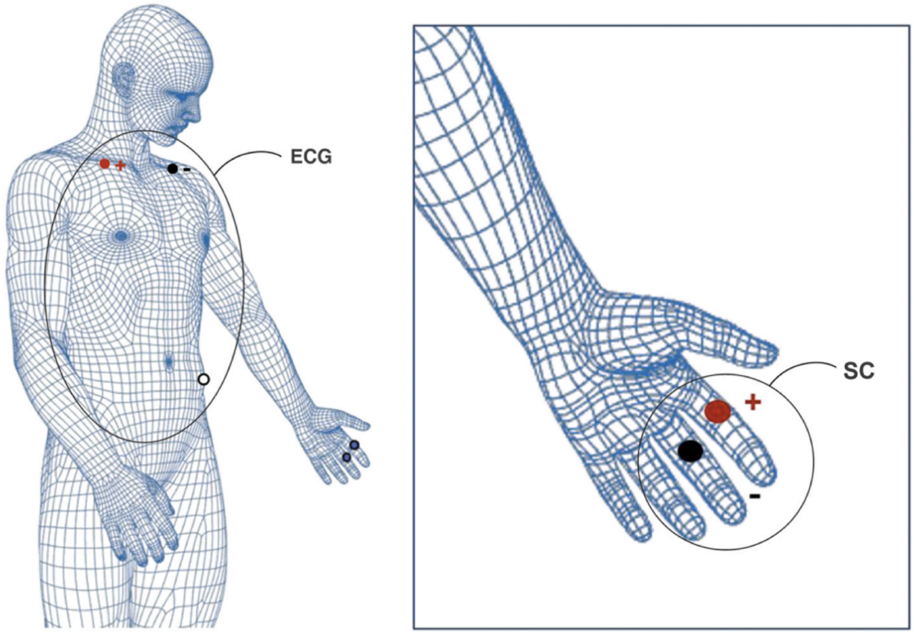

Fig. 1. Position for measuring skin conductance and heart rate.

Fig. 2. The condition of the experiment's subject and equipment.

2.3. Landmarks selection

Since there is no unified standard for selecting craniofacial landmarks and deciding regional divisions in anatomy, this study identified 30 unilateral landmarks based on anatomy and morphology (Stephan and Simpson, 2008). 14 are located in the midline, while the remaining 16 are on the sides (Fig. 3).

2.4. Data processing and analysis

The raw signal recordings from physiological sensors are prone to noise, artifacts, measuring gaps, and deviations. Therefore, it is crucial to preprocess the raw data in order to filter the noise and remove artifacts to obtain a stable and reliable physiological signal. Neurokit2 (Makowski et al., 2021) is a Python toolbox for processing and analysing neurophysiological signals. For the ECG signal, a 5th order high-pass Butterworth filter at 0.5 Hz was used to remove slow drift and DC offset, followed by smoothing of the signal with a 50Hz power line filter; and finally, heartbeats per minute was calculated from a series of peaks, that is, heart rate (BPM) (Fig. 4). Moreover, we filtered the skin conductance signal using a 4th order low-pass Butterworth filter at 5 Hz, computed the smoothed signal using the convolution of a filter kernel with the input signal, and then obtained the skin conductance (μS) (Fig. 5).

Because the purpose of this paper is to investigate the autonomic response under pressure discomfort and pressure pain, in addition to analysing the overall stimulus segments (20s) under different pressures, we also split the overall segments (20s) into small segments (12s) (Fig. 6). For the selection of the time window, it is important to assure the validity of the physiological signal and to account for the physiological signal's delay of 1–2 s after stimulation onset. Ultimately, 12 s was chosen as the time window for splitting the signal, whereas 20 s was chosen for the overall stimulation segment (which includes 2 s of latency). The signal segments consisted of a 20s overall stimulus segment, a 12s Pre-D (pre-discomfort) segment, a 12s Pre-P (pre-pain) segment, and a 12s Pain-12s segment. For segments less than 12 or 20 s, the pre-stimulus baseline (up to 10 s) is used to complement the signal (−10-0). In terms of baseline selection, the baseline is −22 to −10 for 12s and −30 to −10 for 20s (Fig. 6).

The SC and HR (skin conductance in μS and heart rate in BPM) obtained during stimulation and in the period preceding stimulation onset were separately averaged to obtain the "stimulus mean" and "baseline mean." The difference between the relative "stimulus" and "baseline" mean values was then expressed as the value of the change in signal (i.e., signal-change = mean stimulus - mean baseline). The research confirmed both HR-change and SC-change by evaluating whether the signal-change was a positive or negative value. Paired samples T test was performed to determine the significance of differences between various signal segments and their corresponding baselines, and $p < 0.05$ was considered significant.

2.4.1. Within-segments analysis

The primary focus of the within-stimulus investigation is the autonomic responses of different stimulus segments. The within-segments analysis is divided into two groups: Firstly, the overall segment analysis. The 20s, Pre-D, Pre-P, and P-12s of all landmarks are averaged separately, along with the corresponding 12s baseline and 20s baseline. In order to further investigate the autonomic response of different landmarks to different pressures, the overall segments of each landmark

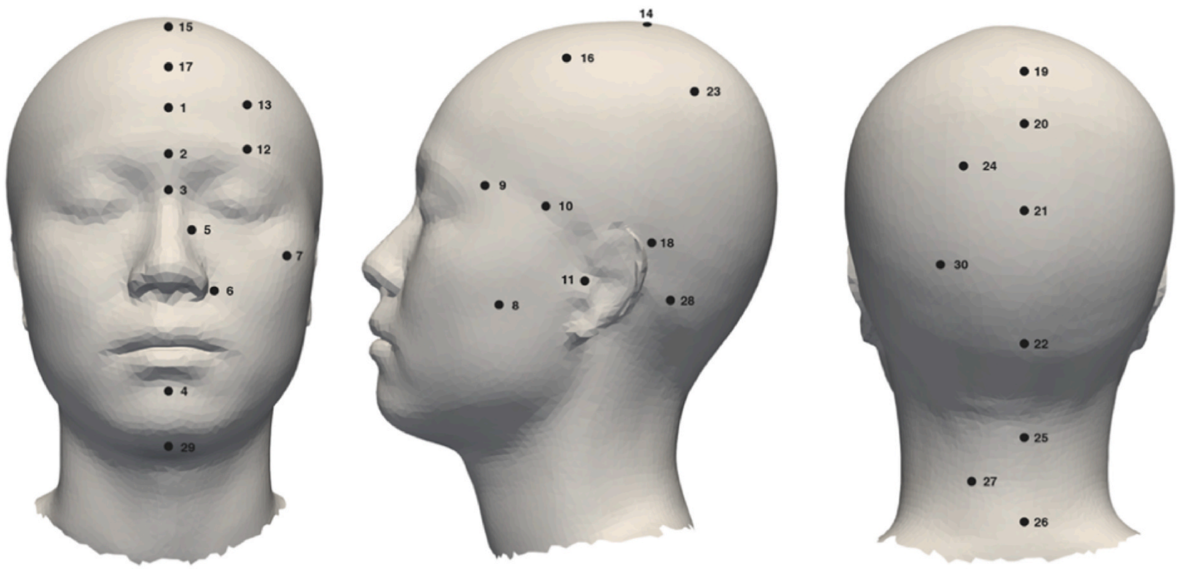

Fig. 3. 30 landmarks of head, face and neck.

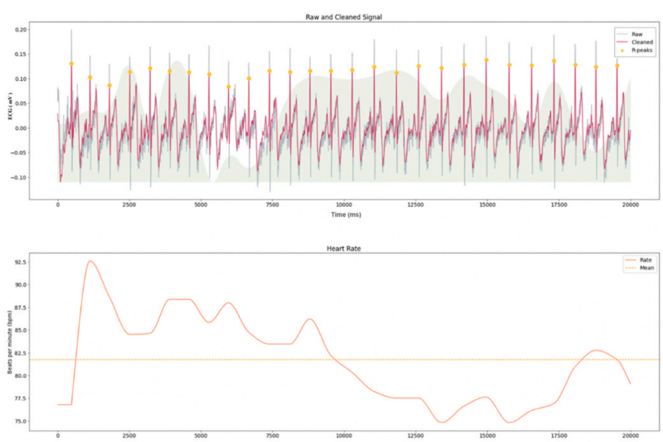

Fig. 4. a. Electrocardiogram (ECG). Grey signal is the raw signal and the pink signal is the cleaned signal b. Heart rate diagram. (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

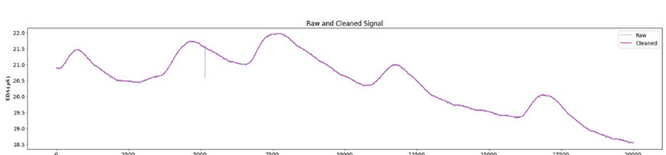

Fig. 5. Skin conductance signal diagram. Grey signal is the raw signal and the purple signal is the cleaned signal. (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

were also split into several small segments in the study. In addition, the analysis of each of the groups mentioned is divided into two sections: the comparison of the four segments (20s, Pre-D, Pre-P, P-12s) to the corresponding baselines (20s baseline and 12s baseline) and the comparison of Pre-P and P-12s. Pre-P can represent the pressure discomfort signal, while P-12s is the pressure pain signal. In addition, because the signals of Pre-D and Pre-P are highly overlapping and do not match the test criteria for data independence, this paper mainly explores the

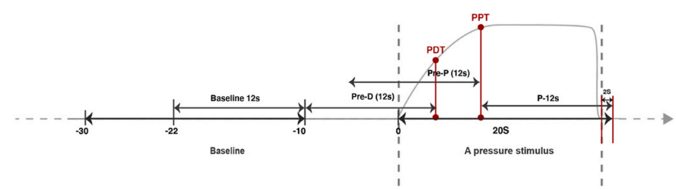

Fig. 6. Separation of segments based on the pressure signal.

differences between Pre-P and P-12s segments. Paired samples T test was performed to determine the significance of differences between various signal segments and their corresponding baselines, and $p < 0.05$ was considered significant.

2.4.2. *Group analysis*

To determine the relationship between pressure levels and autonomic responses, autonomic response segments and pressure thresholds (PDT and PPT) were averaged for each subject. Since only PDT and PPT were recorded for the pressure, the Pre-P signal segment corresponding to PDT and the P-12s signal segment relating to PPT were chosen for the Pearson correlation coefficient analysis.

3. Results

3.1. *Within-segments analysis results*

HR demonstrated a decreasing trend for the data of all participants both in comparisons between Pre-P and P-12s and in comparisons of each segment to baseline ($p < 0.05$) (Fig. 7). The signal of SC showed a decreasing and then increasing tendency, with Pre-D and Pre-P continually decreasing and P-12s increasing ($p < 0.05$). However, there was no statistically significant difference between the 20s stimulus segments and the 20s baseline (Fig. 8). In addition, the gender comparison revealed the same trend ($p < 0.05$) (Table 1).

In addition to averaging the signal segments for all landmarks, the study also analysed the different signal segments for each landmark. In the 20s stimulation segment of HR, except for landmark 1, the remaining 29 landmarks showed a decreasing trend compared with the baseline ($p < 0.05$). However, only 6/30 landmarks were significantly different between Pre-P and P-12s ($p < 0.05$) (Fig. 9). In contrast to HR, 19/30 landmarks in SC had a significant difference between Pre-P and P-12s (p

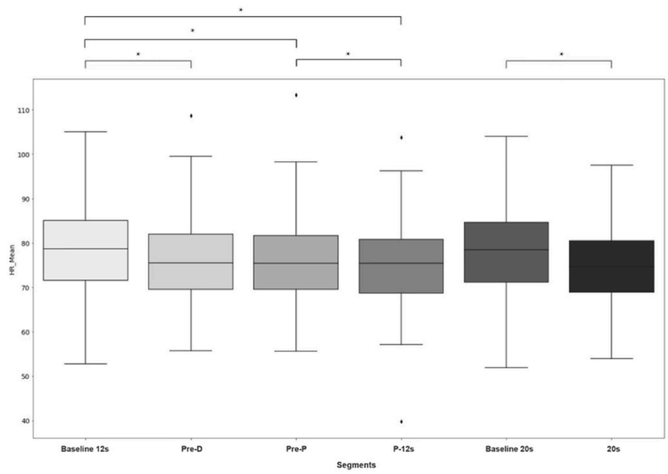

Fig. 7. HR signal segments and corresponding baselines of all landmarks (mean BPM). *p < 0.05, ns: no significant.

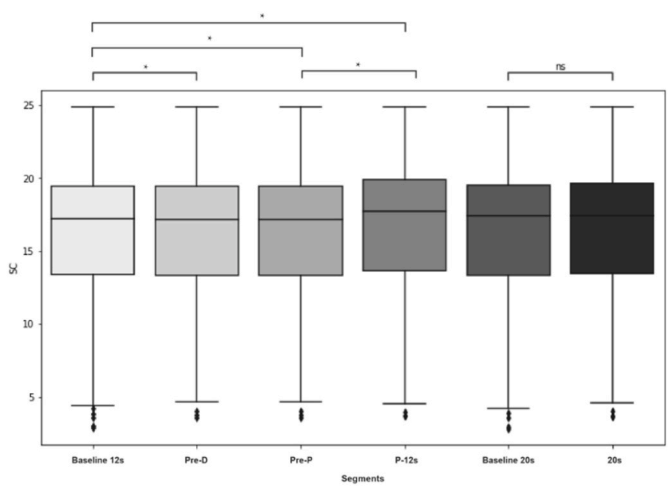

Fig. 8. SC signal segments and corresponding baselines of all landmarks (mean μS). *p < 0.05, ns: no significant.

< 0.05), and P-12s were greater than Pre-P. However, only 8/30 of the 20s stimulus segments were significantly different from its baseline ($p < 0.05$) (Fig. 10).

Comparing gender groups, females had 11/30 landmarks with a negative HR signal-change ($p < 0.05$). The three small segments of 9/30 landmarks were smaller than the 12s baseline ($p < 0.05$). Furthermore, only two landmarks were significantly different between Pre-P and P-12s. For males, the HR signal-change for the 20s segment in 29/30 of the landmarks was negative ($p < 0.05$). In addition, there were significant differences between the Pre-P and P-12s mean values of four landmarks in males ($p < 0.05$).

For SC, females had 5/30 landmarks with 20s pressure stimulus mean values greater than their 20s baseline ($p < 0.05$). Also, the mean Pre-P value for 14/30 landmarks was smaller than their P-12s baseline ($p < 0.05$). In comparison, males had 8/30 landmarks with 20s stimulus mean values that were greater than their 20s baseline ($p < 0.05$). In addition, males had 17/30 landmarks with smaller mean Pre-P values than P-12s baselines ($p < 0.05$).

3.2. *Group analysis results*

In addition to the results of the within-segment analysis, the relationship between subjective pressure thresholds (PDT and PPT) and autonomic responses was explored. The Pearson correlation coefficient between HR at Pre-P and PDT for all subjects was 0.013. Meanwhile, the correlation coefficient between HR at P-12s and PPT was 0.068; the correlation coefficient between SC at Pre-P and PDT was −0.03; and the correlation coefficient between SC at P-12s and PPT was −0.055.

In comparing gender groups, the correlation coefficient between HR at Pre-P and at PDT for females was 0.04, while the correlation at P-12s and at PPT was 0.04. In addition, the correlation coefficient between SC at Pre-P and PDT was −0.08, while the correlation between its values at P-12s and at PPT was −0.09. In comparison, the correlation coefficient between HR at Pre-P and at PDT for men was 0.11, while the correlation between the HR at P-12s and PPT was 0.15. Further, the male correlation coefficient between SC at Pre-P and at PDT was −0.05, while the correlation coefficient between SC at P-12s and at PPT was −0.02.

4. Discussion and conclusion

This study aims to investigate the autonomic responses (heart rate and skin conductance) of the head, face, and neck to pressure discomfort and pain. With the final goal is to help individuals with impaired speech or motor abilities reduce pressure discomfort and pain from head-related products, and to provide an objective method for assessing pressure discomfort in the head, face, and neck for regular subjects. Overall, the major conclusions of this paper are summarized in the following sections:

Firstly, pressure discomfort and pressure pain are associated with

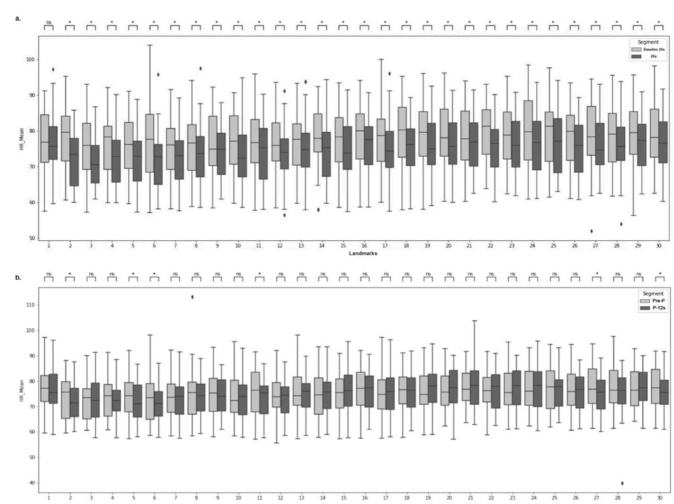

Fig. 9. HR signal segments for 30 landmarks. a. Comparison of the 20s segments and baseline for the 20 s b. Comparison of the Pre-P and P-12s signal segments. *p < 0.05, ns: no significant.

Table 1
Overall within-stimulus signal segments of all landmarks for 31 samples and the corresponding baseline (mean).

Gender	Signal	Baseline 12s	Pre-D	Pre-P	P-12s	Baseline 20s	20s
F	HR (BPM)	77.57	75.87	75.78	74.72	77.26	74.85
	SC (μS)	15.56	15.45	15.46	15.97	15.62	15.66
M	HR (BPM)	78.92	75.72	75.44	75.22	78.77	74.53
	SC (μS)	17.99	17.7	17.73	18.18	18.04	17.87

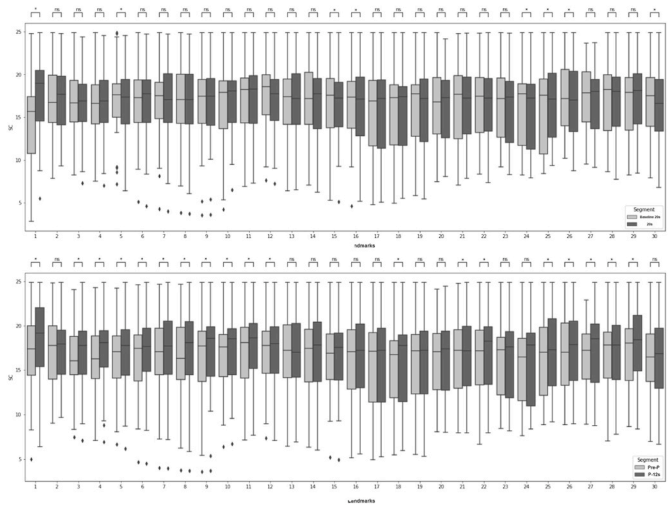

Fig. 10. SC signal segments for 30 landmarks. a. Comparison of the 20s segments and baseline for the 20 s b. Comparison of the Pre-P and P-12s signal segments. *$p < 0.05$, ns: no significant.

changes in HR and SC. HR continued to decrease from pressure discomfort to pressure pain, while SC decreased and followed by an increased. In particular, the within-segment comparison results of all landmarks demonstrated that HR continued to decrease after the start of pressure stimulation ($p < 0.05$). Similarly, the mean-HR of the 20s stimulation segment was also lower than that of the 20s baseline ($p < 0.05$), which further verified this trend. However, in the within-segment comparison of each landmark, with the exception of landmark 1, the mean-HR of the 20s stimulus segment for the remaining 29 landmarks was also lower than the its 20s baseline ($p < 0.05$). However, there were no statistically significant differences between the Pre-P and P-12 segments with in 23/29 landmarks. This demonstrates that the HR of these 23 landmarks began to decrease when they were initially stimulated, but there was no significant difference between discomfort and pain for the majority of the landmarks during continuous stimulation (Fig. 11). This indicated that HR can be a variable to distinguish between Pre-P and P-12s segments if the mean of all landmark segments is determined. However, HR cannot effectively distinguish pressure discomfort from pressure pain if specific to individual landmarks.

In addition, the average within-segment measurements of all landmarks indicated that the SC exhibited a decreasing and subsequently increasing tendency following pressure stimulation ($p < 0.05$). There was, however, no statistically significant difference between the 20s stimulation segment and the corresponding baseline. For individual landmarks, the comparison of Pre-P and P-12s segments of 19/30 landmarks revealed a decreased followed by an increased trend ($p < 0.05$). But for the 20s segment of 4/19 landmarks was significantly different from its 20s baseline ($p < 0.05$). This is due to the pressure discomfort leading to a decrease in SC, followed by an increase in pressure pain. This trend of a decrease followed by an increase resulted in no significant change in the final 20s of mean SC (Fig. 12). The results demonstrate that even if the final overall SC stimulus signal was not significantly different from baseline in future assessments of autonomic responses to pressure discomfort and pain, the detailed changes in the within-segment cannot be ignored.

In contrast to other studies on short-term electrical and thermal pain stimuli (Bari et al., 2018a; Loggia et al., 2011), previous research has shown that painful stimuli can activate sympathetic nerves, causing an increase in heart rate and skin conductance. However, the findings of this study indicate that short-term pressure stimulation can decrease heart rate. These internal and external factors might have influenced this result. For the internal elements, the galvanic skin response (GSR) is an independent indicator of sympathetic activity, whereas heart rate (HR) is controlled primarily by the parasympathetic nervous system (Akselrod et al., 1981). The sympathetic nervous system controls sweat gland activity, and increasing sympathetic activity increases GSR, whereas parasympathetic activation decreases HR (Wang et al., 2018). Parasympathetic activity generally dominates when both parasympathetic and sympathetic activity are present. Increased parasympathetic activity can lead to bradycardia, and bradycardia is more pronounced when there is a high level of sympathetic firing (Mendelowitz, 1999). In this experiment, pressure stimulation may have increased parasympathetic activity, decreasing heart rate.

The external reasons may have the following points: 1. Different methods of applying stimulation. The previous electrical or thermal pain stimulation was mechanically controlled and could attain the stimulation standard in less than 1 s. In this study, the pressure stimulation was manually controlled, and the researchers attempted to apply pressure at a consistent and slow rate so that the participants could differentiate between pressure discomfort and pressure pain. 2. Electrical pain stimulation and thermal pain stimulation were using “invisible” electrodes to apply stimulation. While a pressure gauge was utilized to apply pressure in this study, this “tangible” stimulation may have affected the patients’ autonomic reactions. 3. Apply stimuli at various landmarks. Previous studies usually applied varying levels of stimulation to a fixed region (palm or forearm). In this study, 30 landmarks were chosen to apply pressure to different areas of the head, face, and neck. The outcomes in this paper demonstrate that the autonomic responses of various landmarks differ. These differences may lead to inconsistent conclusions regarding heart rate. In addition, the result that skin conductance increases in response to pressure pain stimuli is consistent with previous studies.

Second, SC has a faster response rate under pressure stimulation than HR, which can be more useful in assessing pressure discomfort than HR for specific landmarks. Compared to the Pre-P and P-12s segments for each landmark, SC had 19/30 landmarks with significant changes in pressure discomfort and pressure pain, but HR only had 5 landmarks ($p < 0.05$). In addition, landmark 1, as the first landmark stimulated by pressure, can appropriately indicate the pressure sensitivity of different signals. The HR of landmark 1 did not change significantly either comparing each segment with its corresponding baseline or Pre-P and P-12s segments. In contrast, the SC of landmark 1 showed a significant change ($p < 0.001$), both comparing each segment to its corresponding baseline and comparing Pre-P to P-12 segments. Moreover, the range of change is the largest among all landmarks. Even this maximum value is probably a consequence of the subjects’ stress reaction when suddenly exposed to pressure stimuli. This indicates that when the human body is

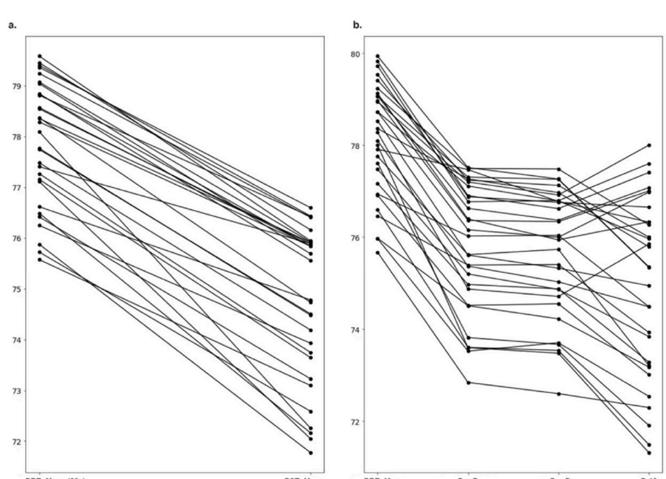

Fig. 11. HR signal trends of 30 landmarks. a. Change in trend before and after stimulation of the 20s segment. b. Change in trend before and after stimulation with different within-segments.

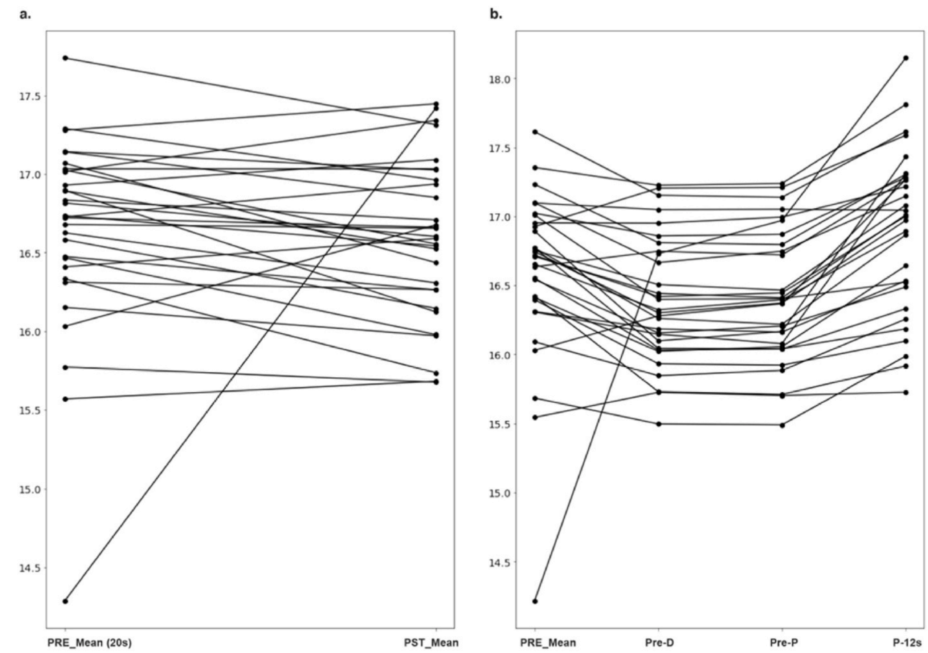

Fig. 12. SC signal trends of 30 landmarks. a. Change in trend before and after stimulation of the 20s segment. b. Change in trend before and after stimulation with different within-segments.

subjected to pressure stimulation, despite the HR's delayed response, the SC is highly sensitive. Due to the fact that head-related products will apply pressure on numerous body areas simultaneously, the detection of pressure discomfort and pressure pain using HR and SC simultaneously could be the optimal method for assessing the discomfort of head-related products.

Third, in the gender group comparison of each landmark, the number of landmarks with significant differences in females is much less than that in males. In addition, women had lower subjective pressure thresholds (PDT and PPT) than men. These results demonstrate that although men can withstand greater pressure than women, i.e., men are subjectively less sensitive than women, the autonomic responses (HR and SC) in men's bodies are significantly more intense than women. This could be a result of gender related hormones. Studies indicate gender variations in autonomic responses, and sympathoexcitation in women may be attenuated by sex hormonal estrogen (Sie et al., 2019).

Fourth is the relationship between subjective pressure thresholds and autonomic responses. The results of the Pearson correlation of the pressure discomfort group (PDT and Pre-P) and the pressure pain group (PPT and P-12s) showed that there was no significant correlation between the subjective pressure threshold (PDT and PPT) and the autonomic response intensity (HR and SC).

However, this study still has many limitations. The first is that the researchers manually apply the pressure, and it is difficult to maintain a steady rate of pressure increase. Second, there are some landmarks attached to the hair cap in this study, and the hair cap and hair may affect subjective pressure thresholds and autonomic responses. Third, this study only recruited participants of a single age group; in future research, the differences in autonomic responses between participants of other age groups and even different races can be investigated. Fourth, there are various skin conductance and heart rate variability indications, and future research might investigate the impact of multiple indicators (e.g. respiration) on pressure sensitivity.

The results of this study have significant practical implications for ergonomics, particularly the design and evaluation of head-related products. By investigating autonomous responses in humans to pressure discomfort and pain in the head, face, and neck regions, this research provides insights that can help individuals with impaired speech or motor abilities reduce the discomfort and pain caused by such products. This is crucial for enhancing user experience and ensuring greater inclusivity, and accessibility of head-related products. The study also introduces an objective method for evaluating pressure discomfort in the head, face, and neck regions, using heart rate (HR) and skin conductance (SC) as indicators. In addition, this study provides an objective approach to more reliable assessments and standardized optimizations of head, face and neck-related product designs, material choices, and pressure distribution. Furthermore, by considering specific markers in autonomous responses and individual differences, it emphasizes a need for and facilitates customized design approaches to address unique characteristics and minimize discomfort and pain. Additionally, by identifying gender and other differences in autonomous responses, it highlights the importance of considering individual and gendered characteristics and preferences and suggests that gender-specific adjustments or customization options may enhance user comfort and satisfaction.

In summary, the practical significance of this research in ergonomics lies in its contribution to improving the design, evaluation, and customization of head-related products to reduce pressure discomfort and pain, thereby increasing user well-being and satisfaction.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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