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Assessment of pressure sensitivity in the head region for Chinese adults

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Abstract

Measurement of pressure threshold has found its applications in the fields of medical sciences and product design. Hence it has been a profound area of research interest for several decades. However, hardly any detailed investigation has been undertaken to measure the pressure threshold in the head region. In this study, Pressure Discomfort Threshold (PDT) and Pressure Pain Threshold (PPT) were measured for two hundred eighteen healthy Chinese adults at seventy-six anatomical locations, and further statistical analyses were performed on the acquired data to understand the relationship between different demographic parameters. The results suggest that the pressure sensitivity is low in the vertex region, moderate in the forehead and temporal area, and high in the facial and nasal region. From this study, pressure sensitivity maps were developed for PDT and PPT for Chinese adults. The measured pressure threshold data showed no significant relationship with age and Body Mass Index (BMI).

Keywords: Human head, Pressure threshold, Pressure sensitivity maps.

1. Introduction:

The head is one of the most critical parts of the human body as it houses the brain and various sensory organs such as the eyes, ears, nose, and mouth(Farkas and Schendel, 1995; Gray, 1977; Waugh and Grant, 2014). These organs are highly delicate and vulnerable(Ball, 2011) to any impact injuries. Commonly used head-related products are designed for protection (like the helmet, eyewear, and face protectors) or address healthcare needs (like masks, respirators, spectacles, and hearing aid). To perform their function efficiently, they need to maintain a close fit with the corresponding body part(Shah and Luximon, 2018). Because of a tight fit, there is constant pressure exerted by the headgear on the soft tissues. If the pressure generated is very high, it may lead to discomfort or even pain, and the user may avoid using that product. Even if the exerted pressure is low, as these products need to be used for a longer duration, they may lead to rashes, sores, or ulcers in that region(Callaghan and Trapp, 1998). These are the common problem faced by mine and construction site workers(Gibb et al., 2005; Wong et al., 2020), who need to compulsorily wear protective devices based on the Occupational Safety and Health Administration (OSHA) guidelines (OSHA, 1994a, b). At times, it may lead to avoidance of wearing safety equipment, leading to fatal injuries. A similar problem was encountered with the healthcare workers during the COVID-19 pandemic, as they were wearing the Personal Protective Equipment (PPE) kits for long hours. It resulted in the occurrence of face rashes, ulcers, and bruises (Long et al., 2020; Singh et al., 2020). Therefore, it is necessary to understand pressure sensitivity and pressure thresholds for discomfort and pain in different head regions to ensure better ergonomic and comfortable headgear design.

Engen (1988) considered the stimulus threshold to be a classical psychophysical assumption and defined a threshold as the weakest stimulus a person can perceive. Based on this approach, various researchers(Maquet et al., 2004; Melia et al., 2019; Xiong et al., 2011; Xiong et al., 2013; Zhang et al., 2013) have defined Pressure Discomfort Threshold (PDT) as the minimum amount of pressure generated by applying a force, which can cause discomfort to an individual. Similarly, Pressure Pain Threshold (PPT) has been defined as the minimum amount of pressure causing pain. Studies(Shah et al., 2018; Xiong et al., 2011) suggest that pressure sensitivity maps, developed from pressure threshold data, can be used as significant references for designing ergonomic products with enhanced user experience and comfort. Besides, the difference in pressure threshold from standard values has been used as an early marker to indicate anatomical and morphological changes, muscular tenderness, hypersensitivity, or dysfunction in several clinical and diagnostic studies(Duan and Zhang, 2012; Fernández-de-Las-Peñas et al., 2007; Fischer, 1986; Fryer et al., 2004; Granges and Littlejohn, 1993; Jensen et al., 1988; Jensen et al., 1992; Keating et al., 2001; King et al., 2017; List et al., 1989; Maquet et al., 2004).

Traditionally, different types of pressure algometers or dolorimeters have been used (Fischer, 1986, 1987; Jensen et al., 1986; Reeves et al., 1986) to measure pressure thresholds. These systems' essential components include a force gauge fitted with a rubber disk, a mechanical display setting, and a pointer with the maximum hold function to retain the pressure threshold value. Ohrbach and Gale (Ohrbach and Gale, 1989) further developed a system where a strain gauge was used with additional electronics to collect and amplify data and present it on a chart using a recording system. With advancements in technology, digital hand-held and easy to use pressure algometers have been developed and used in several studies(Brennum et al., 1989; Chung et al., 1993; Fingleton et al., 2014; Jones et al., 2007; Park et al., 2011; Persson et al., 2004; Prushansky et al., 2004; Vaughan et al., 2007; Walton et al., 2011) to measure pressure pain threshold at different parts of the body. However, most of these studies focus on accumulating data from very few landmarks. There has hardly been any detailed study leading to a specific body part's pressure sensitivity map. Hence, in this paper, the authors present an experimental study to measure pressure thresholds in different regions of the head and resultant pressure sensitivity maps for healthy Chinese adults.

It has been established in previous studies (Baillie et al., 2015; Bulut et al., 2014; Chan et al., 2011; Jia et al., 2016; Kotrashetti and Mallapur, 2016; Sahni et al., 2008) that Body Mass Index (BMI) has a significant influence on soft tissue thickness. In addition, significant age-related changes in facial soft tissues have also been presented in prior studies (Albert et al., 2007; Li et al., 2013; Taister et al., 2000). With aging, there are pathological changes in the soft tissues in the facial region (Ezure and Amano, 2012; Wollina et al., 2017). Hence it is essential to identify if these parameters influence pressure sensitivity as well. This can help achieve a holistic understanding of pressure sensitivity in the head and face region. Hence in this paper, the relationship between pressure threshold data and demographic parameters has also been examined.

2. Methods:

2.1. Participants

A total of 218 healthy adult Chinese participants (109 males and 109 females) participated in the study. All the participants had no facial soft tissue or bone deformities. The descriptive statistics of the demographic data of the participants have been summarized in Table 1.

Table 1. Descriptive statistics of demographic data of the participants

	Male				Female			
	Minimum	Maximum	Mean	Std. Dev.	Minimum	Maximum	Mean	Std. Dev.
Age (Years)	18	67	27.79	11.55	19	66	26.36	9.24

Height (cm)	160.30	187.40	172.82	5.17	148.70	177.40	161.16	6.10
Weight (Kg)	48.80	98.90	66.63	9.64	37.29	81.50	53.33	7.37
BMI (Kg/m^2)	16.53	30.89	22.27	2.73	16.02	30.61	20.52	2.50

2.2. Equipment and software

Previous studies(Dohi et al., 2004; Mak et al., 1994; Xiong et al., 2010) have used a fixed system setup for indentation devices to measure pressure threshold or soft tissue properties. Some of these systems incorporate a stepper motor to control the system's indentation rate; this makes the setup for measurement bulky. Such systems have been mainly used to acquire data from flat body surfaces like the foot surface or limbs; however, the head region has a more complex contour, and such a setup would reduce the range of motion for data collection. Since the study aimed to collect pressure threshold data from different head and face regions to generate a pressure sensitivity map, it demanded a more flexible indentation device. So, a hand-held ultrasound indentation device was developed for this study. It was designed to house a compressive load cell (Model: ELFS-T3E-2L, Entran Devices Inc., Fairfield, NJ, USA), connected in series with the ultrasound sensor via a plexiglass plug-in socket to measure the force. The range of the sensor was 10N. The tip of the indenter was flat and had a diameter of 3mm. Auxiliary circuits comprising of amplifiers and analog to digital converters were used for digitizing the data. The previous studies conducted by Xiong et al. (Xiong et al., 2010) used a controlled indentation rate from 0 to 5 mm/s in increments of 0.1 mm/s with a theoretical maximum rate of 10 mm/s to measure the pressure threshold and based on the observations of the pilot study they later(Xiong et al., 2011) suggested the range 0 to 2mm/sec for measurement of pressure threshold to avoid the premature sensation of discomfort or pain. Although the system's indentation rate was manually controlled, care was taken that the indentation rate was less than 2 mm/sec. Ultrasound gel was applied to the skin as a coupling medium to ensure continuous contact. A schematic representation of the system used for the experiment is shown in Figure 1. A footswitch was used to start recording the force data. Participants were provided with a keypad switch to press specific buttons on the perception of discomfort and pain. The raw data were first processed in a customized software developed using Microsoft C++, and further for extraction of force data, a GUI was designed in MATLAB software.

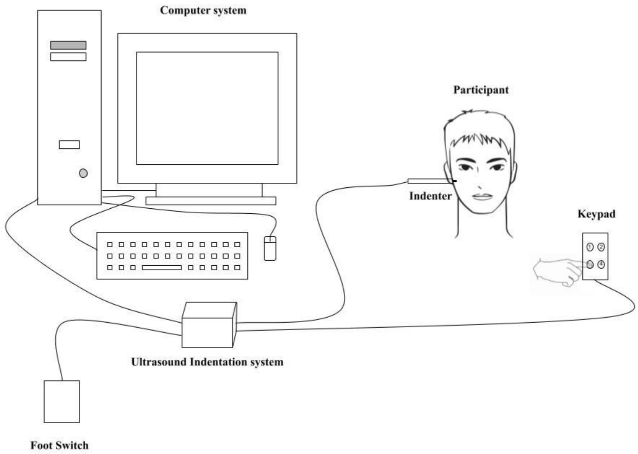

Fig. 1. Schematics of the experimental setup used to measure pressure thresholds.

The system's calibration was conducted by comparing the force values measured by the indentation device and using an electronic weighing scale. The setup for the calibration experiment is shown in Figure 2. A silicon phantom was placed on the electronic weighing machine, and then the scale of the weighing machine was adjusted to zero. The indentation device was held upside down using a clamp in a fixed position to avoid any errors due to misalignment or movement. Different load(force) values were applied on the silicon phantom by the indentation device, and the corresponding values were measured using both the weighing machine and the ultrasound indentation system. A very high Correlation coefficient (R^2 = 0.9984) was obtained for the acquired force values. Based on the equation derived from the linear regression of the measured values, a *Force Acquisition Factor* of 1.22 was introduced in the TUPS software to compensate for the measurement difference. The offset value was adjusted in the software program automatically so that its reading was zero N when no force was applied. The mean error in force measurement after calibration and offset adjustment was found to be 0.04±0.03N.

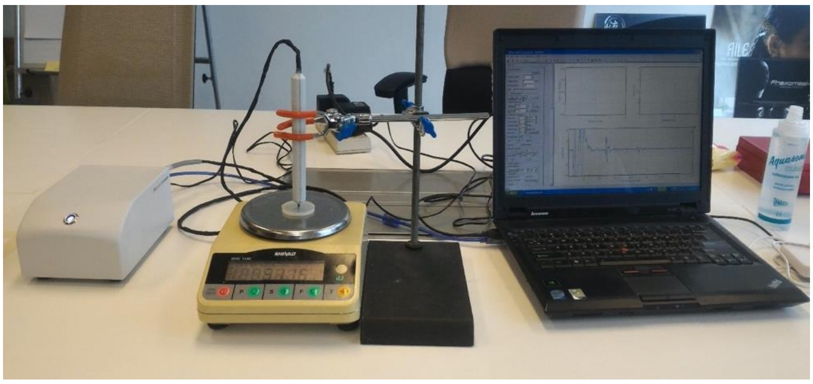

Figure 2. Setup for calibration of Ultrasound Indentation device

2.3. Landmarks selected for the study

For this study, a total of seventy-six landmarks were selected based on anatomical and morphological features and the location of contact regions of everyday used head-related products. The selected landmarks are shown in Figure 3. Of the seventy-six landmarks, twenty-three were located on the head and the forehead region, thirteen landmarks were on the frontal part of the face, sixteen landmarks each were situated on both sides of the face, and eight landmarks were located in the neck region. Three trials of loading and unloading were performed at every landmark to measure the Pressure Discomfort Threshold and Pressure Pain Threshold accurately. A counterbalanced approach was used while selecting the landmarks to avoid any bias due to order and time effect.

1 Vertex (Top of head)
2 Semi landmark
3 Semi landmark
4 Semi landmark
5 Semi landmark
6 Neck Right lateral
7 Semi landmark
8 Semi landmark
9 Semi landmark
10 Semi landmark
11 Neck Posterior
12 Semi landmark
13 Semi landmark
14 Semi landmark
15 Semi landmark
16 Neck Left lateral
17 Trichion
18 Semi landmark
19 Semi landmark
20 Semi landmark
21 Right Top of ear attachemtn (TEA)
22 Right Tragion
23 Right Otobasion Inferius
24 Right Gonion
25 Semi landmark
26 Right Zygomatic Arch
27 Right Occlusal Line
28 Right Frontotemporale
29 Right Zygofrontale
30 Right Zygion
31 Right Supra M2
32 Right Sub M2
33 Right Mid mandibular
34 Right Frontotemporale
35 Right Superciliare
36 Right Infraorbitale
37 Right Inferior malar
38 Right Supra Canina
39 Right Sub Canina
40 Right Outer Chin
41 Glabella
42 Sellion
43 Right nasal root point
44 Left nasal root point
45 Semi landmark
46 Rhinion
47 Semi landmark
48 Right Alare
49 Pronasale
50 L eft Alare
51 Philtrum
52 Sublabiale
53 Chin
54 Menton
55 Semi landmark
56 Neck anterior
57 Left Frontotemporale
58 Left Superciliare
59 Left Infraorbitale
60 Left Inferior malar
61 Left Supra Canina
62 Left Sub Canina
63 Left Outer Chin
64 Left Top of ear attachemtn (TEA)
65 Left Tragion
66 Left Otobasion Inferius
67 Left Gonion
68 Semi landmark
69 Left Zygomatic Arch
70 Left Occlusal Line
71 Left Frontotemporale
72 Left Zygofrontale
73 Left Zygion
74 Left Supra M2
75 Left Sub M2
76 Left Mid mandibular

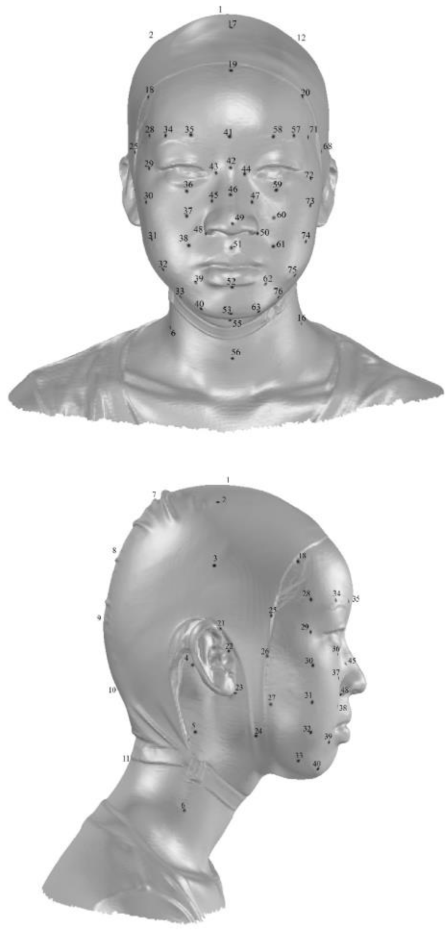

Figure 3. Location of the landmarks used for this study

2.4. Procedure

Approval was acquired from the University Human Subjects Ethics Committee (Reference no. HSEARS20160715002) for conducting this study. The experiment's details were explained to participants, and their written consent was obtained before starting the experiment. The experimental protocol was described in English, Cantonese, or Putonghua language based on their preference for the ease of their understanding. To familiarize participants with the equipment and testing procedure, they were given 5-minute training before the experiment began. Around five to eight practice trials were also performed during this time. During data collection, the participants were asked to sit on a comfortable table and rest their heads on a head-mount to avoid head movement. Figure 4 depicts the experimental procedure adopted for this study. Ultrasound gel was used as a coupling medium to ensure continuous contact between the indenter and the skin surface. A four-button keypad switch was provided to participants for recording the PDT and PPT. During the experiment, the indenter was placed perpendicular to the surface of the landmark. When the researcher started applying load manually, the researcher said the word "Start," The participants were asked to press button 1 on the keypad. The load was gradually applied by manually pushing the indenter at a steady rate. At the onset of perception of discomfort, participants were asked to press button 2 on the keypad. This point was marked as the Pressure Discomfort Threshold in the system. The load was further increased to a moment when the participant started feeling pain. At this time, the participants were informed to intimate this by pressing button 3 on the keypad. This point represented the Pressure Pain Threshold. After the pressing of switch three, the load was gradually removed. Three trials were performed at every landmark. In the event of any error, while recording the data due to head movements, extra cycles of loading were conducted. The data were separately recorded and saved for every landmark, which was later processed offline. The entire experimental duration was approximately two hours per participant.

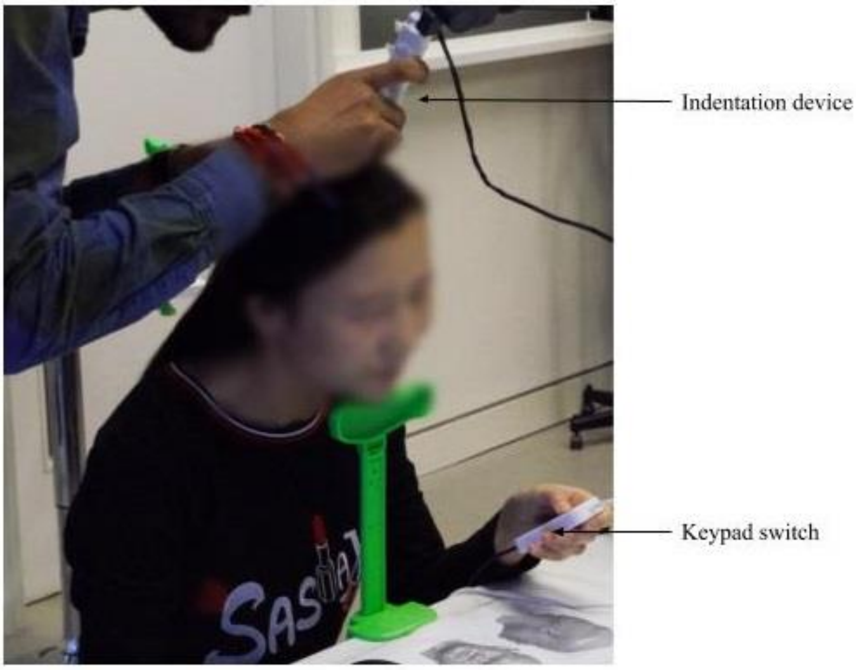

Figure 4. Experimental procedure

2.5. Data processing

The acquired force data and the time marker data for button press 1, 2, and 3 were extracted using a customized Microsoft VC++ software in a text file. This file was further imported in a MATLAB-based GUI, designed to export the entire data into excel sheets. All the data were cross-checked, and the data of the erroneous cycles were removed. Mean values of force at PDT and PPT for all the trials at every individual point were calculated. The pressure values were calculated using the force value and cross-section area of the indenter, which was 7.07 mm^2 (indenter radius of 1.5 mm) for every landmark.

2.6. Reliability testing

It is crucial to identify the acquired data's consistency, considering the subjective nature of the pressure threshold data. Hence, a separate study was conducted to check the reliability of the data. One of the most commonly used techniques to measure psychometric data's test-retest reliability is Intraclass correlation (ICC) analysis. Several researchers have used this approach (Cathcart and Pritchard, 2006; Frank et al., 2013; Jones et al., 2007; Xiong et al., 2010; Ylinen et al., 2007) in the past. Sixty Chinese adult participants (30 males and 30 females) who had previously participated in the study were invited again to participate in this study after a minimum gap of two months. PDT and PPT data were collected for all the participants at all the selected seventy-six landmarks by the same researcher who collected this data previously. The acquired mean PDT and PPT data for all three trials at every landmark was compared with the previously acquired data.

2.7. Data Analysis

Statistical analysis was performed on the resultant mean data using IMB SPSS Statistics Version 22 software. Descriptive statistical analyses were performed to find mean values and the standard deviation for PDT and PPT. To understand the gender-specific difference, Independent-Samples Mann-Whitney U-Test was used. Spearman Correlation analysis was performed to identify the relationship between Pressure threshold data and demographic parameters (age and BMI). Based on the literature (Koo and Li, 2016; Trevethan, 2017), the ICC model (3,3) was adopted to measure the reliability of the pressure threshold data. The ICC analysis was based on two-way mixed effects and tested for absolute agreement.

3. Results

3.1. Pressure Threshold-Descriptive statistics

Pressure threshold measurements were conducted at all the seventy-six landmarks for all the participants. Three cycles of loading and unloading were performed at every landmark, and the mean value of the trials was considered during the data analysis. The descriptive statistics for pressure values at discomfort and pain thresholds for male and female participants have been summarized in Table 2, Table 3, respectively.

Table 2. Summary of statistical analysis results for PDT data

Landmark	Male			Female			Gender based difference	Landmark	Male			Female			Gender based difference
	Mean ± S.D.	Correlation with BMI (r)	Correlation with age (r)	Mean ± S.D.	Correlation with BMI (r)	Correlation with age (r)	*p-value*		Mean ± S.D.	Correlation with BMI (r)	Correlation with age (r)	Mean ± S. D.	Correlation with BMI (r)	Correlation with age (r)	*p-value*
1	564.36±206.51	0.058	0.059	504.95±154.17	0.117	-0.112	0.047#	39	172.56±135.79	0.017	0.008	124.47±79.21	-0.007	-0.230*	0.018#
2	487.98±203.68	0.116	0.095	466.76±158.42	0.080	-0.149	0.815	40	231.97±137.20	0.084	0.000	168.32±86.28	0.026	-0.233*	0.001#
3	449.79±195.19	-0.011	0.062	380.48±144.27	0.059	-0.146	0.011#	41	248.94±124.47	0.054	-0.050	234.79±113.15	-0.029	-0.251**	0.492
4	356.44±169.73	-0.009	0.035	287.13±106.08	0.049	-0.089	0.007#	42	176.80±114.57	0.228*	0.084	147.10±62.23	0.053	-0.243*	0.181
5	233.38±130.13	0.036	-0.006	169.73±84.87	-0.019	-0.190*	0.000#	43	217.82±128.71	0.081	-0.060	158.42±86.28	-0.014	-0.256**	0.000#
6	219.24±121.64	0.055	0.014	154.17±84.87	-0.082	-0.069	0.000#	44	195.19±117.40	0.109	-0.042	131.54±82.04	-0.017	-0.292**	0.000#
7	441.30±186.70	0.075	-0.065	377.65±132.96	0.018	-0.075	0.024#	45	212.16±130.13	0.018	-0.075	149.93±84.87	-0.048	-0.286**	0.000#
8	415.84±169.73	0.130	-0.033	370.58±127.30	-0.029	-0.025	0.113	46	172.56±96.18	0.157	-0.029	140.03±57.99	0.118	-0.170	0.052
9	407.36±178.22	0.125	0.058	359.26±140.03	-0.055	-0.052	0.076	47	181.05±111.74	0.087	-0.035	124.47±82.04	-0.051	-0.310**	0.000#
10	349.36±185.29	0.164	0.095	288.54±135.79	-0.091	0.034	0.040#	48	193.78±130.13	0.082	0.039	145.69±86.28	-0.017	-0.122	0.010#
11	306.93±178.22	0.069	0.078	261.67±125.88	-0.077	-0.045	0.156	49	138.61±84.87	0.159	0.021	107.50±53.75	-0.092	-0.237*	0.003#
12	434.23±186.70	0.144	0.003	408.77±128.71	0.015	-0.088	0.663	50	181.05±117.40	0.073	-0.010	127.30±77.79	0.017	-0.229*	0.001#
13	429.99±193.78	0.112	0.129	355.02±123.06	0.041	-0.157	0.012#	51	130.13±93.35	0.001	0.053	113.15±69.31	-0.029	-0.157	0.514
14	333.80±164.07	0.091	0.058	272.98±111.74	0.046	-0.185	0.015#	52	164.07±115.98	0.106	0.059	135.79±84.87	-0.063	-0.296**	0.194
15	237.62±141.44	0.076	0.068	166.90±83.45	-0.037	-0.146	0.000#	53	196.61±113.15	0.131	0.049	158.42±89.11	-0.032	-0.273**	0.012#
16	217.82±121.64	0.035	0.038	161.24±83.45	0.029	-0.022	0.001#	54	182.46±113.15	0.172	0.078	147.10±72.14	0.114	-0.267**	0.028#
17	451.20±192.36	0.056	-0.068	398.87±137.20	0.050	-0.170	0.071	55	140.03±104.67	0.095	0.008	91.94±46.68	-0.048	-0.235*	0.001#
18	371.99±151.34	0.047	0.010	333.80±104.67	0.216*	-0.107	0.146	56	137.20±82.04	0.060	-.020	86.28±48.09	-0.060	-0.228*	0.000#
19	347.95±162.66	0.115	0.062	338.05±114.57	0.048	-0.196*	0.767	57	239.04±123.06	0.079	-0.006	206.51±86.28	-0.054	-0.223*	0.130
20	288.54±147.10	0.111	0.030	294.20±110.33	0.019	-0.188	0.216	58	229.14±110.33	0.085	-0.041	198.02±96.18	-0.058	-0.301**	0.049#
21	297.03±188.12	-0.064	-0.065	233.38±97.60	-0.010	-0.175	0.051	59	169.73±101.84	0.116	-0.035	108.91±67.89	-0.038	-0.317**	0.000#
22	231.97±147.10	0.040	-0.045	179.63±82.04	0.028	-0.160	0.031#	60	188.12±124.47	0.101	0.012	123.06±83.45	-0.057	-0.283**	0.000#
23	236.21±151.34	0.059	0.004	178.22±84.87	-0.051	-0.190*	0.015#	61	149.93±106.08	0.045	-0.022	90.52±63.65	-0.005	-0.277**	0.000#
24	243.28±172.56	0.036	-0.033	181.05±99.01	-0.039	-0.185	0.028#	62	172.56±134.37	0.100	-0.015	111.74±76.38	0.001	-0.246*	0.001#
25	319.66±161.24	0.091	-0.062	270.16±104.67	0.127	-0.196*	0.059	63	216.41±135.79	0.045	0.038	145.69±76.38	-0.028	-0.243*	0.000#
26	280.06±154.17	0.132	-0.006	216.41±100.42	0.045	-0.203*	0.004#	64	282.89±166.90	0.047	-0.062	222.07±97.60	-0.019	-0.160	0.040#
27	229.14±147.10	0.084	-0.044	171.15±96.18	0.037	-0.190*	0.014#	65	234.79±140.03	0.104	-0.018	173.97±77.79	-0.009	-0.143	0.003#
28	304.10±155.59	0.071	-0.013	241.87±97.60	0.048	-0.216*	0.004#	66	199.43±131.54	0.003	-0.046	141.44±77.79	0.026	-0.258**	0.003#
29	207.92±111.74	0.156	0.002	169.73±87.69	-0.017	-0.244*	0.009#	67	227.72±158.42	-0.019	-0.115	166.90±100.42	0.017	-0.192*	0.012#
30	237.62±140.03	0.088	-0.029	181.05±108.91	-0.069	-0.231*	0.002#	68	312.59±162.66	0.094	0.021	258.84±94.77	0.069	-0.154	0.054
31	192.36±141.44	0.110	-0.054	121.64±79.21	0.024	-0.266**	0.000#	69	261.67±137.20	0.130	-0.010	199.43±96.18	0.108	-0.239*	0.001#
32	205.09±149.93	0.009	0.014	141.44±84.87	-0.008	-0.202*	0.004#	70	236.21±151.34	0.054	-0.006	181.05±103.25	-0.022	-0.290**	0.014#
33	207.92±128.71	0.020	-0.030	149.93±86.28	-0.095	-0.268**	0.001#	71	306.93±149.93	0.102	-0.061	253.18±93.35	0.127	-0.187	0.025#
34	271.57±135.79	0.087	0.017	219.24±77.79	0.073	-0.246*	0.013#	72	237.62±106.08	0.141	-0.039	188.12±84.87	0.107	-0.194*	0.001#
35	241.87±113.15	0.173	0.044	214.99±90.52	-0.042	-0.309**	0.125	73	248.94±130.13	0.112	0.030	176.80±91.94	-0.051	-0.263**	0.000#
36	154.17±106.08	0.131	0.072	104.67±65.06	-0.190	-0.281**	0.000#	74	193.78±127.30	0.068	-0.079	137.20±80.62	0.032	-0.231*	0.001#
37	182.46±118.81	-0.011	-0.065	128.71±86.28	-0.037	-0.271**	0.001#	75	212.16±138.61	0.002	-0.049	155.59±86.28	-0.023	-0.275**	0.008#
38	159.83±111.74	0.080	0.019	120.23±73.55	0.000	-0.184	0.012#	76	209.34±125.88	0.012	-0.031	147.10±90.52	-0.045	-0.183	0.000#

Sample size(*n*) = 218 (109 male and 109 female). Mean and Standard Deviation (S.D.) values of PDT are in kPa
For results of correlation analysis: Correlation coefficient values are displayed (*r*)
**. Correlation is significant at the 0.01 level (2-tailed). *. Correlation is significant at the 0.05 level (2-tailed).
For results Independent Sample Mann-Whitney U analysis (Gender-based differences): Asymptotic significances are displayed. The significance level is 0.05. #. There is a significant difference in PDT values between both the genders

Table 3. Summary of statistical analysis results for PPT data

Landmark	Male			Female			Gender based difference	Landmark	Male			Female			Gender based difference
	Mean ± S.D.	Correlation with BMI (r)	Correlation with age (r)	Mean ± S.D.	Correlation with BMI (r)	Correlation with age (r)	*p-value*		Mean ± S.D.	Correlation with BMI (r)	Correlation with age (r)	Mean ± S.D.	Correlation with BMI (r)	Correlation with age (r)	*p-value*
1	782.18±199.43	0.154	0.036	725.60±158.42	0.161	-0.109	0.020#	39	304.10±151.34	0.177	0.024	229.14±100.42	0.075	-0.130	0.000#
2	698.73±219.24	0.150	0.052	649.22±162.66	0.123	-0.076	0.099	40	367.75±158.42	0.192*	-0.018	268.74±101.84	0.074	-0.189	0.000#
3	636.49±203.68	0.029	0.041	538.90±159.83	0.108	-0.084	0.000#	41	369.17±147.10	0.129	-0.027	342.29±124.47	-0.028	-0.237*	0.182
4	524.75±198.02	0.072	0.024	413.01±128.71	0.101	-0.049	0.000#	42	263.08±130.13	0.245*	0.107	220.65±72.14	0.064	-0.206*	0.050
5	391.80±161.24	0.042	-0.029	285.71±106.08	0.049	-0.107	0.000#	43	318.25±149.93	0.126	-0.059	246.11±100.42	-0.005	-0.254**	0.000#
6	346.53±152.76	0.059	-0.029	247.52±106.08	-0.146	-0.048	0.000#	44	298.44±142.86	0.185	-0.038	212.16±94.77	-0.010	-0.272**	0.000#
7	647.81±202.26	0.080	-0.080	558.70±137.20	0.047	0.036	0.001#	45	316.83±154.17	0.120	-0.047	240.45±100.42	-0.014	-0.259**	0.000#
8	592.64±183.88	0.155	-0.018	517.68±145.69	-0.011	-0.019	0.001#	46	237.62±108.91	0.177	-0.028	190.95±65.06	0.136	-0.169	0.002#
9	586.99±179.63	0.166	0.010	497.88±155.59	-0.029	-0.105	0.000#	47	268.74±125.88	0.187	-0.040	196.61±94.77	-0.015	-0.266**	0.000#
10	533.24±192.36	0.174	0.063	429.99±148.51	-0.002	-0.017	0.000#	48	305.52±145.69	0.150	-0.028	241.87±100.42	0.021	-0.129	0.001#
11	492.22±203.68	0.137	0.050	407.36±144.27	-0.045	0.015	0.002#	49	199.43±106.08	0.228*	0.000	157.00±70.72	-0.113	-0.200*	0.000#
12	611.03±199.43	0.133	-0.012	570.01±135.79	0.042	-0.091	0.141	50	298.44±135.79	0.146	-0.053	219.24±87.69	0.059	-0.246**	0.000#
13	581.33±205.09	0.132	0.102	487.98±137.20	0.025	-0.131	0.001#	51	236.21±113.15	0.086	-0.009	202.26±79.21	-0.003	-0.101	0.054
14	490.81±196.61	0.134	0.110	386.14±132.96	0.024	-0.138	0.000#	52	288.54±138.61	0.241*	0.015	230.55±106.08	-0.057	-0.282**	0.002#
15	383.31±176.80	0.148	0.074	265.91±99.01	-0.061	-0.073	0.000#	53	304.10±128.71	0.196*	-0.007	241.87±101.84	0.007	-0.235*	0.000#
16	340.88±149.93	0.092	0.078	256.01±93.35	-0.047	-0.032	0.000#	54	277.23±145.69	0.242*	0.065	222.07±89.11	0.072	-0.222*	0.003#
17	639.32±214.99	0.098	-0.128	574.26±151.34	0.128	-0.142	0.017#	55	206.51±123.06	0.144	-0.007	142.86±56.58	0.025	-0.152	0.000#
18	524.75±165.49	0.113	0.010	463.93±111.74	0.207*	0-.073	0.009#	56	200.85±107.50	0.090	-0.062	127.30±62.23	-0.003	-0.211*	0.000#
19	489.39±183.88	0.150	0.080	456.86±125.88	0.112	-0.152	0.279	57	360.68±149.93	0.131	-0.039	298.44±96.18	0.013	-0.170	0.002#
20	403.11±171.15	0.148	0.042	404.53±120.23	0.073	-0.132	0.595	58	336.63±134.37	0.141	-0.043	306.93±100.42	0.003	-0.235*	0.138
21	451.20±210.75	-0.020	-0.028	356.44±108.91	-0.019	-0.160	0.001#	59	270.16±130.13	0.232*	-0.033	186.70±77.79	0.051	-0.220*	0.000#
22	366.34±173.97	0.121	0.005	284.30±91.94	0.076	-0.098	0.001#	60	325.32±148.51	0.211*	-0.001	223.48±96.18	0.010	-0.163	0.000#
23	369.17±182.46	0.147	0.034	280.06±89.11	-0.037	-0.166	0.000#	61	272.98±135.79	0.121	-0.058	162.66±79.21	0.049	-0.187	0.000#
24	404.53±198.02	0.102	-0.014	301.27±115.98	-0.009	-0.163	0.000#	62	306.93±158.42	0.183	-0.003	205.09±90.52	0.029	-0.188	0.000#
25	471.00±182.46	0.162	-0.030	400.28±121.64	0.132	-0.163	0.005#	63	350.78±159.83	0.145	0.006	247.52±94.77	0.011	-0.094	0.000#
26	401.70±181.05	0.201*	0.027	323.90±114.57	0.048	-0.195*	0.002#	64	429.99±195.19	0.076	-0.064	338.05±107.50	0.022	-0.165	0.002#
27	379.07±171.15	0.190	-0.052	285.71±108.91	0.032	-0.164	0.000#	65	356.44±159.83	0.144	-0.078	270.16±89.11	0.061	-0.090	0.000#
28	444.13±176.80	0.177	-0.012	355.02±108.91	0.082	-0.224*	0.000#	66	316.83±147.10	0.143	-0.048	239.04±90.52	0.034	-0.223*	0.000#
29	306.93±137.20	0.203*	0.025	265.91±104.67	0.043	-0.180	0.025#	67	366.34±181.05	0.085	-0.096	277.23±110.33	0.039	-0.110	0.000#
30	347.95±168.32	0.120	-0.011	285.71±124.47	-0.020	-0.228*	0.009#	68	442.72±176.80	0.140	0.010	371.99±90.52	0.084	-0.137	0.009#
31	329.56±183.88	0.135	-0.086	209.34±103.25	0.064	-0.265**	0.000#	69	374.82±152.76	0.217*	-0.044	304.10±104.67	0.136	-0.223*	0.001#
32	373.41±176.80	0.106	0.053	257.43±97.60	0.037	-0.208*	0.000#	70	377.65±165.49	0.126	0.019	295.62±108.91	0.015	-0.205*	0.000#
33	335.22±147.10	0.168	-0.017	239.04±97.60	-0.025	-0.229*	0.000#	71	428.57±162.66	0.144	-0.054	366.34±97.60	0.183	-0.143	0.010#
34	397.45±152.76	0.177	0.033	318.25±91.94	0.150	-0.191*	0.000#	72	340.88±132.96	0.163	-0.048	292.79±93.35	0.164	-0.123	0.011#
35	346.53±141.44	0.197*	0.005	309.76±97.60	-0.004	-0.283**	0.080	73	366.34±151.34	0.131	-0.038	284.30±104.67	0.026	-0.155	0.000#
36	248.94±130.13	0.246*	0.035	183.88±76.38	-0.058	-0.231*	0.000#	74	329.56±162.66	0.081	-0.092	227.72±93.35	0.034	-0.196*	0.000#
37	314.00±141.44	0.101	-0.082	230.55±99.01	0.022	-0.189	0.000#	75	362.09±154.17	0.053	-0.026	272.98±93.35	0.047	-0.161	0.000#
38	268.74±127.30	0.156	-0.041	203.68±83.45	-0.008	-0.119	0.000#	76	322.49±149.93	0.094	-0.048	231.97±107.50	-0.019	-0.154	0.000#

Sample size(n) = 218 (109 male and 109 female). Mean and Standard Deviation (S.D.) values of PPT are in kPa

For results of correlation analysis: Correlation coefficient values are displayed (*r*)

**. Correlation is significant at the 0.01 level (2-tailed). *. Correlation is significant at the 0.05 level (2-tailed).

For results Independent Sample Mann-Whitney U analysis (Gender-based differences): Asymptotic significances are displayed. The significance level is 0.05. #. There is a significant difference in PDT values between both the genders

3.2. Gender differences

Independent-Samples Mann-Whitney U Test was performed on the pressure data measured at discomfort and pain thresholds to understand the gender-based difference. It was identified that out of seventy-six landmarks, for fifty-seven landmarks, the distribution of PDT values between genders varied significantly. The distribution of PPT values varied significantly for sixty-seven landmarks between genders. It was also observed that PDT and PPT values for male participants were comparatively higher than those of female participants for all the landmarks. The detailed results for landmarks showing significant variance in the Independent-Sample Mann-Whitney U Test are provided in Tables 2 and 3, respectively.

3.3. Correlation analysis

Spearman Correlation analyses were performed to identify the relationship between pressure threshold data at discomfort and pain and demographic parameters like age and BMI. For male participants, the results indicate a slightly positive significant correlation between BMI and pressure values at the discomfort threshold at only one landmark (landmark 42). The results also showed a slightly positive, statistically significant correlation between BMI and pressure values for 13 landmarks for pain threshold. For all the remaining landmarks, there was no significant correlation between BMI and the pressure threshold values. There was no correlation between age and the pressure values at the discomfort threshold and pain threshold for all the landmarks for male participants.

The results of Spearman Correlation analysis for age, BMI for female participants indicated a statistically significant negative correlation between the age of participants and pressure values at discomfort threshold for 46 different landmarks and at pain threshold for 27 landmarks. The results also show a statistically significant correlation between BMI and pressure values at the discomfort threshold and pain threshold for only one landmark (landmark 18). There was no statistically significant correlation between age, BMI, and the pressure values at the discomfort threshold and pain threshold for all the remaining landmarks. The results for correlation analyses are shown in Table 2 and Table 3.

3.4 Reliability test:

Intraclass Correlation results for individual landmark-based Pressure discomfort threshold and Pressure pain threshold data are presented in Table 4. The table also provides the 95% Confidence Interval limits for Intra Class Correlation results. Based on the literature (Cicchetti, 1994; Fleiss, 2004) related to ICC results for clinical studies, it was observed ICC value <0.4 is considered to have poor reliability, ICC value between 0.40 - 0.59 is deemed to be fair reliability, ICC value between 0.60 – 0.74 reflects good reliability and ICC value in the range of 0.75 -

1.00 suggests excellent reliability. Ten landmarks showed excellent reliability; fifty landmarks showed good reliability, whereas 15 landmarks showed fair reliability, whereas only one landmark (landmark 9) showed poor reliability for PDT data. The results of ICC analysis for PPT data showed only one landmark (landmark 42) had excellent reliability, while twenty landmarks had good reliability and fifty landmarks had fair reliability. However, five landmarks (landmark 9, landmark 13, landmark 35, landmark 70, landmark 72) exhibited poor reliability. Overall all the landmarks showed an acceptable range of reliability. In general, an overall trend was observed where the pressure threshold readings acquired during the second time were relatively higher.

Table 4. Results of ICC analysis for PDT and PPT data

Landmarks	PDT			PPT			Landmarks	PDT			PPT		
	Intraclass Correlation	95% Confidence Interval		Intraclass Correlation	95% Confidence Interval			Intraclass Correlation	95% Confidence Interval		Intraclass Correlation	95% Confidence Interval	
		Lower Bound	Upper Bound		Lower Bound	Upper Bound			Lower Bound	Upper Bound		Lower Bound	Upper Bound
1	0.743	0.569	0.846	0.587	0.314	0.752	39	0.724	0.502	0.842	0.573	0.115	0.777
2	0.729	0.536	0.841	0.628	0.271	0.799	40	0.654	0.193	0.830	0.49	-0.171	0.763
3	0.628	0.161	0.815	0.418	-0.142	0.697	41	0.775	0.534	0.881	0.675	0.101	0.855
4	0.604	0.288	0.773	0.517	-0.002	0.750	42	0.818	0.696	0.891	0.756	0.573	0.858
5	0.557	0.268	0.733	0.486	0.135	0.695	43	0.711	0.288	0.861	0.574	-0.099	0.809
6	0.569	0.280	0.743	0.457	-0.080	0.716	44	0.632	0.223	0.809	0.518	-0.094	0.768
7	0.541	0.223	0.727	0.513	-0.001	0.746	45	0.677	0.156	0.851	0.516	-0.147	0.776
8	0.557	0.005	0.781	0.439	-0.207	0.736	46	0.662	0.256	0.828	0.552	-0.065	0.788
9	0.390	-0.081	0.654	0.249	-0.174	0.549	47	0.724	0.309	0.869	0.634	0.001	0.838
10	0.595	0.221	0.778	0.405	-0.204	0.709	48	0.838	0.625	0.919	0.735	0.315	0.876
11	0.521	0.205	0.712	0.479	0.117	0.693	49	0.734	0.428	0.863	0.605	0.004	0.818
12	0.631	0.346	0.788	0.477	0.010	0.714	50	0.745	0.269	0.886	0.568	-0.146	0.813
13	0.607	-0.196	0.847	0.391	-0.207	0.722	51	0.749	0.577	0.851	0.703	0.434	0.836
14	0.592	0.022	0.805	0.482	-0.204	0.767	52	0.808	0.584	0.900	0.689	0.164	0.858
15	0.613	0.257	0.787	0.463	-0.068	0.718	53	0.701	0.466	0.828	0.662	0.169	0.839
16	0.715	0.404	0.851	0.517	-0.151	0.778	54	0.631	0.381	0.780	0.443	0.089	0.663
17	0.646	0.268	0.814	0.461	-0.082	0.719	55	0.682	0.384	0.827	0.604	0.234	0.785
18	0.765	0.507	0.877	0.699	0.128	0.868	56	0.585	0.201	0.773	0.546	0.143	0.749
19	0.652	0.401	0.796	0.555	0.147	0.756	57	0.718	0.453	0.846	0.582	0.025	0.798
20	0.616	0.347	0.773	0.563	0.184	0.757	58	0.689	0.269	0.847	0.521	-0.169	0.785
21	0.671	0.055	0.856	0.486	-0.222	0.779	59	0.630	0.093	0.824	0.424	-0.217	0.733
22	0.614	0.269	0.786	0.496	-0.131	0.758	60	0.685	0.337	0.835	0.541	-0.166	0.798
23	0.655	0.328	0.812	0.477	-0.137	0.744	61	0.731	0.305	0.874	0.637	-0.172	0.860
24	0.695	0.361	0.840	0.536	-0.076	0.779	62	0.701	0.403	0.839	0.637	0.067	0.832
25	0.585	0.105	0.789	0.507	-0.143	0.769	63	0.748	0.421	0.874	0.627	-0.049	0.839
26	0.626	0.162	0.813	0.530	-0.137	0.785	64	0.699	0.114	0.869	0.472	-0.211	0.762
27	0.557	0.207	0.748	0.414	-0.104	0.684	65	0.638	-0.014	0.842	0.433	-0.214	0.755
28	0.600	0.033	0.810	0.453	-0.215	0.752	66	0.694	0.206	0.857	0.542	-0.221	0.815
29	0.627	0.246	0.801	0.506	-0.063	0.752	67	0.704	0.471	0.830	0.504	0.022	0.735
30	0.620	-0.001	0.829	0.440	-0.222	0.752	68	0.582	0.174	0.775	0.501	-0.152	0.767
31	0.769	0.497	0.881	0.658	-0.017	0.855	69	0.724	0.335	0.866	0.625	-0.040	0.836
32	0.801	0.659	0.883	0.699	0.375	0.842	70	0.597	0.325	0.760	0.387	-0.010	0.632
33	0.638	0.226	0.814	0.478	-0.211	0.767	71	0.626	-0.039	0.837	0.461	-0.212	0.756
34	0.616	0.125	0.810	0.464	-0.160	0.740	72	0.518	-0.097	0.768	0.382	-0.187	0.681
35	0.591	0.053	0.801	0.379	-0.188	0.679	73	0.729	0.141	0.886	0.569	-0.221	0.832
36	0.666	0.347	0.818	0.545	-0.067	0.784	74	0.785	0.620	0.876	0.618	0.153	0.807
37	0.669	0.449	0.801	0.614	0.088	0.813	75	0.811	0.682	0.888	0.689	0.352	0.837
38	0.761	0.599	0.858	0.587	0.204	0.774	76	0.742	0.483	0.861	0.615	0.023	0.822

Sample size = 60 (30 male and 30 female).

4. Discussion and Conclusion

In the current study, PDT and PPT were measured using a hand-held ultrasound indentation device for selected seventy-six landmarks for a total of 218 healthy Chinese adult participants. When processed using statistical analysis tools, the acquired data provided a good understanding of variation in values at PDT and PPT at different locations for participants.

The descriptive analysis provided the details of mean values of pressure at discomfort and pain thresholds for male and female participants. It was found that the PDT and PPT data for both genders demonstrated a similar pattern. The pressure sensitivity in the head and forehead regions was found to be less, i.e., people can handle a comparatively higher pressure in these regions without perceiving a high level of discomfort or pain. In contrast, in the facial area, people have higher pressure sensitivity and could not handle very high pressure.

Research in the field of measurement of pressure thresholds in the head region has still mostly been limited to clinical studies, and very few studies have reported results for a healthy subject. Also, most studies focus on the measurement of PDT or PPT at only a few limited anatomical landmarks. This does not give a proper idea of the pressure sensitivity in the entire region, which may be very important in product design. Table 5 summarizes the results of studies(Chung et al., 1993; Chung et al., 1992; Fernández-de-Las-Peñas et al., 2007; Jensen et al., 1986; Schoenen et al., 1991) previously conducted to measure the pressure threshold in specific regions of the head. The results from the current study are in a similar range as that of previous studies. However, previous studies have also suggested that several parameters like the sample size (Jensen et al., 1986), participants' ethnicity (Komiyama et al., 2007), the indenter tip size (Jensen et al., 1986; Simha et al., 2007), could lead to some amount of variation in the results.

Table 5. Summary of pressure threshold data values from previous studies

Author	Location	No. of participants	Parameter measured	PDT/PPT values (kPa)
Jensen et al. (1986)	Temple	32 male & 25 females	PPT	150 to 400
Schoenen et al.(1991)	Temple Forehead Suboccipital	20 females	PPT	299±16.1 (L) 341±19.0 (L) 310±24.2 (L)
Chung et al. (1992)	Facial region (13 landmarks)	19 males & 21 females	PPT	Middle temporal M=357.8±134.9 (A), F=274.6±60.9 (A) Medial pterygoid M=156.9±30.1 (A) F=133.5±30.4 (A)
Chung et al. (1993)	Temporomandibular joint capsules (Lateral side)	20 males & 19 females	PPT	M=224.1±42.6 (R) M=211.5±37.3 (L) F= 192.5±41.3 (R) F=192.2±43.1(L)
Fernández-de-las-Peñas et al. (2007)	Cephalic region Neck region	12 males & 13 females	PPT	205.94±39.27(A) 245.17±39.27 (A)

M- Male, F-Female, R-Right side, L-Left side, A- Average of both sides

The mean pressure threshold values for discomfort and pain thresholds acquired from the current study were used to develop the pressure sensitivity maps for the head and face regions. In addition, the natural neighbor interpolation technique was used to estimate the approximate pressure threshold values at regions in between two landmarks. Finally, the data was placed on 3D average head models for Chinese adult males and females to better visualize the pressure threshold variance across different head and face regions and gender-based differences. The front view and back view of pressure sensitivity maps for discomfort and pain thresholds for male and female Chinese adults are shown in Figure 5 and Figure 6.

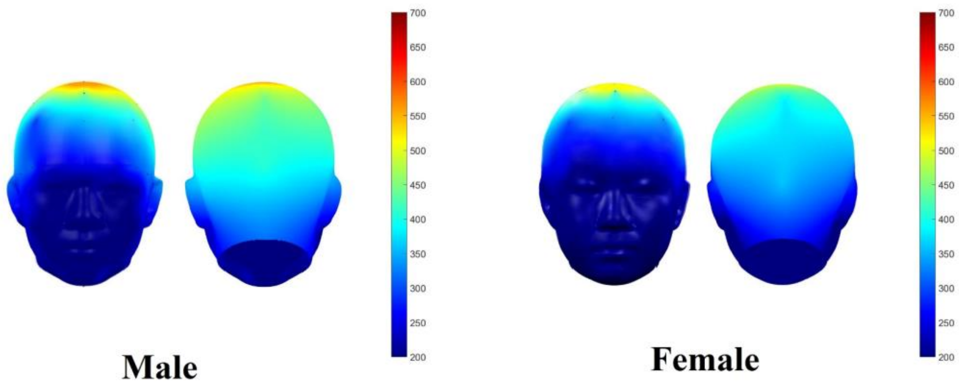

Figure 5. Pressure discomfort threshold maps (front view and back view)

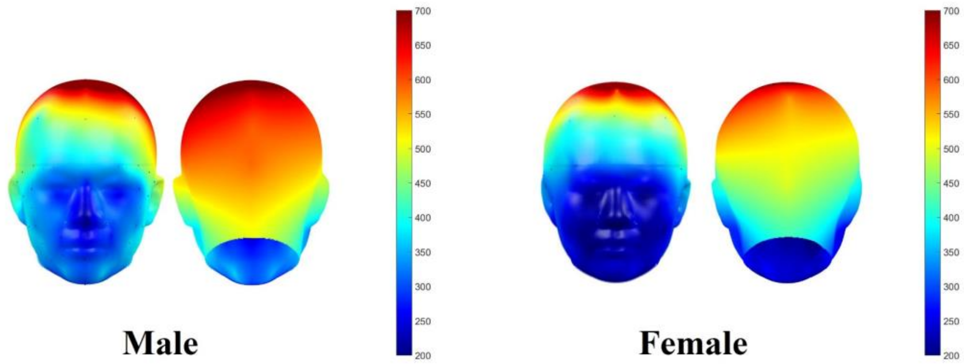

Figure 6. Pressure pain threshold maps (front view and back view)

The head's skull region has one major muscle, the Occipitofrontalis muscle, which covers most of the top region of the head. This region consists mostly of fibrous tissue and has a lower amount of fat. Hence the stiffness of soft tissue in this region is very high, while the thickness is low. The head region's landmarks showed higher values for pressure thresholds for discomfort and pain, suggesting that this region is less pressure-sensitive. The temporal region comprises a fan shape muscle; the Temporalis covered with a tough fascia. The soft tissue thickness in this region is lower than in other facial areas. This was also observed in the soft tissue thickness values measured in previous studies (Dong et al., 2012; Jia et al., 2016). The results show landmarks in the forehead, and the temporal region shows similar pressure threshold values. A medium level of pressure sensitivity was observed in this region. The facial and nasal area comprises several muscles and superficial nerves. The tissue thickness in this region is higher than the skull and forehead region, whereas the tissue stiffness in this region is comparatively lower. The results indicate that the landmarks in the facial area and nasal region have comparatively lower values for pressure threshold, suggesting higher pressure sensitivity in this region.

To evaluate the gender-based differences in the values at PDT and PPT, Independent-Samples Mann-Whitney U Test was performed on the acquired data. The data suggests that the pressure threshold values at discomfort and pain thresholds differed statistically significantly for the majority (PDT-57, PPT-67) of the landmarks. It was also observed that the values of PDT and PPT for males were comparatively higher than females.

The correlation analysis results indicate no significant relationship between age, BMI, and pressure threshold for discomfort and pain. Some landmarks did show a significant correlation, but the correlation coefficient values were relatively small. While performing the correlation analysis, it was observed that pressure threshold data was independent of age or BMI in general. Donat et al. also conducted a similar study (Donat et al., 2005) to identify age-related pressure threshold changes. They observed some pressure threshold changes with age, but the differences were found to be statistically insignificant. Similar results were also inferred from the study conducted previously by Lee et al. (1994).

Pressure threshold data is subjective, and hence there was a need to evaluate the reliability of acquired data. For this, sixty participants who had participated in the previous study were invited to redo the experiment. Intraclass correlation analysis has been effectively used in past studies (Aweid et al., 2014; Cathcart and Pritchard, 2006; Fabio Antonaci, 1998; Koo et al., 2013; Xiong et al., 2010) to measure Pressure Threshold data reliability. Almost all the landmarks showed acceptable reliability except one for PDT and five for PPT. Also, it was noticed that the PDT and PPT values recorded at the second instance were relatively higher than the ones measured in the previous study. It may have been caused due to the effect of habituation; this phenomenon has also been reported by several studies (Arntz et al., 1991; Ernst et al., 1986; LeBlanc and Potvin, 1966; Wolff, 1986). The ICC coefficient results showed lower values than previous studies, which may have been caused due to the manually controlled system used in this study, compared to previously used computer-controlled indentation devices with fixed indentation rates or due to habituation.

While considering head-related products, pressure sensitivity data has been mostly overlooked in the design process. When these parameters are considered and evaluated, it can enhance the product design process, leading to better user experience. An optimal balance between pressure and deformation in a region can be decided based on the pressure threshold maps to ensure maximal user comfort. Pressure sensitivity maps can also help decide the approximate variations for the product's dimensions, maximizing user comfort.

The pressure sensitivity maps developed from this study can help design professionals to understand the interaction between headgear and the corresponding soft tissue. The pressure threshold maps can be used at all the critical stages of the product design process. In the early stage of the design process, this data can help the designers deduce ergonomic design considerations that need to be addressed to improve user comfort. It can also help the designer to understand the amount of available pressure flexibility in each region. This can further help in analyzing the most feasible shape, size, form, and material for a headgear during the design phase.

While designing headgears, once the initial prototype is ready, real-time experiments and usability studies can be conducted to evaluate its effectiveness. Pressure sensors, pressure films, and pressure mats can be used to evaluate the amount of contact pressure generated in the contact area during such testing. These testing results can be collated with the developed pressure sensitivity maps to ensure that the pressure generated in the contact area is well within the ranges of discomfort and pain threshold. The collation of pressure data from such studies with the data acquired from the current research study can help evaluate the prototype. In case there is any region where some parameters are getting compromised, the needs for design improvements can be identified, and further modifications in the prototype can be suggested. Different prototypes with acceptable variation ranges of shape, size, and form can be developed using 3D CAD software and virtually tested for pressure and stress distribution using computer simulation techniques like Finite Element Analysis (FEA).

The data acquired from this study also finds a wide range of applications in the field of medical, clinical, and diagnostic sciences. Anatomical or morphological changes in any head region due to any medical ailment may impact that region's pressure sensitivity. Hence a quick examination of the pressure threshold in that region and comparing it with reference values can be an early indicator of the possibility of any existing medical ailment. The pressure threshold could also serve as a useful reference for identifying muscle/tissue tenderness, hypersensitivity, muscular pain, or dysfunction in clinical studies.

It has already been established that there are errors introduced in anthropometric studies because of landmarking (Kouchi and Mochimaru, 2011). Hence to keep this error low, the researcher underwent training for marking the landmarks using 3D printed head models. The landmarks selected in this study were located mostly in key anatomical regions, making them easier to identify. A single researcher conducted the entire data collection for this study to further reduce this error. Movement-based errors could have also been introduced in the data caused due to head movement of the participants. To address this issue, a head mount was used in the experiment. One of the critical challenges in this study was to ensure that there is no time-based influence. A counterbalanced approach was used in selecting landmarks for data collection to reduce the time-related bias. For the experiment, the indenter was supposed to be held perpendicular to the skin surface. Misalignment of the indenter could have also resulted in an error in acquired data. A study conducted by Zheng et al.(1997) found that for a similar setup, the misalignment range of 0 to 12 degrees would result in a variation in force measurement of less than 0.15%. Also, the indenter tip shape can have a significant influence on the measured pressure threshold. In a study conducted by Fransson-Hall and Kilbom (1993), it was observed that while using the contact surface with a perpendicular edge, the participants felt high pressure, mainly at the surface edge. However, by reducing the indenter tip size as in this study, the pressure distribution can be more uniform, and this effect can be reduced significantly.

In the current study, the size of the indenter was kept smaller and constant. This would lead to the acquisition of a more concentric loading pattern, whereas in the real world, when a wearable product is worn, the contact surface area is more extensive, and the load is distributed. Hence, further studies are required in this area to understand the impact of indenter size and the relationship between pressure thresholds acquired using concentric loading and distributed loading resulting. Although the effect of indenter size would influence the pressure threshold map, the pressure sensitivity distribution on the head and face region would follow a similar trend as predicted by the results of this study. Also, while using a wearable product for the head region, thermal comfort and fit plays a key role. Sweating and ill-fit can lead to irritability and discomfort while using that product. Hence, to acquire a more holistic understanding, it is essential to study their role even with the soft tissue data in the future. This will provide a holistic understanding of the crucial ergonomic parameters and help develop products that can lead to better user-comfort and enhanced user experience.

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Disclosure

The authors declare no conflicts of interest.

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