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Di Brigida, Liliana; Fiorillo, Iolanda; Naddeo, Alessandro; Vink, Peter

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Discomfort threshold evaluation for hand and elbow regions: a basis for hand-held device design

Liliana Di Brigida[1], Iolanda Fiorillo[1], Alessandro Naddeo[1], Peter Vink[2]

[1] Department of Industrial Engineering, University of Salerno, Via Ponte don Melillo, 1, 84084 Fisciano, Salerno, Italy

[2] Faculty of Industrial Design Engineering, Delft University of Technology, Landbergstraat 15, 2628CE Delft, The Netherlands

Corresponding e-mail address: ifiorillo@unisa.it

Abstract.

This study aimed to analyse the discomfort threshold (that could be linked to sensitivity or sensation) of different regions in hand and elbow to support hand-held devices' design. Indeed, there are no studies regarding the hand and elbow discomfort threshold or sensitivity. To overcome this literature gap, the discomfort threshold of hand and elbow were recorded at 24 spots by pushing a cylinder with a diameter of 10 mm until the participants reported not to be longer comfortable. Experiments were performed with 24 participants, 13 females and 11 males. The results showed the map of discomfort threshold (or sensitivity) for the hand and elbow. The olecranon, situated at the ulna's upper (proximal) end, one of the two bones in the forearm, could withstand more pressure than the elbow area surrounding it. The fingertips and the area close to the metacarpals were most sensitive (lower discomfort threshold).

Keywords: Discomfort · Pressure · Human centred design · Localized contact · Upper limbs

Introduction

In recent years, there has been competition amongst manufacturers to introduce increasingly compact forms of these products that contact the hand. In the design, sometimes attention has been paid to the user's ergonomics needs to work harmlessly, effortlessly and comfortably with these products [1]; and sometimes comfort studies are done to improve the interactions with hand-held devices [2], such as tablets [3, 4], smartphones [5], PDA, eReaders or gaming systems [6, 7]. However, not much attention has been paid to contact areas between device and hand, and how to adapt them considering the difference in sensitivity (or discomfort threshold) of the various areas in hand. This study aims to be a further step in the assessment of tactile perceptions focusing on contact areas and perceived discomfort levels when using tools or daily devices. Regarding literature studies, Fransson-Hall and Kilbom [8] studied the sensitivity to surface pressure on the hand, recording each region's pain levels. Hokari et al. [9] studied the relationship between gripping comfort to contact pressure and hand posture describing the palm region as the most sensitive. However, it is hard to find data on discomfort threshold (or sensitivity) for the hand and elbow, especially in open-hand, which could be useful for designing smartphones as they are often held in this position. Moreover, while using a hand-held device, the elbow is often resting on an armrest [10]. For instance, considering the armrest [10] as a support during the use of a tablet or smartphone, it could be useful to know the most sensitive hand and elbow areas to realize a comfortable design. Accordingly, the data gathered in this paper are relevant to designers. There is some evidence regarding existing relationships between the physical magnitude (force) & the subjective perception of applied pressure and between the discomfort & pain thresholds [11, 12]. Discomfort is associated with feelings of slight pain, soreness, numbness, stiffness, and can be reduced by eliminating physical constraints, but this does not necessarily produce comfort [13]. Pain can cause discomfort but not every discomfort can be attributed to pain [14]. Thus, in a continuum discomfort scale, pain can be considered an extremity on it, where the value of discomfort is highest.

Thus, the research question is: what is the discomfort threshold (or sensitivity) of different hand and elbow regions relevant for holding hand-held devices?

Materials and method

Positions of spots for discomfort threshold evaluation

The spots choice had two main constraints: 1) the purpose of investigating the regions most in contact with armrests (for the elbow) and with handled objects (for the hand); 2) the possibility of identifying the same points of interest on each participant. This goal has been achieved by using known anatomical landmarks.

For the elbow, the area of interest was around the medial epicondyle bone. Five spots were selected, as shown in Fig. 1, to check on sensitivity. Spot 1 was collocated on the olecranon bone, spots 2-5 were placed 1.5 cm from spot 1 according to two directions: the first along the ulna bone and the second perpendicular to this.

Regarding the hand, the spots positions were selected according to the main contact area with hand-held devices, as shown in Fig. 1. Given the participants' morphological characteristics variability

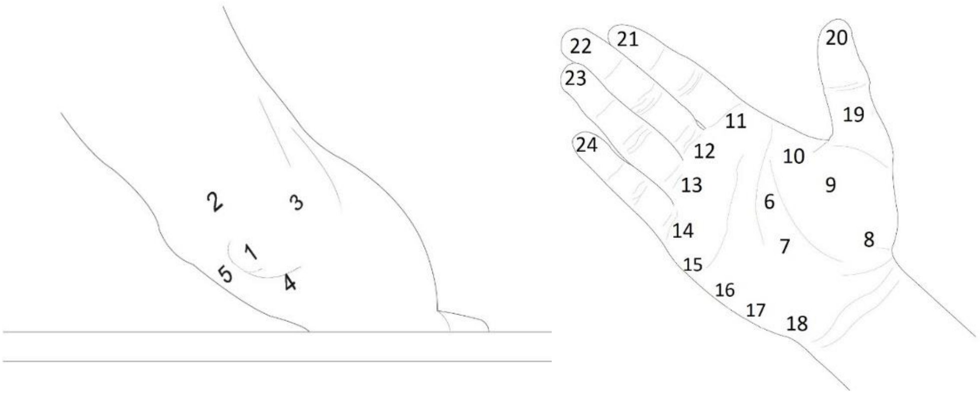

Fig. 1. Sensitivity spots for elbow and hand. Note, spots 15-17 are on the lateral side of the hand.

of the hand and elbow, following anatomical landmarks were used for the positioning of the spots:

- Spots 20-24 are positioned on the tips of the distal phalanges of digits 1-5.
- Spots 11-14 and 19 at the base of the proximal phalanges, just proximal to the metacarpophalangeal crease of digits 1-5.
- Spot 18 is placed in the area of the pisiform bone.
- Spots 15-17 are positioned in correspondence or the abductor digiti minimi (hypothenar eminence) equally spaced.
- Spots 8-9 are positioned at the extremities of the metacarpal of digit 1.
- Spot 7 at the base of the metacarpal of digit 3.
- Spots 6 and 10 in correspondence of upper extremity of adductor pollicis, among the spaces between metacarpals of digits 2-3 and 1-2, respectively.

Equipment and data analysis

An advanced force gauge (AFG) meter, (Mecmesin AFG 500N) useful to study human discomfort threshold (or sensitivity) [15, 16], was connected to a cylindrical rod to apply pressure. The rod was printed in PLA (Polylactic Acid), using an Ultimaker S5 (diameter=10 mm) 3D printer, with a fillet radius of 3 mm [16]. The rod's choice was made to compare with the study of Fransson-Hall and Kilbom [8] who suggested a round-edge surface instead of a perpendicular edge or rubber covered contact surface.

An adjustable height table was used for participants of different anthropometric sizes to create similarities on how the arm is supported. A hole with a diameter of 11 mm was made in the table to record the PDT (Pressure Discomfort Threshold) of some spots at the elbow (spot 1) and hand (spots 15, 16 and 17). Using only one hole on the table was due to the difference in hand length, which did not create three holes relevant for all sizes. Also, additional holes could influence the perceived sensitivity due to the sharp edges at the table's hole.

As in previous studies recording sensitivity [15, 16], the first recording was deleted as these values vary a lot, probably because of getting used to the measurement. The second and third recording were further analysed. Averages and standard deviations over all participants were calculated per spot on the hand and elbow.

The force values (in Newton [N]) where participants started feeling discomfort had been recorded during the test, reporting the displayed force, and after that, the PDT (Pressure Discomfort Threshold) has been calculated according to the formulas (1) and (2) already used in the work of Buso and Shitoot [16]:

$$PDT[kPa] = \frac{Force\ [N]}{Area_{indentation}\ [mm^2]} \quad (1)$$

$$Area_{indentation} = \pi * (Radius_{indenter})^2 \quad (2)$$

Then, statistical evaluations were done. First of all, the Shapiro Wilk test has been performed using the software R to know whether the data were distributed with a normal distribution. Due to the non-normal distribution of data [17], the Wilcoxon test and a Mann-Whitney-U test were used to investigate significant differences between second & third trial, male & female, respectively.

Participants

Twenty-four participants were recruited for the experiment: 13 females and 11 males, aged between 20 and 62 (Table 1). Three participants were left-handed, the others right-handed. Tustumi et al. [18] found no significant difference in sensitivity between the dominant and non-dominant hands. Therefore, we did not exclude the three left-handed.

The age and nationality of the participants do not discriminate the inclusion criteria for the test. A discriminating factor for inclusion in the test, however, was being right-handed. The recruitment was online and spread through social channels such as TU-Delft platform, emails, where data about height, weight, and possible diseases were collected.

Table 1: Demographic data of participants

	Variables	*Mean*	*SD*	*Maximum*	*Minimum*
# Males = 11					
	Age (*years*)	28,36	11,43	62	20
	Stature (*m*)	1,82	0,07	1,96	1,69
	Body weight (*kg*)	75,91	13,85	110	64
	BMI (kg/m^2)	22,80	2,82	28,63	19,11
# Females = 13					
	Age (*years*)	25,69	5,25	37	21
	Stature (*m*)	1,66	0,09	1,89	1,53
	Body weight (*kg*)	56,85	5,71	63	47
	BMI (kg/m^2)	20,74	2,48	25,81	17,63

People affected either by diabetes or by any other disease that could influence skin sensitivity, or undergone hand/wrist/arm/forearm surgery within the previous two years, were excluded. Additionally, the hand's picture was taken before the experiment, and the size of the hand was measured with a measuring tape (covering all the spots). Each finger length corresponds to each phalange length (from the top of the distal phalanges to the bottom of proximal phalanges). The thumb's measurement was from the top to the distal phalange (spot 20) to the end of the metacarpal (spot 8) of digit 1. The hand's width was measured along the transverse metacarpal ligament (spots 11-14), while the hand's length along with the hypothenar eminence (spots 15-18). The mean values of the fingers length, hand width and length are shown in Table 2:

Table 2: Mean values of the hand dimension of participants

Body Parts	Mean values (All participants)	Mean values Female	Mean values Male
Thumb lenght [cm]	6.93	6.38	7.60
Index lenght [cm]	7.48	7.05	7.95
Middle finger lenght [cm]	7.98	7.58	8.47
Ring finger lenght [cm]	7.33	6.91	7.78
Little finger lenght [cm]	6.17	5.76	6.67
Hand width [cm]	8.37	7.75	9.05
Hand length [cm]	18.43	16.86	20.47

Experimental procedure

Before the experiment, participants were asked to sign the Informed Consent, and on their right hand and elbow, the regions numbers were marked with a pen. Furthermore, data about age, height, body weight, hand-, arm- and forearm-length were gathered.

Experiments were conducted in a lab, a quiet environment, at the Faculty of Industrial Design Engineering, the Delft University of Technology (TUDelft). During the experiment, participants were asked to adopt a natural posture with a large part of the forearm resting on the table to simulate the use of a hand-held device. Then, photos of the hand and the elbow were taken for control purposes for each subject. In this way, atypical values of the Pressure Discomfort Threshold (PDT) could be justified by the presence, for example, of a hand callus. The gauge (AFG) was pressed on the skin at 24 locations numbered 1-24 for three times in a systematically varied order. The spots 6-14 and 21-24 were pressed with open-hand on the table. The evaluation of spots 15, 16, 17 took place using the hole on the table; so participants were asked to place their hypothenar eminence on the table. This choice was dictated by the impossibility of imparting perpendicular forces on this hand side, keeping the hand open on the table as happened to evaluate previous spots, due to the thickness of the advanced force gauge.

During the pretesting, it was found out that the best way to measure the sensitivity of the spot 1 (elbow) was through the hole to minimise the skin slip under the pressure application of the cylinder. Indeed, applying the force on the elbow in the open space, the skin used to slip at the contact with the cylinder and the gauge was not able to record any pressure. Moreover, analysing the system of forces acting between the table and the elbow during the test, it must be noted that there are two main forces to which the participant's elbow is subjected. One is the contact force between the table and the forearm on the table that reduced skin slippery. The other one is the active force applied by the advanced force gauge that increased with a rate equal to 1 N/s, controlled both by the researcher in charge to increase the displayed force and a second researcher who beat time by a chronometer. The gradual increase was meant to help participants being aware of differences and not to influence the sensitivity. Humans are not aware of small differences, but on relatives changes [19]. For all spots, the AFG was pressed applying the controlled force, maintaining the rate of 1 N/s, until the participant declared to start feeling discomfort. Then, the force value has been recorded in the Excel sheet.

Results and discussion

Table 3 shows the mean value and the standard deviation of the force [N] and PDT [kPa] for each spot. Results are also represented in the sensitivity map (Fig. 2). A scale of colours from dark grey to white (see Table 3 and Fig. 2) was used to differentiate the different regions from the most sensitive (lowest discomfort threshold) to the least sensitive ones (highest discomfort threshold). For the elbow, the olecranon (spot 1) can withstand much pressure while the sensitivity around the medial epicondyle bone (spots 2-5) increases (lower discomfort thresholds). However, spot 5 presented lower discomfort threshold values than spots 2-4 and could be anatomically explained. In correspondence of spot 5, the underlying level of the right posterior part of the ulnar collateral ligament is present, while the right elbow joint capsule at spots 2-3 and the ulna at spot 4. The fingertips (spots 22-24) and area close to the metacarpals (spots 12-14) are most sensitive (lowest discomfort thresholds).

This study's sensitivity values (PDT) are lower than those detected (PPT) in the study of Fransson-Hall and Kilbom [8] since there is a substantial difference between discomfort and pain thresholds. Thus, results confirm the difference between pain and discomfort [14].

The Wilcoxon test showed no significant difference between the second and the third trial. The Mann-Whitney U test showed a significant difference (p=0.011) between male-female (see Fig. 3). According to Farage [20], the general perception is that woman have more sensitive skin. However, Farage found no significant difference in general, but differences were found for specific ages. However, for the hands, the sensitivity difference between genders is clear. The difference in hand and elbow sensitivity between genders is accordant with the previous work of back and buttocks sensitivity [15] and in contrast with the absence of difference in gender for foot sensitivity [16].

Table 3: Mean values of the applied force and the PDT for each region where discomfort is noticed.

		Force [N]		PDT [kPa]	
	Locations	Mean	SD	Mean	SD
Elbow	1	30.44	14.86	387.54	189.22
	2	15.34	11.74	195,31	149,42
	3	15.91	10.36	202,55	131,97
	4	17.17	11.75	218,63	149,57
	5	12,43	7.56	158,23	96,30
Hand	6	11,50	7.01	146,48	89,26
	7	13,72	9.51	174,65	121,11
	8	11,39	7.10	145,04	90,37
	9	10,62	6.11	135,23	77,78
	10	10,84	6.92	138,01	88,11
	11	11,01	6.64	140,19	84,58
	12	10,58	6.24	134,67	79,40
	13	10,05	5.76	128.01	73.30
	14	10.65	5.78	135.57	73.63
	15	12.70	6.78	161.70	86.26
	16	13.24	7.92	168.52	100.85
	17	13.66	7.75	173.88	98.67
	18	12.70	7.55	161.67	96.09
	19	10.91	6.20	138.86	78.99
	20	11.53	6.51	146.79	82.83
	21	10.55	6.91	134.38	87.95
	22	9.92	6.42	126.32	81.80
	23	9.00	5.04	114.62	64.19
	24	9.07	5.87	115.44	74.77

Fig. 2. Sensitivity map for elbow and hand.

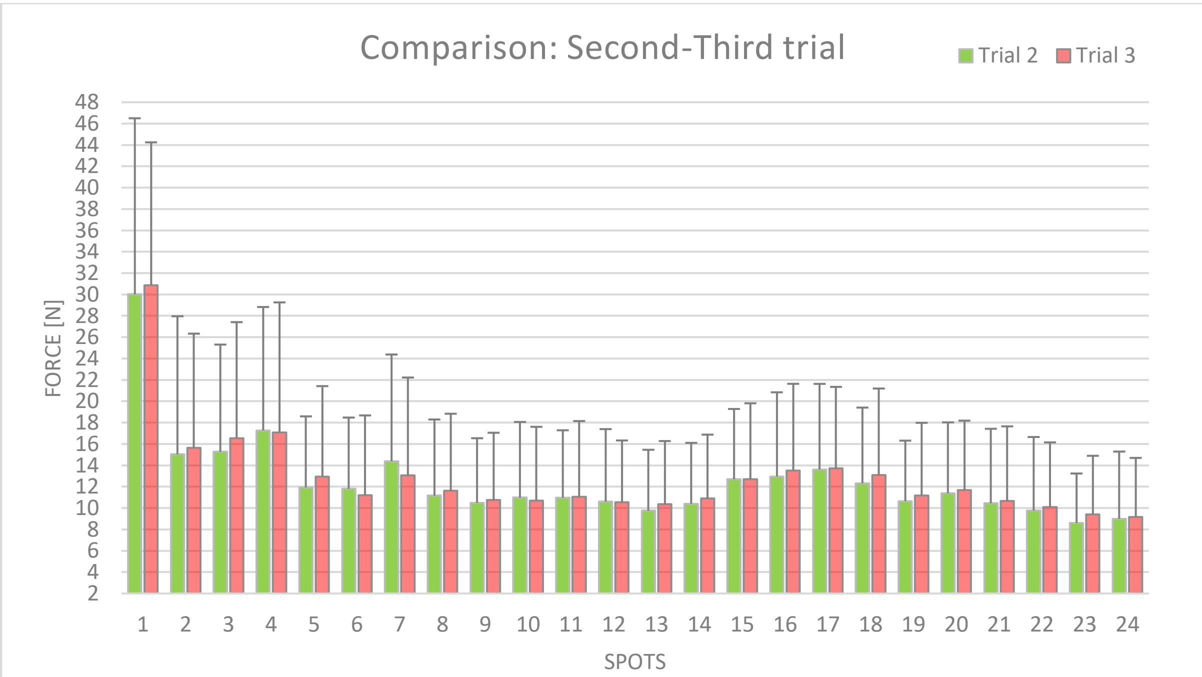

Fig. 3. Comparison between female and male - there were significant differences between male and female. For female, the discomfort thresholds were lower.

Conclusion

Understanding the sensitivity of different regions in hand and elbow could help designing hand-held devices. This study aimed to map the sensitivity of hand and elbow using the advanced force gauge (AFG) meter: the pressure is related to the perceived discomfort, making it possible to understand where the sensitivity areas are. The results showed that the elbow hard-bone could withstand much pressure, while the sensitivity around bone increases. The fingertips and area close to the metacarpals were most sensitive in the palmar hand area. Some limitations of this study have to be acknowledged, such as the limitations of the participants' age and nationality that were not investigated because the sample is too small to be significant. The females' age in this study was maximal 37, perhaps studies with older subjects might give different results, something which might be studied further as well. Furthermore, it could be useful to replicate experiments creating personalized support structures for every subject for the hand and elbow sensitivity analysis and compare data with this study.

References

1. Aptel, M., Claudon, L., Marsot, J.: Integration of ergonomics into hand tool design: Principle and presentation of an example. Int. J. Occup. Saf. Ergon. 8, 107–115 (2002). https://doi.org/10.1080/10803548.2002.11076518.

2. Kuijt-Evers, L.F.M., Bosch, T., Huysmans, M.A., de Looze, M.P., Vink, P.: Association between objective and subjective measurements of comfort and discomfort in hand tools. Appl. Ergon. 38, 643–654 (2007). https://doi.org/10.1016/j.apergo.2006.05.004.

3. Salazar, C.A.F., Henze, N., Wolf, K.: Ergonomics of Thumb-Based Pointing While Holding Tablets. In: Proceedings of the 18th International Conference on Human-Computer Interaction with Mobile Devices and Services Adjunct. pp. 730–737. Association for Computing Machinery, New York, NY, USA (2016). https://doi.org/10.1145/2957265.2961864.

4. Pereira, A., Miller, T., Huang, Y.-M., Odell, D., Rempel, D.: Holding A Tablet Computer With One Hand. Proc. Hum. Factors Ergon. Soc. Annu. Meet. 57, 1634–1638 (2013). https://doi.org/10.1177/1541931213571363.

5. Trudeau, M.B., Asakawa, D.S., Jindrich, D.L., Dennerlein, J.T.: Two-handed grip on a mobile phone affords greater thumb motor performance, decreased variability, and a more extended thumb posture than a one-handed grip. Appl. Ergon. 52, 24–28 (2016). https://doi.org/10.1016/j.apergo.2015.06.025.

6. Yesodha, K.K.R.K., Narasimhan, V., Li, Y., Craig, B.: Ergonomic Evaluation of Videogame Controllers. In: Ahram, T. and Falcão, C. (eds.) Advances in Usability and User Experience. pp. 384–391. Springer International Publishing, Cham (2018).

7. Gutierrez, A.M.J., Cadiz, L., Filoteo, N., Juan, I., Leopando, B.: Enhancement of Gaming Experience and Performance through an Ergonomically Designed Console Chair. In: International Conference on Industrial Engineering and Operations Management. pp. 31–41 (2019).

8. Fransson-Hall, C., Kilbom, Å.: Sensitivity of the hand to surface pressure. Appl. Ergon. 24, 181–189 (1993). https://doi.org/10.1016/0003-6870(93)90006-U.

9. Hokari, K., Pramudita, J.A., Ito, M., Noda, S., Tanabe, Y.: The relationships of gripping comfort to contact pressure and hand posture during gripping. Int. J. Ind. Ergon. 70, 84–91 (2019). https://doi.org/10.1016/j.ergon.2019.01.010.

10. Van Veen, S., Hiemstra-van Mastrigt, S., Kamp, I., Vink, P.: Improving car passengers' comfort and experience by supporting the use of handheld devices. Work. 49, 215–223 (2014). https://doi.org/Discomfort, neck flexion, user experience, armrests, car seat.

11. Naddeo, A., Califano, R., Vink, P.: The effect of posture, pressure and load distribution on (dis)comfort perceived by students seated on school chairs. Int. J. Interact. Des. Manuf. (2018). https://doi.org/10.1007/s12008-018-0479-3.

12. Le Johansson, L., Kjellberg, A., Kilbom, A., Hagg, G.M.: Perception of surface pressure applied to the hand. Ergonomics. 42, 1274–1282 (1999). https://doi.org/10.1080/001401399184947.

13. Zhang, L., Helander, M.G., Drury, C.G.: Identifying Factors of Comfort and Discomfort in Sitting. Hum. Factors. 38, 377–389 (1996). https://doi.org/10.1518/001872096778701962.

14. Ashkenazy, S., Ganz, F.D.: The Differentiation Between Pain and Discomfort: A Concept Analysis of Discomfort. Pain Manag. Nurs. (2019). https://doi.org/https://doi.org/10.1016/j.pmn.2019.05.003.

15. Vink, P., Lips, D.: Sensitivity of the human back and buttocks: The missing link in comfort seat design. Appl. Ergon. 58, 287–292 (2017). https://doi.org/10.1016/j.apergo.2016.07.004.

16. Buso, A., Shitoot, N.: Sensitivity of the foot in the flat and toe off positions. Appl. Ergon. 76, 57–63 (2019). https://doi.org/10.1016/j.apergo.2018.12.001.

17. Groenesteijn, L.: Seat design in the context of knowledge work, (2015). https://doi.org/10.4233/uuid:19060a11-6d6c-46dd-9f47-8583d1610b94.

18. Tustumi, F., Nakamoto, H.A., Tuma, P., Milcheski, D.A., Ferreira, M.C.: Prospective study on tactile sensitivity in the hands of a Brazilian population using the pressure-specified sensory device. Rev. Bras. Ortop. 47, 344–347 (2012). https://doi.org/10.1590/S0102-36162012000300011.

19. Vink, P.: Vehicle Seat comfort and design. Pumbo, (2016).

20. Farage, M.A.: Does sensitive skin differ between men and women? Cutan. Ocul. Toxicol. 29, 153–163 (2010). https://doi.org/10.3109/15569521003774990.