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EFFECT OF CONTACT AREA AND CONTACT LOCATION ON THERMOTACTILE THRESHOLDS AT THE FINGERTIP

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Abstract

This study investigated the influence of three contact areas and three contact locations on hot and cold thresholds at the fingertip. Twenty healthy subjects (10 females and 10 males) aged between 20 and 30 years participated in a two-part experiment. For the first part, thermotactile thresholds were obtained at one location with three different contacts: three circular discs with diameters of 9 mm, 12 mm and 55 mm. For the second part, thresholds were obtained using a 6-mm diameter circular disc in contact with the skin along the distal phalanx of the finger at three locations: (i) distal, (ii) middle, and (iii) proximal. Higher hot thresholds and lower cold thresholds with the smaller contact areas, and significant differences in the cold thresholds at the different locations, indicate the importance of controlling the contact area when using thermal thresholds for diagnosis.

1. Introduction

Thermotactile thresholds at the fingertip are used as part of a standardized test battery for the diagnosis of the neurological components of the hand-arm vibration syndrome (HAVS) in the UK [1]. Hot and cold thresholds separately assess warm and cold receptors because they are mediated by different fibres. Warm receptors are innervated by the unmyelinated C-fibres and cold receptors by the myelinated A-δ fibres. A high hot threshold or a low cold threshold demonstrates a dysfunction in the thermal sensory system [1].

Various factors affect thermotactile thresholds, such as stimulus area, rate of change of stimulus temperature, body location and the reference temperature (when using the method of limits and forced-choice method) [2-5]. These factors should be controlled if test results are to be compared to reference values. In practice, the area of skin contacting the thermal source is often uncontrolled during the measurement of thermotactile thresholds.

Spatial summation can occur in thermotactile thresholds, so that sensitivity to temperature increases (i.e. lower hot thresholds and higher cold thresholds) as the

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area in contact with the stimulus increases [6-8]. Temperature sensitivity can also vary over an area of skin when using a small contact area [9]. However, there are no known studies of the effects of contact area on thresholds at the fingertip (i.e. the distal phalanx of the finger).

The experiment described in this paper investigated the importance of controlling the contact area when measuring thermotactile thresholds at the fingertip.

2. Methods

2.1 Subjects

Twenty healthy subjects (ten females and ten males) aged between 20 and 30 years (median 26.0, IQR 4.8) participated in the experiment. All subjects were either staff or students at the University of Southampton. Subjects were screened using a health questionnaire to exclude those with prior regular exposure to hand-transmitted vibration, diabetes, injuries to the upper extremities or neurological problems. The experiment was approved by the Human Experimentation, Safety and Ethics Committee of the Institute of Sound and Vibration Research at the University of Southampton.

2.2 Experimental conditions

Subjects attended two experimental sessions during which hot thresholds were measured in the first session and cold thresholds were measured in the second session. The experiment was conducted in a quiet room with a temperature of 25.0 ±2°C (first session - median 24.9, IQR 1.2; second session – median 25.1, IQR 2.0). Subjects were habituated in the room temperature for five minutes before the tests began. Subjects were asked to warm their hands if finger skin temperature was below 30°C. Finger skin temperature measured at the start of each session on the distal phalanx of the non-dominant finger using a thermocouple ranged between 30.0 and 35.5°C (first session - mean 34.0, IQR 0.8; second session - median 33.7, IQR 1.6).

2.3 Experimental procedures

Written instructions were given to the subjects prior to the tests. All subjects practiced with hot and cold thresholds using the ring finger of their non-dominant hand before measurements were conducted on the middle finger of the non-dominant hand. Nineteen of the subjects were right-handed and one was left-handed, so thresholds were determined on nineteen left middle fingers and one right middle finger. Subjects were seated during the tests with their forearm supported (Figure 1(a)).

Each session was divided into two parts. In the first part of each session, thresholds were determined with three different contact areas centred on one location (middle position at the centre of the whorl, Figure 1(b)) using circular aluminium discs with diameters 9 mm, 12 mm and 55 mm (0.64 cm^2, 1.13 cm^2 and 23.76 cm^2 respectively). The 55-mm diameter disc was sufficient to ensure that contact with the distal phalanx was not limited by the size of the disc. In the second part of each session, thresholds were measured using one contact area, a circular aluminium disc with a diameter of 6 mm (0.28 cm^2), at three different locations along the distal phalanx of the finger: (i) distal position (at 5 mm from the base of the nail), (ii) middle

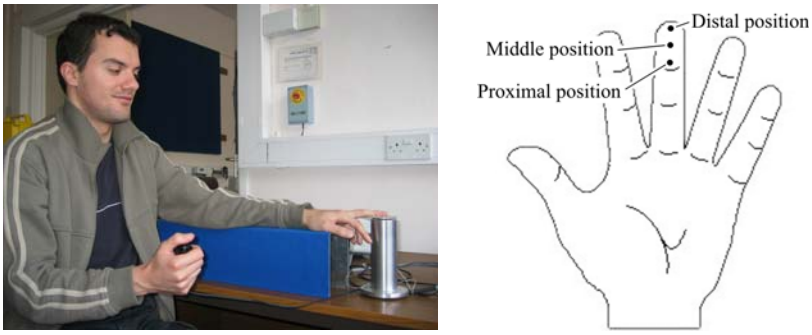

Figure 1 - Posture of a subject during the experiment (left) and the three locations marked on the distal phalanx on the middle finger (right).

position (at the centre of the whorl), and (iii) proximal position (at 3 mm from the crease of the distal interphalangeal joint). The fingertip was marked at the three locations prior to commencement of each session.

The *HVLab* Thermal Aesthesiometer was used to measure thermotactile thresholds via the method of limits. The aesthesiometer consisted of an ‘applicator’ with a circular flat surface (normally 55 mm diameter) that varied in temperature (between 5 and 55 °C). The applicator was connected to an electronic box (*HVLab* TA version 1.0) and was controlled by a computer using *HVLab* diagnostic software version 7.0. Subjects placed their fingertip so that the appropriate mark on their distal phalanx coincided with the centre of a disc. They were instructed to apply a constant finger force of 2 N, which they monitored using a digital scale located below the applicator. Depending on the test (i.e. hot or cold), the temperature of the applicator increased or decreased (at 1°C per second) from the reference temperature (32.5°C). Subjects were instructed to press a response button as soon as they perceived a change in temperature. The temperature of the applicator then returned to the reference temperature at the same rate (1°C per second) and was then held at 32.5°C for between 3 and 5 seconds before the temperature increased or decreased again. Six successive judgements were made for each contact condition. The mean threshold was calculated from the last four judgements.

At the end of the second session, a fingerprint of the distal phalanx of the middle finger was obtained using a similar force and posture to that during the threshold measurements. This was used to estimate of the area of the fingertip in contact with the largest aluminium disc (i.e. 55-mm diameter disc).

3. Results

The group of males encompassed a smaller age range (median 25.5, range 22 to 28 years) compared to females (median 26, range 20 to 30 years) but there was no statistically significant gender difference in age. There was also no gender difference between finger skin temperatures in either of the two sessions. However, room temperatures for the second session were slightly lower during sessions with males (me-

Table 1 Medians, inter-quartile ranges, minimum, maximum and mean values of thermotactile thresholds using three different contact areas

Test	Area	Median (°C)	Inter-quartile Range (°C)	Minimum (°C)	Maximum (°C)	Mean (°C)
Hot	9 mm	40.7	4.8	34.6	46.6	40.6
	12 mm	38.4	2.4	35.5	45.1	38.9
	55 mm	37.5	2.0	34.7	43.3	37.9
Cold	9 mm	27.0	4.4	11.2	29.9	25.9
	12 mm	28.6	3.3	17.3	30.6	27.8
	55 mm	29.2	1.5	26.7	30.6	28.9

dian 24.6°C, IQR 2.3) compared to sessions with females (median 25.4°C, IQR 1.6) (p=0.03, Mann-Whitney U). Males had larger fingertip contact areas (median 2.20 cm^2, range 1.80 to 2.56) than females (median 1.78 cm^2, range 1.36 to 2.16) (p=0.002, Mann-Whitney U). The males also had larger hands when comparing the length of the hand (i.e. from the tip of the middle finger to the crease at the wrist), the length of the middle finger (i.e. from the tip of the middle finger to the crotch of the middle finger), the length of the distal phalanx (i.e. from the tip of the middle finger to the distal interphalangeal joint) and the breadth of the distal phalanx (i.e. at the distal interphalangeal joint) (p<0.02, Mann-Whitney U).

3.1 Comparing three contact areas at one location on the fingertip

Table 1 shows the thermotactile thresholds over all twenty subjects when using the three different contact areas. Stimulus area significantly affected both hot and cold thresholds (p<0.001, df=2; Friedman). Sensitivity to hot and cold increased with increased stimulus area (Figure 2). The hot thresholds differed significantly between all three contact areas (p≤0.015, Wilcoxon) with the 9-mm diameter contact giving the highest thresholds and the 55-mm giving the lowest thresholds. The cold thresholds also differed significantly between all three contact areas (p≤0.038, Wilcoxon) with the 9-mm diameter contact giving the lowest thresholds and the 55-mm giving the highest cold thresholds. There were significant correlations between the hot thresholds obtained with each contact area, and also between the cold thresholds

Table 2 Correlation coefficients between hot and cold thresholds obtained with three different contact areas (Spearman's rho; * = p<0.05, ** = p≤0.01).

Test	Contact area	9 mm	12 mm	55 mm
Hot	9 mm	1.000	0.721**	0.555*
	12 mm		1.000	0.537*
	55 mm			1.000
Cold	9 mm	1.000	0.775**	0.517*
	12 mm		1.000	0.629**
	55 mm			1.000

obtained with each contact area (Table 2). There were no significant correlations between the hot and cold thresholds with any of the three contact areas.

Hot thresholds within the sub-groups of male and female subjects were also significantly lower with larger contact areas ($p\leq0.020$, df=2; Friedman). Within the males, contact with the 55-mm diameter disc gave lower hot thresholds than the 12-mm diameter disc and 9-mm diameter disc ($p\leq0.013$, Wilcoxon). However, within the females, contact with the 55-mm diameter disc only gave lower thresholds when compared with the 9-mm diameter disc ($p=0.016$) and not with the 12-mm diameter disc ($p=0.445$, Wilcoxon). The hot thresholds were significantly lower in females compared to males with the 12-mm diameter disc ($p=0.007$, Mann-Whitney U), but not with the smaller or larger contact areas, although the median values in females were generally lower with all contact areas. There were no correlations between the hot thresholds and the measured area of the fingertip within either gender. The median hot thresholds when using the 55-mm diameter disc were 37.9°C and 37.3°C for males and females, respectively. There were no correlations between the hot thresholds and finger skin temperature or room temperature with any of the contact areas.

Cold thresholds within the sub-groups of male and female subjects were significantly higher with larger contact areas ($p\leq0.007$, df=2; Friedman). Within both males and females, contact with the 55-mm diameter disc gave higher cold thresholds than the 9-mm diameter disc ($p\leq0.028$, Wilcoxon). However, when comparing the 55-mm diameter disc with the 12-mm diameter disc, the difference was not significant in males ($p=0.262$, Wilcoxon) and only marginally significant in females ($p=0.059$, Wilcoxon), although the 12-mm diameter disc gave higher median thresholds. There were no significant differences in cold thresholds between males and females with any contact area ($p\geq0.739$, Mann-Whitney U). There was a significant

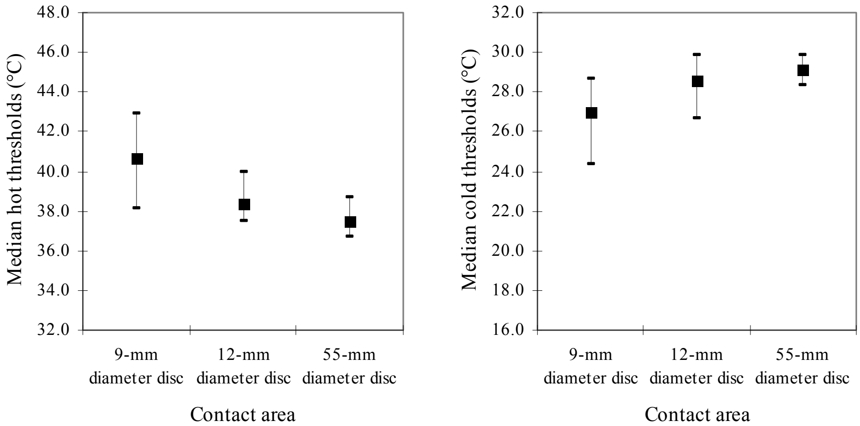

Figure 2 Median hot and cold thresholds for all 20 subjects with three different diameters of contact disc. Error bars show inter-quartile ranges.

positive correlation between the measured area of the distal phalanges of the males and their cold thresholds obtained with the largest contact area (p=0.021, Spearman) indicating greater sensitivity to cold in males with larger fingers. The correlation between finger size and cold thresholds was not statistically significant within females (p=0.199, Spearman). The median cold thresholds when using the 55-mm diameter disc were 29.0°C and 29.3°C for males and females, respectively. There was no correlation between cold thresholds and finger skin temperature or room temperature with any of the contact areas.

3.1 One contact area at three locations on the fingertip

Table 3 shows the thermotactile thresholds over all twenty subjects when using the 6-mm diameter contactor at three locations along the fingertip. Sensitivity to hot stimuli was not significantly affected by location (p=0.705, df=2; Friedman) but sensitivity to cold increased from the distal to the proximal positions along the fingertip (p=0.006, df=2; Friedman) (Figure 3). For the cold thresholds, there were significant differences in threshold between the proximal and distal locations and between the proximal and middle positions ($p \leq 0.030$, Wilcoxon). There were significant correlations between the cold thresholds obtained with each location, but only between the hot thresholds at the distal and middle position (Table 4)

Within the sub-groups of males and females, there was no significant difference in hot thresholds with the 6-mm diameter disc between the three different locations ($p \geq 0.301$, df=2; Friedman). There were no significant differences between males and females in hot thresholds at distal and proximal locations using the 6-mm diameter disc ($p \geq 0.353$, Mann-Whitney U); the hot thresholds were marginally not significantly different at the middle position (p=0.063, Mann-Whitney U), where the median thresholds for females tended to be lower. There was no correlation between the hot thresholds and finger skin temperature or room temperature at any of the locations.

Within males, sensitivity to cold increased from the distal to the proximal positions along the fingertip (p=0.027, df=2; Friedman) but this was not significant within females (p=0.150, df=2; Friedman), although median cold thresholds for the

Table 3 Medians, inter-quartile ranges, minimum, maximum and mean values of thermotactile thresholds at three locations on the distal phalanx when using a 6-mm diameter contactor.

Test	Location	Median (°C)	Inter-quartile Range (°C)	Minimum (°C)	Maximum (°C)	Mean (°C)
Hot	Distal	44.4	5.5	39.0	51.7	44.3
	Middle	43.6	3.9	38.5	50.9	43.8
	Proximal	43.5	5.6	36.2	48.7	43.4
Cold	Distal	23.1	8.0	6.4	28.5	21.0
	Middle	24.4	8.4	<5.0	30.1	22.1
	Proximal	25.7	5.5	16.4	30.1	25.1

Table 4 Correlation coefficients between hot and cold thresholds obtained at three locations on the distal phalanx when using a 6-mm diameter contactor. (Spearman's rho; * = $p<0.05$, ** = $p\leq0.01$).

Test	Contact area	Distal	Middle	Proximal
Hot	Distal	1.000	0.559*	0.071
	Middle		1.000	-0.002
	Proximal			1.000
Cold	Distal	1.000	0.448*	0.741**
	Middle		1.000	0.573**
	Proximal			1.000

females increased from the distal to the proximal positions along the fingertip. Within males and females, cold thresholds were significantly higher at the proximal position than the distal position when using the 6-mm diameter disc ($p\leq0.028$, Wilcoxon). However, significance levels were low in the proximal position compared to the middle position within males (p=0.169, Wilcoxon) and within females (p=0.093, Wilcoxon) compared to the overall group ((p=0.030, Wilcoxon). There was no correlation between the cold thresholds and finger skin temperature or room temperature at any of the three locations.

4. Discussion

The results confirm that temperature sensitivity is not uniform over the fingertip. Early thermotactile studies reported the presence of warm and cold spots randomly distributed over the human skin when using punctate stimuli. The number of cold spots per square centimetre on the fingertip skin is reported to be between 2 and

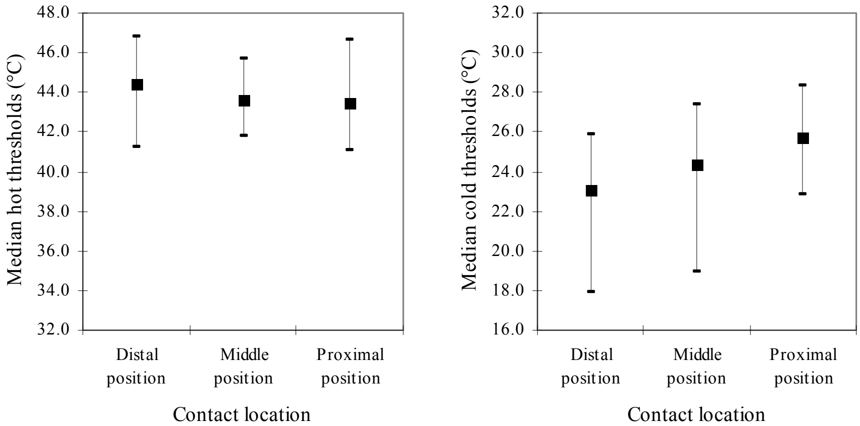

Figure 3 Results of median hot and cold thresholds for all 20 subjects at three locations on the distal phalanx when using a 6-mm diameter contactor. Error bars denote inter-quartile ranges.

4.0 and the number of hot spots per square centimetre on the fingertip is reported to be about 1.6 [10, 11], suggesting the presence few temperature receptors at the fingertip.

Green and Cruz (1998) [12] investigated what they termed "warmth-insensitive fields" (WIFs) and found that warm sensitive areas in the human skin are distributed quite randomly and are few in number. They also found that the density of warm sensitive areas varies greatly between individuals. They suggested that small stimuli tend to be associated with high hot thresholds and low cold thresholds because they are less likely to be in contact with a sensitive area rather than because they do not excite enough receptors.

Green and Zaharchuk (2001) [9] investigated the effect of stimulus size on hot and cold detection thresholds at sensitive sites using a multiple-thermode array on the forearm. They found that when exciting only the most sensitive sites, an increase in stimulus area resulted in only a very small difference in threshold. They concluded that temperature perception is not so dependent on how much area is stimulated but on whether or not the 'right' (i.e. sensitive) area is stimulated.

In the present study, thresholds at the fingertip reflected greater sensitivity (i.e., lower hot thresholds and higher cold thresholds) as the stimulus area increased. Since the finger has few temperature receptors, the chances of stimulating a warm or cold spot increase with increasing stimulus area. This is most evident in the large change in the minimum cold thresholds among all the subjects when using the three different stimulus areas (Table 1). The inter-quartile ranges, minimum and maximum thresholds across subjects generally decreased with an increase in the area of excitation.

The absence of statistically significant correlations between the hot thresholds at the three different locations, and the non-significant differences in thresholds between the three locations, is consistent with a low density and a randomness in the distribution of hot receptors at the fingertip. The significant correlations between cold thresholds at the three locations, together with the significant differences between cold thresholds at the three locations, are consistent with a greater density of cold receptors than hot thresholds with the greatest density of cold receptors at proximal locations of the fingertip.

5. Conclusions

Temperature sensitivity is not uniform over the fingertip, and is affected by both the size and the location of the area of contact. There is therefore a need to control the contact area when measuring thermotactile thresholds at the fingertip. Small contact areas should be avoided when measuring thermal thresholds for diagnostic purposes.

6. References

[1] C.J. Lindsell, M.J. Griffin "Standardised diagnostic methods for assessing components of the hand-arm vibration syndrome". HSE Books, CRR197/1998, ISBN 0 7176 1640 1, 1998.

[2] H. Hensel "Thermoreception and Temperature Regulation". London: Charles C Thomas, ISBN 0 1234 1260 9, 1981.

[3] D.R. Kenshalo "Psychophysical studies of temperature sensitivity". Contributions to Sensory Physiology. New York: Academic Press, 1970.

[4] E. Harju "Cold and warmth perception mapped for age, gender and body area". Journal of Somatosensory and Motor Research, 19 (1), 61-75, 2002.

[5] M.J. Hilz , S. Glorius, A. Beric "Thermal perception thresholds: influence of determination paradigm and reference temperature". Journal of Neurological Sciences, 129, 135-140, 1995.

[6] J.D. Hardy, T.W. Oppel "Studies in temperature sensation: III. The sensitivity of the body to heat and spatial summation of the end-organ responses". Journal of Clinical Investigation, 16, 533-540, 1937.

[7] J.C. Stevens, L.E. Marks "Spatial summation and the dynamics of the warmth sense". Perception and Psychophysics, 9: p 391-398, 1971.

[8] I. Kojo, A. Pertovaara "The effects of stimulus area and adaptation temperature on warm and heat pain thresholds in man". International Journal of Neuroscience, 32: p 875-880, 1987.

[9] B.G. Green, R. Zaharchuk, "Spatial variation in sensitivity as a factor in measurements of spatial summation of warmth and cold". Journal of Somatosensory and Motor Research, 18 (3): p 181-190, 2001.

[10] H. Strughold, R. Porz "Die Dichte der Kaltpunkte auf der Haut des menschlichen Körpers". Z. Biol., 91, 563-571, 1931.

[11] F.H. Rein "Über die Topographie der Warmemfindung. Beziehungen zwischen Innercation und receptorischen Endorganen". Z. Biol., 82, 189-212, 1925.

[12] B.G. Green, A. Cruz "'Warmth-insensitive fields': evidence of sparse and irregular innervation of human skin by the warmth sense". Journal of Somatosensory and Motor Research, 15 (4), 269-275, 1998.