Thermotactile Perception Thresholds Measurement Conditions

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Abstract: The purpose of this paper is to investigate the effects of posture, push force and rate of temperature change on thermotactile thresholds and to clarify suitable measuring conditions for Japanese people. Thermotactile (warm and cold) thresholds on the right middle finger were measured with an *HVLab* thermal aesthesiometer. Subjects were eight healthy male Japanese students. The effects of posture in measurement were examined in the posture of a straight hand and forearm placed on a support, the same posture without a support, and the fingers and hand flexed at the wrist with the elbow placed on a desk. The finger push force applied to the applicator of the thermal aesthesiometer was controlled at a 0.5, 1.0, 2.0 and 3.0 N. The applicator temperature was changed to 0.5, 1.0, 1.5, 2.0 and 2.5°C/s. After each measurement, subjects were asked about comfort under the measuring conditions. Three series of experiments were conducted on different days to evaluate repeatability. Repeated measures ANOVA showed that warm thresholds were affected by the push force and the rate of temperature change and that cold thresholds were influenced by posture and push force. The comfort assessment indicated that the measurement posture of a straight hand and forearm laid on a support was the most comfortable for the subjects. Relatively high repeatability was obtained under measurement conditions of a 1°C/s temperature change rate and a 0.5 N push force. Measurement posture, push force and rate of temperature change can affect the thermal threshold. Judging from the repeatability, a push force of 0.5 N and a temperature change of 1.0°C/s in the posture with the straight hand and forearm laid on a support are recommended for warm and cold threshold measurements.

Key words: Thermotactile threshold, Vibration, Posture, Push force, Repeatability

Introduction

Neurological disturbances such as finger numbness or tingling, and impaired skin perceptions are often encountered in hand-arm vibration syndrome. In Japan, as a medical checkup of hand-arm vibration syndrome, the measurement of pain thresholds has been performed according to the Labour Standards Bureau Notification No.609, but measurement with a weighted syringe needle is a question under discussion due to the risk of infection. A new index

for special medical checkup of vibration syndrome is required in place of the pain threshold measurement. Meanwhile, the usefulness of the thermotactile threshold has been reported as a diagnostic measure for evaluating the function of small sensory nerve fibers involving unmyelinated C fibers and myelinated A- σ fibers^{1,2,4}). As pain threshold measurement is also expected to examine the dysfunction of small sensory nerve fibers, thermotactile threshold measurement can be a substitute for pain threshold measurement.

A deterioration in thermotactile thresholds has been demonstrated among vibration-exposed workers^{2,4}) and thermotactile threshold testing is recommended to evaluate

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the function of small sensory nerve fibers¹⁾. It is, however, indicated that the thermotactile threshold is affected by various factors in the measuring conditions such as the reference temperature or skin temperature^{3, 7, 11)}, the applicator size³⁾, the rate of temperature change^{3, 6, 10)}, and the push force^{6, 10)}. With respect to the reference temperature or skin temperature, previous studies have shown that the repeatability of thermal testing is sufficiently accurate when the skin temperature of subjects is over 30°C^{3, 11)}. It is also reported that the thermal threshold is lower with a big probe than with a small one³⁾. These two factors are physiologically fundamental measuring conditions.

Previous studies have also indicated that a 1°C temperature change^{3, 6, 10)} and a 2 N push force^{6, 10)} are recommendable. But the effects of the rate of temperature change and the push force were not investigated at once, nor was the effect of the push force itself examined fully. It is not clear whether these measurement conditions can apply to Japanese people, although many researches have been done to measure the thermotactile perception thresholds around the world.

In addition, Lindsell and Griffin⁶⁾ suggested that the measurement posture of flexion or rotation of the wrist during thermal measurements might result in compression of the ulnar or median nerve and affect the measured threshold. This means that nerves and blood vessels may be pressed in thermal measurement. Moreover, the posture of wrist flexion might possibly compress the vessels as well as the nerves in the wrist, which could reduce blood flow to the finger and deteriorate the nerve function.

Nevertheless, the effects of measurement posture on the thermal thresholds have not been investigated experimentally.

Therefore, the purpose of this study was to investigate the effect of posture, push force and rate of temperature change on the thermotactile threshold, considering these three conditions simultaneously, and to clarify suitable measurement conditions.

Subjects and Methods

Subjects

Eight male subjects participated in the present study. All subjects were healthy male students at the Human Factors Research Unit, Kinki University, who had no neuromuscular or vascular disorder and no previous serious injury to the upper extremities. Their mean age was 22.6 (SD: 0.7) years were, height 170.1 (6.0) cm and weight 62.2 (5.0) kg. The present series of experiments were conducted according to the safety recommendations and with the approval of the Human Experimentation Safety and Ethics Committee of

the Department of Industrial Engineering, Kinki University.

Equipment specifications and procedure

Thermotactile (warm and cold) thresholds on the palmar surface of the distal phalanges of the right middle finger were measured with an *HVLab* thermal aesthesiometer⁶⁾. The measurements were conducted in a soundproof room, where the room temperature ranged from 24 to 26°C, and the noise level was 35 dB(A).

Each subject was seated and relaxed in the room. Skin temperature of the right middle finger was measured with a temperature probe of the aesthesiometer. When the temperature was above 30°C, the temperature was set as the starting temperature of the applicator of the aesthesiometer. If not, the subject's finger was warmed beforehand to above 30°C with a heater, so that the starting temperature of all subjects was above 30°C (Mean; 34.4°C, SD; 1.2°C).

The right middle finger of the subject was put on the applicator, and then the temperature of the applicator was increased or decreased from the starting temperature at a rate of change which could be varied by mean of a software program. When the subject perceived warm or cold sensation and pressed the response button, the temperature was reversed and returned to the starting temperature. The applicator temperature was held at that temperature for 5 s and then began to increase or decrease at the same rate of change. An automatic test program repeated this process several times to establish the mean threshold levels of warm or cold sensation. In the present study, this process was repeated six times to obtain each warm and cold threshold respectively. The warm or cold threshold for each subject was then determined as the mean of the last four measurements, excluding the first two measurements that were regarded as trials. During the measurement, the push force on the applicator was controlled by the subject's visual feedback from electronic scales.

After each measurement under different measurement conditions, the subjects were asked about comfort during each measurement (+1 comfortable; 0 fair; and -1 uncomfortable).

Measurement parameters

In the present series of experiments, thermal thresholds were measured under different conditions of posture, push force applied to the applicator, and the rate of change of applicator temperature. The effect of posture was studied with three different postures: 1) straight hand and forearm laid on a support (posture 1), 2) the fingers and hand flexed

Posture 1 (Straight hand and forearm laid on a support)

Posture 2 (The fingers and hand flexed at the wrist with elbow placed on a desk)

Posture 3 (Straight hand and forearm without a support)

Fig. 1. Postures for thermotactile threshold measurement.

at the wrist with the elbow placed on a desk (posture 2), and 3) straight hand and forearm without support (posture 3) as shown in Fig. 1.

Push force was examined in four conditions, 0.5, 1.0, 2.0 and 3.0 N, because a 2 N push force has been recommended⁶. The applicator temperature was increased or decreased at a rate of 0.5, 1.0, 1.5, 2.0 and 2.5°C/sec, as some studies have

suggested that a 1°C/s temperature change rate was recommended^{3, 10}.

The present study investigated these three measurement conditions, considering them simultaneously. As a result, the experiment conditions were 60 conditions (3 postures × 4 push forces × 5 temperature change rates). The subjects took part in 5 sets of 60 conditions with a rest for more than

Table 1. Mean threshold values and standard deviations in parenthesis for Posture 1

Rate of temperature change: °C/s	Push force: N	Day 1		Day 2		Day 3	
		Warm threshold (°C)	Cold threshold (°C)	Warm threshold (°C)	Cold threshold (°C)	Warm threshold (°C)	Cold threshold (°C)
0.5	0.5	37.51 (1.62)	31.86 (0.99)	37.56 (1.93)	31.14 (1.72)	38.48 (1.89)	31.36 (1.69)
	1	37.69 (1.70)	32.31 (1.34)	37.48 (0.94)	31.64 (2.03)	38.09 (1.77)	31.53 (1.57)
	2	37.28 (2.20)	31.63 (1.43)	37.48 (1.51)	31.79 (1.31)	37.98 (2.39)	31.55 (1.69)
	3	37.54 (1.79)	31.71 (1.78)	37.55 (1.22)	31.39 (2.17)	38.15 (1.69)	31.34 (1.62)
1	0.5	38.69 (1.95)	32.03 (1.28)	37.98 (1.87)	31.89 (1.66)	37.78 (1.60)	31.80 (1.35)
	1	37.85 (2.35)	32.40 (1.85)	38.33 (1.93)	32.36 (1.77)	38.39 (1.37)	32.40 (1.02)
	2	38.41 (1.93)	32.26 (1.01)	37.89 (1.90)	32.08 (1.32)	37.49 (2.24)	31.49 (1.79)
	3	37.88 (1.40)	32.60 (1.03)	37.90 (1.71)	32.25 (1.53)	37.89 (1.64)	32.26 (1.76)
1.5	0.5	38.29 (1.63)	31.25 (0.91)	39.31 (2.44)	30.91 (1.04)	38.99 (2.32)	30.80 (1.98)
	1	39.26 (1.34)	31.66 (1.46)	38.56 (1.79)	31.36 (1.15)	39.01 (1.94)	31.21 (1.50)
	2	38.16 (1.15)	31.55 (0.79)	38.48 (1.53)	31.36 (0.83)	38.74 (1.44)	30.89 (1.52)
	3	38.53 (0.96)	32.08 (1.09)	38.64 (1.46)	31.43 (0.96)	38.60 (1.20)	31.60 (0.93)
2	0.5	39.68 (2.41)	30.38 (1.34)	40.25 (1.87)	30.43 (1.74)	40.40 (1.98)	30.30 (1.70)
	1	39.11 (2.25)	30.61 (1.37)	39.84 (1.89)	30.81 (1.28)	39.68 (2.16)	30.29 (1.53)
	2	38.73 (1.83)	30.56 (0.78)	39.43 (1.90)	30.90 (1.70)	39.10 (1.75)	30.21 (1.57)
	3	38.88 (1.81)	30.34 (1.22)	39.61 (2.25)	30.48 (1.39)	38.79 (2.12)	30.25 (1.27)
2.5	0.5	40.44 (1.81)	31.43 (1.68)	39.68 (2.03)	31.06 (1.48)	40.44 (1.51)	31.49 (0.92)
	1	39.71 (1.48)	31.60 (1.70)	39.35 (0.59)	31.54 (1.70)	39.78 (1.11)	31.66 (1.47)
	2	39.30 (1.61)	31.30 (1.28)	39.09 (1.53)	31.34 (0.98)	39.65 (1.62)	31.29 (1.35)
	3	39.96 (1.37)	31.59 (0.83)	39.16 (1.29)	30.74 (1.16)	39.43 (0.61)	31.56 (0.99)

60 min between experiments in one day between 9:00 a.m. and 5:00 p.m. Accordingly it took 12 days to finish one series of experiments under the 60 conditions. To investigate the repeatability of each set of measurement conditions, all subjects took part in another series of experiments under 60 conditions on different 12 days, and repeated them again on another 12 days, so that all subjects underwent three series of experiments under 60 conditions on 36 days different.

Statistical analysis

Data analyses were conducted with SPSS for Windows, version 9.0. Repeated measures analysis of variance (ANOVA) was used to analyze factors of posture, push force, rate of temperature change and measurement day which may affect warm and cold thresholds. The repeatability of thermotactile thresholds on two different days under the same measurement conditions was evaluated with Pearson's correlation coefficients and r.m.s. errors⁸⁾. The r.m.s. error was calculated from the following formula:

$$\text{r.m.s. error} = \sqrt{\sum_{i=1}^n (X_i - Y_i)^2}$$

where X_i are the data for day X, Y_i are the data for day Y, and i is the subject number. Pearson's correlation coefficient

was greater and the r.m.s. error was smaller, and the measurement conditions were thought to have a good repeatability of thermal threshold measurements. Differences were considered statistically significant at $p < 0.05$.

Results

Warm and cold thresholds

Tables 1, 2 and 3 show the results of mean and standard deviations of warm and cold thermotactile thresholds obtained under different measurement conditions.

Thresholds tended to be higher in the order posture 1, posture 2 and posture 3. The standard deviations of thermal thresholds also tended to increase in that order. With a warm threshold a small value means more sensitivity to warmth, whereas with a cold threshold a large value implies more sensitivity to cold. The means and the standard deviations of thermal thresholds were likely to be the smallest when the right straight hand and forearm was laid on a support (posture 1). As the rate of change of the applicator temperature was increased, the warm threshold tended to increase a little. With an increase in the push force, the warm or cold threshold also tended to decrease or increase

Table 2. Mean threshold values and standard deviations in parenthesis for Posture 2

Rate of temperature change: °C/s	Push force: N	Day 1		Day 2		Day 3	
		Warm threshold (°C)	Cold threshold (°C)	Warm threshold (°C)	Cold threshold (°C)	Warm threshold (°C)	Cold threshold (°C)
0.5	0.5	37.65 (2.68)	30.48 (2.30)	38.55 (1.96)	31.23 (1.96)	38.76 (2.94)	30.28 (2.45)
	1	38.14 (1.59)	31.30 (2.37)	38.03 (1.95)	30.81 (1.83)	38.03 (2.67)	30.46 (2.34)
	2	37.65 (2.53)	30.74 (2.70)	38.03 (2.00)	31.29 (2.31)	37.58 (2.89)	30.30 (2.29)
	3	37.83 (2.28)	30.69 (2.64)	37.83 (1.84)	31.46 (2.92)	38.35 (2.43)	31.00 (2.75)
1	0.5	39.00 (2.10)	30.48 (2.35)	38.86 (1.94)	30.43 (1.29)	39.61 (2.75)	30.49 (2.12)
	1	38.94 (1.77)	30.85 (1.35)	38.95 (2.04)	30.90 (1.33)	38.95 (1.65)	30.74 (2.14)
	2	38.78 (1.36)	31.36 (1.57)	37.86 (2.30)	31.11 (1.34)	39.04 (1.91)	31.78 (1.77)
	3	38.51 (1.07)	31.30 (1.60)	38.74 (1.66)	31.25 (0.90)	38.69 (1.53)	31.41 (1.21)
1.5	0.5	39.06 (2.65)	30.20 (1.55)	40.54 (2.72)	30.20 (1.73)	40.61 (2.81)	30.83 (1.59)
	1	39.06 (2.80)	30.39 (1.29)	39.85 (2.47)	30.40 (2.07)	39.50 (2.28)	30.90 (1.59)
	2	38.91 (3.00)	30.73 (1.12)	39.13 (2.20)	30.95 (1.88)	39.85 (2.76)	30.96 (1.87)
	3	38.59 (2.48)	31.03 (1.25)	39.63 (2.24)	30.93 (2.41)	39.83 (2.53)	31.16 (2.00)
2	0.5	39.94 (3.42)	29.50 (2.48)	40.83 (3.69)	29.96 (2.65)	40.51 (2.89)	30.08 (1.79)
	1	40.36 (2.44)	30.50 (2.52)	40.14 (3.50)	30.18 (1.98)	39.85 (2.53)	30.40 (1.52)
	2	40.28 (3.27)	30.20 (2.60)	40.03 (3.52)	30.05 (2.61)	39.94 (3.35)	30.04 (2.39)
	3	39.69 (2.84)	30.14 (2.40)	39.69 (3.61)	29.94 (2.33)	39.15 (1.87)	30.51 (2.06)
2.5	0.5	40.69 (3.27)	29.51 (1.37)	40.44 (3.27)	29.20 (3.19)	41.26 (3.21)	30.64 (2.26)
	1	40.60 (3.50)	29.90 (1.04)	41.31 (3.23)	28.86 (2.14)	40.59 (2.92)	29.69 (1.73)
	2	40.05 (2.49)	29.88 (1.59)	39.90 (2.98)	29.81 (1.87)	41.06 (2.83)	30.26 (2.35)
	3	39.76 (2.44)	30.10 (1.83)	39.35 (3.05)	29.70 (1.80)	40.14 (2.22)	30.64 (1.47)

Table 3. Mean threshold values and standard deviations in parenthesis for Posture 3

Rate of temperature change: °C/s	Push force: N	Day 1		Day 2		Day 3	
		Warm threshold (°C)	Cold threshold (°C)	Warm threshold (°C)	Cold threshold (°C)	Warm threshold (°C)	Cold threshold (°C)
0.5	0.5	39.30 (2.80)	29.91 (2.85)	38.60 (3.09)	29.73 (2.64)	39.05 (2.51)	29.98 (2.45)
	1	38.64 (2.70)	30.23 (2.64)	38.54 (2.44)	29.61 (2.62)	38.14 (2.25)	29.94 (2.51)
	2	38.75 (2.47)	30.24 (2.32)	38.29 (2.82)	30.06 (2.97)	38.16 (2.04)	31.05 (2.47)
	3	38.43 (2.84)	30.45 (2.84)	38.01 (2.68)	30.71 (2.76)	38.03 (1.94)	30.15 (2.46)
1	0.5	39.34 (3.92)	29.15 (2.84)	39.68 (2.26)	29.39 (4.08)	39.64 (3.19)	30.21 (2.01)
	1	38.44 (2.60)	29.83 (2.78)	39.63 (3.02)	29.29 (3.00)	39.11 (2.57)	30.24 (2.40)
	2	39.26 (3.75)	29.55 (2.88)	39.56 (3.66)	30.58 (2.99)	38.60 (2.69)	30.45 (2.34)
	3	39.03 (3.46)	29.53 (2.44)	39.25 (3.37)	29.74 (3.22)	39.00 (2.85)	30.14 (2.45)
1.5	0.5	40.09 (3.41)	29.79 (2.49)	40.48 (3.85)	29.23 (3.54)	39.53 (3.19)	29.16 (2.69)
	1	39.88 (3.24)	30.35 (2.50)	39.55 (3.48)	29.28 (3.25)	38.81 (3.19)	29.50 (2.41)
	2	39.50 (2.52)	30.04 (2.54)	39.25 (3.34)	29.43 (2.93)	38.79 (2.99)	29.65 (2.75)
	3	39.65 (3.02)	29.91 (2.49)	39.55 (3.20)	29.86 (3.13)	38.60 (2.47)	29.39 (2.90)
2	0.5	40.80 (5.25)	29.08 (2.83)	41.66 (4.01)	29.38 (3.02)	41.14 (4.02)	29.39 (3.04)
	1	39.69 (4.40)	29.19 (2.28)	40.30 (4.14)	29.69 (3.40)	40.38 (4.07)	28.91 (3.29)
	2	39.79 (3.78)	29.80 (2.22)	40.56 (3.10)	29.99 (3.07)	40.29 (3.88)	30.20 (3.15)
	3	39.34 (3.55)	28.73 (3.52)	40.29 (3.66)	29.98 (2.80)	40.04 (3.16)	29.44 (3.07)
2.5	0.5	41.38 (4.62)	28.98 (2.58)	41.24 (3.31)	29.41 (3.02)	42.09 (3.76)	29.03 (3.12)
	1	41.10 (4.66)	29.23 (2.21)	41.83 (3.68)	29.08 (2.75)	41.83 (4.30)	29.38 (2.88)
	2	41.08 (4.64)	29.38 (2.77)	41.48 (4.40)	29.50 (2.82)	40.80 (3.02)	29.24 (3.47)
	3	40.70 (4.16)	29.85 (2.11)	40.34 (3.33)	29.93 (2.78)	40.58 (3.52)	29.84 (2.91)

Table 4. Differences in thermotactile perception threshold among measurement conditions

Rate of change of applicator temperature	Push force	Posture	Measurement day		
			Day 1	Day 2	Day 3
Cold threshold					
1°C	0.5 N	Posture 1	32.0 ± 1.3	31.9 ± 1.7	31.8 ± 1.4
		Posture 2	30.5 ± 2.3	30.4 ± 1.3	30.5 ± 2.1
		Posture 3	29.2 ± 2.8 ⁺	29.4 ± 4.1	30.2 ± 2.0
1°C	0.5 N	Posture 1	32.0 ± 1.3	31.9 ± 1.7	31.8 ± 1.4
	1.0 N		32.4 ± 1.8	32.4 ± 1.8	32.4 ± 1.0*
	2.0 N		32.3 ± 1.0	32.1 ± 1.3	31.5 ± 1.7
	3.0 N		32.6 ± 1.0*	32.3 ± 1.5	32.3 ± 1.8
0.5°C	0.5 N	Posture 1	31.7 ± 1.0	31.1 ± 1.7	31.4 ± 1.7
1.0	32.0 ± 1.3		31.9 ± 1.7	31.8 ± 1.4	
1.5	31.3 ± 0.9		30.9 ± 1.0	30.8 ± 2.0	
2.0	30.4 ± 1.3*		30.4 ± 1.7	30.3 ± 1.7	
2.5	31.4 ± 1.7		31.1 ± 1.5	31.5 ± 0.9	
Warm thresholds					
1°C	0.5 N	Posture 1	38.7 ± 2.0	38.0 ± 1.9	37.8 ± 1.6
		Posture 2	39.0 ± 2.1	38.9 ± 1.9	39.6 ± 2.8 ⁺
		Posture 3	39.3 ± 3.9	39.7 ± 2.3*	39.6 ± 3.2
1°C	0.5 N	Posture 1	38.7 ± 2.0	38.0 ± 1.9	37.8 ± 1.6
	1.0 N		37.9 ± 2.3	38.3 ± 1.9	38.4 ± 1.4
	2.0 N		38.4 ± 1.9	37.9 ± 1.9	37.5 ± 2.2
	3.0 N		37.9 ± 1.4*	37.9 ± 1.7	37.9 ± 1.6
0.5°C	0.5 N	Posture 1	37.5 ± 1.6	37.6 ± 1.9	38.5 ± 1.9
1.0	38.7 ± 2.0		38.0 ± 1.9	37.8 ± 1.6	
1.5	38.3 ± 1.6		39.3 ± 2.4	39.0 ± 2.3	
2.0	39.7 ± 2.4		40.3 ± 1.9 ⁺	40.4 ± 2.0*	
2.5	40.4 ± 1.8*		39.7 ± 2.0	40.4 ± 1.5*	

⁺p<0.1, ^{*}p<0.05.

slightly.

Repeated measures ANOVA showed that the warm threshold was significantly affected by the rate of temperature change ($F=3.449$, $p<0.05$) and the push forces ($F=27.816$, $p<0.01$). The cold threshold was significantly affected by the push forces ($F=9.725$, $p<0.01$), posture ($F=9.998$, $p<0.01$) and the interactions between push forces and the posture ($F=3.651$, $p<0.05$). The effect of measurement day was not significant ($F=1.173$, $p=0.338$ for warm thresholds; $F=0.206$, $p=0.817$ for cold thresholds), so that factors of posture, push force and rate of temperature change affected warm or cold threshold measurements.

Differences among measuring conditions for posture, rate of temperature change, and push force were then compared by means of paired t-test. Some of the results are shown in Table 4.

Under the measuring conditions with a 0.5 N push force at a change rate of 1°C, statistical differences in cold or

warm thresholds were not encountered among different measuring postures. Nevertheless, warm thresholds tended to increase in the order posture 1, posture 2 and posture 3, and the differences between posture 1 and posture 3 were on average 1.6–2.5°C for cold thresholds and 0.6–1.8°C for warm thresholds. On the other hand, although significant differences in thermal thresholds were observed among different conditions of push force, the difference was less than 1°C: 0.5–0.9°C for cold thresholds and 0.4–0.8°C for warm thresholds. Statistical differences were found among different rates of change in temperature, particularly in warm thresholds. The differences were 0.6–1.5°C for cold thresholds and 2.6–2.9°C for warm thresholds. It is therefore thought that it is necessary to standardize the measuring posture and the rate of temperature change as fundamental measurement conditions, whereas the effect of the push force may be small in practice.

Table 5. Mean values for subject comfort in thermotactile measurement

Rate of temperature change: °C	Push force: N	Posture 1	Posture 2	Posture 3
0.5	0.5	0.6	0.4	-0.9
0.5	1	0.6	0.3	-0.9
0.5	2	0.7	0.3	-1
0.5	3	0.6	0.3	-1
1	0.5	0.7	0.5	-0.8
1	1	0.7	0.5	-0.8
1	2	0.6	0.4	-0.9
1	3	0.6	0.3	-0.9
1.5	0.5	0.7	0.5	-0.8
1.5	1	0.7	0.5	-0.8
1.5	2	0.6	0.4	-0.9
1.5	3	0.5	0.4	-0.9
2	0.5	0.7	0.5	-0.7
2	1	0.7	0.5	-0.7
2	2	0.6	0.5	-0.8
2	3	0.5	0.5	-0.8
2.5	0.5	0.7	0.5	-0.7
2.5	1	0.7	0.5	-0.7
2.5	2	0.6	0.5	-0.8
2.5	3	0.6	0.5	-0.8

Subject's comfort assessment of measuring condition

Table 5 shows the mean values for subject comfort assessment of each measurement condition.

A value close to 1 showed that the measuring condition was comfortable for the subject. Posture 3, with straight hand and forearm without a support was the most uncomfortable posture, whereas posture 1 with straight hand and forearm with a support was the most comfortable for the subjects. The values for the comfort assessment were likely to increase a little with a decrease in the push force. The rate of temperature change seemed to have only a little effect.

Repeatability of threshold measurement

The repeatability of thermal measurement on different days was evaluated with correlation coefficients and r.m.s. errors. Good repeatability should show a high correlation coefficient and a small r.m.s. error⁸⁾. The correlation coefficients varied among different measuring postures. The r.m.s. errors tended to be greater in posture 2, but the errors were almost the same in postures 1 and 3. Nevertheless, the comfort assessment showed that posture 1 was the most comfortable for the subjects. Table 6 shows Pearson's correlation coefficients and r.m.s. errors for different measurement days for posture 1 only.

The correlation coefficients for both warm and cold thresholds on different days under the same measurement conditions were relatively high for the following four conditions: a 0.5°C/s temperature change rate and a 2 N push force, a 1°C/s temperature change rate and a 0.5 N push force, a 1.5°C/s temperature change rate and a 1 N push force, and a 2°C/s temperature change rate and a 0.5 N push force.

Among these four conditions, the r.m.s. errors looked the smallest under the measurement condition of a 1°C/s temperature change rate and a 0.5 N push force.

Discussion

In the present study, the measurement postures significantly affected cold threshold measurements. The means and standard deviations of thermal thresholds were likely to be smallest in posture 1 (straight hand and forearm on a support), and they tended to be greatest in posture 3 (straight hand and forearm without a support). In posture 2 (the fingers and hand flexed at the wrist with the elbow placed on a desk) they were in between them. These results may be associated with the stability of the hand and arm examined. In posture 2, the flexion or rotation of the wrist during the measurements might compress the median or ulnar nerve

Table 6. Pearson correlation coefficients and root-mean-square differences in parenthesis for cold and warm thresholds obtained in Posture 1 on different days

Rate of temperature change: °C/s	Push force	Cold thresholds			Warm thresholds		
		Days 1 and 2	Days 1 and 3	Days 2 and 3	Days 1 and 2	Days 1 and 3	Days 2 and 3
0.5	0.5	0.604 (4.162)	0.521 (4.096)	0.699 (3.564)	0.926** (1.980)	0.841** (3.838)	0.850** (3.783)
	1	0.542 (4.893)	0.592 (4.053)	0.865** (2.751)	0.635 (3.548)	0.721* (3.620)	0.741* (3.724)
	2	0.831* (2.179)	0.846** (2.392)	0.788* (2.830)	0.910** (2.804)	0.931** (3.046)	0.759* (4.427)
	3	0.749* (3.932)	0.481 (4.720)	0.871** (2.909)	0.780* (2.998)	0.769* (3.582)	0.631 (3.878)
1	0.5	0.668 (3.330)	0.841** (2.074)	0.826* (2.496)	0.879** (3.208)	0.847** (3.775)	0.939** (1.849)
	1	0.734* (3.497)	0.383 (4.587)	0.383 (4.419)	0.340 (6.702)	0.439 (5.849)	0.819* (2.998)
	2	0.269 (3.822)	-0.045 (5.762)	0.486 (4.458)	0.700 (4.190)	0.534 (5.980)	0.905** (2.786)
	3	0.695 (3.082)	0.520 (4.120)	0.440 (4.647)	0.919** (1.844)	0.628 (3.514)	0.832* (2.571)
1.5	0.5	0.114 (3.576)	0.490 (4.761)	0.440 (4.732)	0.519 (6.304)	0.482 (9.880)	0.728* (4.741)
	1	0.715* (2.839)	0.719* (3.197)	0.845* (2.163)	0.720* (3.837)	0.529 (4.490)	0.785* (3.493)
	2	0.690 (1.775)	0.778* (3.309)	0.598 (3.493)	0.716* (2.968)	0.826* (2.702)	0.798* (2.617)
	3	0.164 (3.947)	0.404 (3.212)	0.652 (2.135)	0.656 (2.938)	0.576 (2.702)	0.384 (3.956)
2	0.5	0.868** (2.332)	0.742* (3.033)	0.770* (3.105)	0.754* (4.500)	0.919** (3.305)	0.872** (2.631)
	1	0.523 (3.481)	0.592 (3.611)	0.714* (3.243)	0.926** (3.089)	0.823* (3.828)	0.927** (2.211)
	2	0.233 (4.595)	-0.093 (4.903)	0.647 (4.134)	0.829* (3.504)	0.848** (2.825)	0.788* (3.295)
	3	0.216 (4.227)	0.149 (4.312)	0.862** (1.975)	0.817* (4.009)	0.816* (3.263)	0.758* (4.660)
2.5	0.5	0.581 (3.989)	0.782* (2.968)	0.516 (3.578)	0.864** (3.457)	0.805* (2.850)	0.919** (3.158)
	1	0.407 (4.855)	0.744* (3.061)	0.711* (3.252)	-0.045 (4.387)	0.357 (3.966)	-0.351 (3.960)
	2	0.536 (2.968)	0.745* (2.492)	0.739 (2.417)	0.804* (2.850)	0.277 (8.471)	-0.067 (10.10)
	3	0.677 (3.298)	0.760* (1.709)	0.623 (3.418)	0.043 (5.378)	0.511 (3.477)	0.560 (2.944)

* $p < 0.05$; ** $p < 0.01$.

and affect the threshold⁶). The present findings on subject's comfort assessment also indicated that the posture 1 was the most comfortable for the subjects, and posture 3 was the reverse, so that the posture in which the straight hand and forearm are laid on a support can be the most comfortable for the subjects and is recommended for thermal threshold measurements.

The present repeated ANOVA also indicated that the rate of change in the applicator temperature significantly influenced warm thresholds, and the push force affected warm and cold thresholds. As the rate of temperature change rose from 0.5°C/s to 2.5°C/s, warm thresholds tended to increase. Hilz *et al.* also showed that thermal thresholds were higher with a 3°C/s stimulation than with a 1°C/s stimulation³). Ruffell and Griffin found that incremental rates of temperature did not significantly affect thermal thresholds, except that cold thresholds were significantly higher at 0.5°C/s than at 2.5°C/s¹⁰). On the other hand, increasing the push force tended to produce slightly lower thermal thresholds. Although there were no studies investigating the effect of the push force on thermal thresholds, similar findings were shown by previous studies on vibrotactile thresholds^{5, 9}).

When the repeatability of thermal thresholds was compared in the measuring posture of the straight hand and forearm on a support, a relatively good repeatability was obtained at a 1°C/s temperature change rate and a 0.5 N push force for warm and cold thresholds. The repeatability was evaluated with correlation coefficients and r.m.s. errors⁸). Relatively good repeatability was observed in various measuring conditions for warm thresholds, but for cold thresholds it was encountered in a small number of measuring conditions, as shown in Table 6, where repeatability differed with the rate of temperature change and the push force. Considering both warm and cold thresholds, the present findings have shown that a 1°C/s temperature change rate and a 0.5 N push force are recommendable measuring conditions. A 1°C/s temperature change rate was in accordance with previous studies^{3, 6, 10}), where the effect of the temperature change rate was investigated with a fixed push force of 2 N. In thermal threshold measurements, a 2 N push force was often used^{6, 10}), but for Japanese subjects, a weaker push force may be more suitable, since similar findings were found in vibrotactile studies⁹). In comparison of 0.5°C/s and 1°C/s temperature change rates, 1.0°C/s is

also preferable to 0.5°C/s in practice, because the former condition requires only a shorter measurement time than the latter. And it turns out that the shorter measurement time is similar to that shown in Table 4. In view of this, if measurement time becomes long in actual on-site measurement, it will be expected that the subject is made to feel unpleasant.

In the present study the starting temperature of the applicator was set at the subject's finger skin temperature. Some studies have shown that when the skin temperature of the subject is over 30°C, thermal testing is sufficiently accurate^{3,11}. The present experiments were conducted under conditions in which the skin temperature of all subjects was over 30°C (34.4 ± 1.2°C) in a soundproof room with an air temperature of 24 to 26°C. It is therefore considered that the effect of the starting temperature is negligible.

Conclusion

The present series of experiments investigated the effect of measurement postures, the rate of change in temperature, and push forces on thermotactile thresholds, by means of an *HVLab* thermal aesthesiometer. Warm thresholds were significantly affected by the push force and the rate of temperature change and cold thresholds were influenced by postures and push force. The measurement posture of straight hand and forearm laid on a support was the most comfortable for the subjects. A push force of 0.5 N and a rate of temperature change of 1.0°C/sec in posture 1, straight hand and forearm laid on a support can be suitable conditions for the measurement of warm and cold thresholds from the viewpoints of repeatability of measurement and subject's comfortable.

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References

- 1) Anonymous (1995) Clinical and laboratory diagnostics of neurological disturbances in workers using hand-held vibrating tools. In: Stockholm Workshop 94, Hand-arm vibration syndrome: Diagnostics and quantitative relationships to exposure, Proceedings. eds. by Gemne G, Brammer AJ, Hagberg M, Lundström R, Nilsson T, 187–93, Sweden's National Institute of Occupational Health, Solna.
- 2) Ekenvall L, Nilsson BY, Gustaveson P (1986) Temperature and vibration thresholds in vibration syndrome. *Brit J Ind Med* **43**, 825–9.
- 3) Hilz MJ, Stemper B, Axelrod FB, Kolodny EH, Neundorfer B (1999) Quantitative thermal perception testing in adults. *J Clin Neurophys* **16**, 462–71.
- 4) Hirokawa I (1983) Original construction of thremoesthesiometer and its application to vibration disease. *Int Arch Occup Environ Health* **52**, 809–15.
- 5) Lindsell CL (1997) Vibrotactile thresholds: Effect of contact forces and skin indentation. Proceedings of the United Kingdom Group Meeting on Human Response to Vibration, ISVR, University of Southampton, Southampton, England, September 1–11.
- 6) Lindsell CL, Griffin MJ (1996) Standardized diagnostic methodology for assessing components of the Hand-Arm Vibration Syndrome. Draft final report submitted to Health and Safety Executive, Institute of Sound and Vibration Research, University of Southampton, H.F.R.U. 96/26
- 7) Mito H, Shimizu T (1981) Experimental thermoesthesiometer incorporating peltier thermal modules - its rationale and instances of application. *Acta Med Kinki Univ* **6**, 125–30.
- 8) Maeda S, Griffin MJ (1994) A comparison of vibrotactile thresholds on the finger obtained with different equipment. *Ergonomics* **37**, 1391–406.
- 9) Maeda S, Yonekawa Y, Kanada K, Takahashi Y (2000) Effects of push forces on vibrotactile thresholds measurement. In: Lundström R, Lindmark A (eds) Eighth International Conference on Hand-Arm Vibration 9–12 June 1988, Umeå, Sweden, Proceedings. Umeå: National Institute for Working Life. 143–50.
- 10) Ruffell CM (1994) The effect of temperature incremental rate on the repeatability of thermal thresholds. Proceedings of the United Kingdom Informal Group Meeting of the Human Response to Vibration, Institute of Naval Medicine, Alverstoke, Gosport, Hants, September 1–9.
- 11) Ruffell CM, Griffin MJ (1995) Effect of starting temperature on the repeatability of thermotactile thresholds. *Centr Eur J Pub Health* **3**, 81–4.