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Normal values for thermotactile and vibrotactile thresholds in males and females

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Abstract

Objectives

This study was undertaken to compare normal values of thermotactile and vibrotactile thresholds in males and females and in younger and older age groups. In addition, for thermal thresholds, the effects of the contact area (small and large) and stimulus location (glabrous and non-glabrous skin) were investigated.

Method

Eighty male and female subjects participated in the study. Twenty males and twenty females were aged 20 to 30 years. Twenty males and twenty females were aged 55 to 65 years. Subjects attended one 45-minute experimental session consisting of acclimatisation for 10 minutes followed by 35 minutes of testing. Using the method of limits, warm thresholds and cold thresholds were measured on the non-dominant upper limb at three locations (the distal phalanx of the middle finger, the thenar eminence, and the forearm) using two circular stimuli of 10 mm and 28 mm diameter. Using the von Békésy method, vibrotactile thresholds at 31.5 Hz and 125 Hz were measured on the distal phalanx of the middle finger of the non-dominant hand.

Results

Among the younger subjects there were significant gender differences in thermotactile thresholds but not vibrotactile thresholds. Age did not have any significant effect on thermotactile or vibrotactile thresholds. Hot thresholds were significantly higher and cold thresholds significantly lower when the larger stimulus area was used. The thresholds exceeded by 18% (the mean plus one standard deviation) and 2.5% (the mean plus 2 standard deviations) are provided and may be used to consider whether thresholds are within a ‘normal’ range.

Conclusions

For males and females the same ranges of normal values may be used for vibrotactile thresholds but different ranges of normal values may be required for thermotactile thresholds. An age correction may not be needed for thermotactile or vibrotactile thresholds in persons aged 20 to 65 years. Contact area has an influence on thermotactile thresholds and should be controlled.

Introduction

Thermotactile thresholds and vibrotactile thresholds are used in the diagnosis of the neurological components of the hand-arm vibration syndrome (HAVS) (Lindsell and Griffin, 1998). A hot threshold and a cold threshold are used to assess the function of warm and cold receptors. Similarly, two vibrotactile thresholds, at 31.5 Hz and 125 Hz, assess the function of the Meissner and Pacinian corpuscles, respectively. Tests are usually performed on the distal phalanges of the index finger and little finger (i.e. one site innervated by the median nerve and one site innervated by the ulnar nerve) on both hands.

When diagnosing sensorineural disorders, thresholds are compared to normal values, but the normal values are currently not adjusted for either gender or age. Age tends to lead to deterioration in neurological function that should be considered during diagnosis (Lindsell and Griffin, 2002). Some studies have found that older subjects have decreased sensitivity to thermotactile thresholds (e.g., Bartlett *et al.*, 1998; Doeland *et al.*, 1989; Lindsell and Griffin, 2002) and vibrotactile thresholds (e.g., Bartlett *et al.*, 1998; Hilz *et al*., 1998; Wild *et al*. 2001). However, other studies have found no age effects with thermotactile thresholds (e.g., Ekenvall *et al*., 1986; Harju, 2002; Liou *et al*., 1999) and vibrotactile thresholds (e.g., Ekenvall *et al*., 1986; Liou *et al*., 1999).

Some studies have found females to be more sensitive to temperature than males (e.g., Doeland *et al*., 1989; Liou *et al.*, 1999). Vibration thresholds have been said to be higher in males (Hilz *et al*., 1998; Wild *et al*., 2001) but differences were small. It has been suggested that the effects of gender on thermotactile thresholds are not clinically important because differences are small (Bartlett *et al*., 1998). Generally no gender effects have been found in vibration thresholds (Liou *et al*., 1999).

Thermotactile and vibrotactile thresholds depend on the methods used to obtain thresholds, including the contact conditions and characteristics of the psychophysical procedures employed. This study was undertaken to determine normal values of thermotactile and vibrotactile thresholds in healthy persons obtained using procedures currently employed to assist the diagnosis of the hand-arm vibration syndrome in the UK. The study was designed to compare thresholds in males and females and to compare thresholds in younger and older age groups. In addition, for thermal thresholds, the effects of the contact area (small and large) and stimulus location (glabrous and non-glabrous skin) were investigated.

Methods

Subjects

Eighty male and female subjects participated in the study as four groups. Twenty males and twenty females were aged 20 to 30 years. Twenty males and twenty females were aged 55

Table 1 Mean (IQR) of age, height and weight and distribution of handedness, smoking and alcohol consumption for the different subject groups.

Age range	Gender	Age (years)	Height (cm)	Weight (kg)	Smoking		Alcohol consumption (units)			
					No	Yes	0	1-3	4-6	>6
20-30	Female	23.5 (2.8)	161.5 (11.3)	55.5 (10.8)	19	1	11	8	1	0
	Male	23.5 (3.8)	176.5 (10.3)	72.5 (20.5)	16	4	6	10	1	3
55-65	Female	59.0 (5.5)	162.0 (10.0)	68.5 (18.0)	18	2	6	3	7	4
	Male	58.5 (6.5)	178.0 (10.0)	79.0 (10.0)	19	1	3	4	7	6

to 65 years. Subjects were students or office workers with no regular use of hand-held vibrating tools and were screened using a health questionnaire. None reported cardiovascular or neurological disorders, connective tissue disease, injuries to the upper extremities, a history of cold hands, or were on medication likely to affect finger systolic blood pressures. Table 1 shows the ages, height, weights and the distribution of smoking and alcohol consumption in the four subject groups.

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.

Experimental conditions

The experiment was conducted in a quiet room with a temperature range of 22 to 26°C. Subjects attended a 45-minute experimental session consisting of acclimatisation for 10 minutes followed by 35 minutes of testing. Markings were made on the subjects' non-dominant upper limbs at three locations – the distal phalanx of the middle finger, the thenar eminence, and the forearm. Skin temperature was measured at the start of each session at these locations the using a thermocouple. All skin temperatures were greater than 27°C.

Experimental procedure

Written instructions were given to the subjects prior to the tests. All subjects practiced all tests using the index finger of their non-dominant hand. Subjects were seated for the duration of the tests with their forearms supported. The thermotactile thresholds were measured before the vibrotactile thresholds.

An *HVLab* Thermal Aesthesiometer was used to measure thermotactile thresholds (warm and cold thresholds) via the method of limits. Thresholds were measured on the non-dominant upper limb at the three marked locations (the distal phalanx of the middle finger, the thenar eminence, and the forearm) using two circular stimuli: 1 cm diameter (0.79 cm^2 area) and 2.8 cm diameter (6.18 cm^2 area). Depending on the test, the temperature of the applicator increased or decreased (at 1°C per second) from the reference temperature (32.5°C) (see Table 2). Subjects were instructed to press the response button as soon as they perceived a change in temperature. The temperature of the applicator then returned to the reference temperature at 1°C per second and was held at 32.5°C for a random interval (between 3 and 5 seconds) before the temperature increased or decreased again. Six hot and six cold thresholds were determined and the means of the hot and cold thresholds were calculated from the last four judgements.

An *HVLab* Tactile Vibrometer was used to measure vibrotactile thresholds (thresholds at 31.5 Hz and 125 Hz) via the von Békésy method in a manner compliant with the methods in ISO 13091-1 (2001). Thresholds were measured on the distal phalanx of the middle finger of the non-dominant hand. Subjects were instructed to place their finger such that the centre of the whorl was situated over the centre of the probe of the applicator. The magnitude of the vibration on the applicator increased from zero at the start of the test. Subjects were instructed to press and hold the response button down as soon as they perceived a vibration sensation and to release the response button as soon as they did not perceive the vibration. Measurements were performed for a minimum of six reversals over a duration of at least 45 seconds and the mean was calculated from all the peaks and troughs with the exception of the first peak and first trough. Table 2 summarises the parameters of the *HVLab* Thermal Aesthesiometer and *HVLab* Tactile Vibrometer applicators and test procedures.

Statistical methods

Non-parametric tests (Friedman test for k-related samples, the Wilcoxon matched-pairs signed ranks test for two-related samples, and the Mann-Whitney U-test for two-independent

Table 2 Parameters of the *HVLab* Thermal Aesthesiometer and *HVLab* Tactile Vibrometer.

	Parameter	Condition
Thermotactile thresholds	Contactor area	Circular, 55 mm diameter
	Contactor surface	Smooth and planar
	Psychophysical method	Method of limits
	Number of judgements	Six hot or cold
	Reference temperature	32.5°C
	Rate of change of temperature	1°C/s
Vibrotactile thresholds	Contactor shape	Cylindrical, 6 mm diameter
	Contactor surface	Smooth and planar
	Surround surface	Smooth and planar
	Hole in surround	Circular, 10 mm diameter
	Psychophysical method	von Békésy
	Number of reversals	Six (minimum)
	Rate of change of stimulus	3 dB/s
	Measurement duration	45 seconds (minimum)
	Push force	2 N

samples) were employed for statistical analysis. Correlations were investigated using the Spearman rank correlation.

Results

Table 3 shows the hot and cold thresholds for younger and older female and male subjects obtained with the smaller stimulus (1-cm diameter) and larger stimulus (2.8-cm diameter) at three locations. Table 4 shows the vibrotactile thresholds at 31.5 Hz and 125 Hz for the groups of younger and older male and female subjects.

Thermotactile thresholds

Younger Subjects

Females were more sensitive to temperature than males. Hot thresholds were significantly lower in females with the 1.0-cm diameter stimulus at the finger and the thenar eminence and with the 2.8-cm diameter stimulus at the finger, the thenar eminence and the forearm (p<0.05, Mann-Whitney). Cold thresholds were significantly higher in females with both the 1.0-cm and the 2.8-cm diameter stimulus at the finger (p<0.05).

Stimulus area and location also affected thermotactile thresholds. Hot thresholds were significantly lower and cold thresholds were significantly higher at all locations within both genders when the larger (2.8-cm diameter) stimulus was used (p≤0.002, Wilcoxon).

Within younger males, when using the 2.8-cm diameter stimulus, hot thresholds were significantly lower at the thenar eminence than at the finger and the forearm, and cold thresholds were significantly lower at the finger than at the thenar eminence and the forearm

Table 3 Median (IQR) hot and cold thresholds.

Age (years)	Gender	Stimulus diameter	Hot Thresholds (°C)			Cold Thresholds (°C)		
			Finger	Thenar eminence	Forearm	Finger	Thenar eminence	Forearm
20–30	Female	1.0 cm	37.91 (3.54)	38.07 (3.69)	39.74 (8.43)	27.13 (5.25)	28.87 (3.39)	27.45 (3.79)
		2.8 cm	35.89 (2.19)	34.03 (1.96)	35.62 (2.12)	29.43 (1.65)	30.80 (1.88)	30.84 (2.64)
	Male	1.0 cm	41.92 (5.40)	41.64 (4.56)	43.70 (8.34)	23.28 (9.21)	28.45 (5.51)	26.56 (7.75)
		2.8 cm	37.29 (2.30)	35.60 (2.11)	37.16 (4.19)	26.93 (2.86)	30.52 (2.89)	30.39 (3.60)
55–65	Female	1.0 cm	40.70 (6.65)	39.09 (3.75)	39.22 (5.86)	24.03 (9.33)	26.02 (5.68)	24.84 (4.32)
		2.8 cm	37.44 (3.86)	34.71 (1.46)	35.29 (1.55)	28.62 (5.36)	30.48 (1.23)	30.85 (2.99)
	Male	1.0 cm	44.19 (7.96)	42.18 (5.95)	43.52 (6.17)	21.87 (15.81)	24.45 (6.24)	25.74 (8.15)
		2.8 cm	38.24 (5.51)	34.87 (1.50)	36.30 (2.51)	27.53 (3.71)	30.10 (2.19)	29.78 (4.37)

($p<0.001$). When using the 1.0-cm diameter stimulus, there were no differences between the three locations in the hot thresholds but cold thresholds were significantly higher at the thenar eminence than at the finger or at the forearm ($p \leq 0.04$). There was a significant correlation between room temperature and cold thresholds at both the thenar eminence and the forearm when using the 2.8-cm diameter stimulus ($p<0.05$, Spearman). There was significant correlation between skin temperature and cold thresholds at forearm when using the 2.8-cm diameter stimulus ($p=0.009$, Spearman).

Within younger females, when using the 2.8-cm diameter stimulus, hot thresholds were significantly lower at the thenar eminence than at the finger and the forearm, and cold thresholds were significantly lower at the finger than at the thenar eminence and the forearm ($p \leq 0.001$). When using the 1.0-cm diameter stimulus, hot thresholds were significantly higher at the forearm than at the finger and the thenar eminence, and cold thresholds were significantly higher at the thenar eminence than at the finger ($p \leq 0.05$). There was a significant correlation between room temperature and hot and cold thresholds at the finger when using the 2.8-cm diameter stimulus ($p<0.05$, Spearman). There was significant correlation between skin temperature and hot thresholds at finger when using the 2.8-cm diameter stimulus ($p=0.004$, Spearman).

Older subjects

Differences in sensitivity between the genders was less apparent in the older subjects. Hot thresholds were significantly lower in females with the 1.0-cm diameter stimulus at the thenar eminence and the forearm and with the 2.8-cm diameter stimulus at the forearm ($p<0.05$, Mann-Whitney). There was no gender differences in cold thresholds with either stimulus area at any of the three locations.

The larger stimulus (2.8-cm diameter) gave lower hot thresholds and higher cold thresholds at all locations and with both genders ($p<0.001$, Wilcoxon).

Within older males, when using the 2.8-cm diameter stimulus, hot thresholds were lower at the thenar eminence than at the finger and the forearm ($p \leq 0.001$, Wilcoxon), and lower at

Table 4 Median (IQR) vibrotactile thresholds

Age (years)	Gender	31.5 Hz (ms^{-2} r.m.s.)	125 Hz (ms^{-2} r.m.s.)
20-30	Female	0.114 (0.062)	0.232 (0.362)
	Male	0.122 (0.09)	0.229 (0.69)
55-65	Female	0.123 (0.11)	0.288 (0.36)
	Male	0.144 (0.05)	0.229 (0.31)

the forearm than at the finger (*p*=0.002), and cold thresholds were lower at the finger than at the thenar eminence and the forearm (*p*≤0.021). When using the 1.0-cm diameter stimulus, hot thresholds were lower at the thenar eminence than at the finger (*p*=0.03) and cold thresholds were lower at the finger than at the thenar eminence and the forearm (*p*≤0.04). There were no correlations between room temperature and the threshold at any location. There was a significant correlation between skin temperatures and cold thresholds at forearm when using the 2.8-cm diameter stimulus (*p*=0.026, Spearman).

Within older females, when using the 2.8-cm diameter stimulus, hot thresholds were lower at the thenar eminence than at the finger and the forearm (*p*≤0.05, Wilcoxon), and lower at the forearm than at the finger (*p*=0.001), and cold thresholds were lower at the finger than at the thenar eminence and the forearm (*p*≤0.015). When using the 1.0-cm diameter stimulus, hot thresholds were lower at the thenar eminence than at the finger (*p*=0.003), but there were no differences in cold thresholds at any other locations. In the older females there were no correlations between either room temperature or skin temperature and thermotactile threshold at any location.

Comparison between younger and older subjects

When using the 2.8-cm diameter stimulus, there were no statistically significant differences in thermotactile thresholds at any location between the younger and older males or between the younger and older females. When using the 1.0-cm diameter stimulus, there were no age differences between the younger and older males but hot thresholds were higher and cold thresholds were lower at the finger and the forearm for the older females.

Table 5 Predicted thermotactile thresholds for ‘possible disorder’ (mean plus one standard deviation for hot thresholds or mean minus one standard deviation for cold thresholds) and ‘probable disorder’ (mean plus two standard deviations for hot thresholds or mean minus two standard deviation for cold thresholds) for the four groups of 20 subjects and the combined group of 80 subjects.

Criterion	Age (years)	Gender	Predicted values of thermotactile thresholds (°C)	
			Hot	Cold
‘Possible disorder’ (mean – 1 SD)	20-30	Female	37.9	27.6
		Male	41.0	24.9
	55-65	Female	41.1	24.5
		Male	42.0	24.5
		Overall	40.7	25.2
‘Probable disorder’ (mean – 2 SD)	20-30	Female	39.6	26.1
		Male	44.0	22.6
	55-65	Female	44.3	21.1
		Male	44.9	21.6
		Overall	43.6	22.6

Vibrotactile thresholds

Younger subjects

There were no statistically significant differences in vibrotactile thresholds between the younger males and females. There was a significant correlation between vibrotactile thresholds at 31.5 Hz and vibrotactile thresholds at 125 Hz within males (*p*<0.001, Spearman). There were no significant correlations between either room temperature or skin temperature and either of the two vibrotactile thresholds.

Older subjects

There were no statistically significant differences in vibrotactile thresholds between older males and females. There were correlations between vibrotactile thresholds at 31.5 Hz and vibrotactile thresholds at 125 Hz within males (*p*<0.001, Spearman) and within females (*p*=0.011). There were no significant correlations between either room temperature or skin temperature and either of the two vibrotactile thresholds.

Comparison between younger and older subjects

There were no significant differences in vibrotactile thresholds between the younger and older males or between the younger and older females.

Discussion

There were gender differences only in thermotactile thresholds in younger subjects, where females were more sensitive, having lower hot thresholds and higher cold thresholds. There were also no statistically significant age differences in thermotactile thresholds.

There were no age or gender differences in vibrotactile thresholds at 31.5 Hz and 125 Hz. This differs from many, although not all, other studies and the common assumption that

Table 6 Predicted values of vibrotactile thresholds for 'possible disorder' (mean plus one standard deviation) and 'probable disorder' (mean plus two standard deviations) for the four groups of 20 subjects and the combined group of 80 subjects.

Criterion	Age (years)	Gender	Predicted values of vibrotactile thresholds (ms^{-2} r.m.s.)	
			31.5 Hz	125 Hz
'Possible disorder' (mean – 1 SD)	20-30	Female	0.20	0.51
		Male	0.35	0.95
	55-65	Female	0.22	0.68
		Male	0.19	0.59
		Overall	0.24	0.68
'Probable disorder' (mean – 2 SD)	20-30	Female	0.33	1.06
		Male	0.79	3.25
	55-65	Female	0.39	1.48
		Male	0.26	1.04
		Overall	0.43	1.60

vibrotactile thresholds increase with increasing age, especially for thresholds at 125 Hz which reflect the function of the Pacinian channel. The absence of significant effects of age in the present study may be due to the use of subjects in which there were no known disorders and an upper age limit of 65 years.

When diagnosing the hand-arm vibration syndrome in the UK, the criteria for abnormality is currently categorised in two categories: a 'possible disorder' and 'probable disorder'. These categories correspond to the mean threshold plus (or minus) one standard deviation and the mean threshold plus (or minus) two standard deviations, as determined by Lindsell and Griffin (1998). These correspond to values exceeded by 18% and 2.5%, respectively, of a population of healthy persons. For thermotactile thresholds, a 'possible disorder' is assumed for hot thresholds greater than 45°C and cold thresholds less than 22°C; a 'probable disorder' is assumed for hot thresholds greater than 48.5°C and cold thresholds less than 19°C. For vibrotactile thresholds, a 'possible disorder' is assumed for 31.5 Hz thresholds greater than 0.3 ms^{-2} r.m.s. and 125 Hz thresholds greater than 0.7 ms^{-2} r.m.s.; a 'probable disorder' is assumed for 31.5 Hz thresholds greater than 0.4 ms^{-2} r.m.s. and 125 Hz thresholds greater than 1.0 ms^{-2} r.m.s. Tables 5 and 6 show the means plus (or minus) one and two standard deviations for the thermotactile and vibrotactile thresholds of subjects in the current study. For the vibrotactile thresholds, the means and standard deviations were calculated after logarithmic transformation to obtain Gaussian distributions – transformation was not required for the thermal thresholds.

The hot and cold thresholds corresponding to 'possible disorder' and 'probable disorder' in each subject group, and for all 80 subjects, were within range of values determined by Lindsell and Griffin (1998). This indicates that less than 18% and less than 2.5% of healthy persons will exceed the currently used thermal thresholds corresponding, respectively, to possible and probable disorders. The predicted 31.5 Hz and 125 Hz vibrotactile are also within range of the range of values determined by Lindsell and Griffin (1998), with the exception of the younger males where three men had thresholds outside the criterion for 'probable disorder' at both 31.5 and 125 Hz, compared to about one in forty (2.5%) for a normal distribution. Apart from their unusual thresholds, there were no reasons to exclude these subjects, so it is assumed they either occurred by chance or were due to undetected disorder. The high thresholds of these three young males affected the overall results as well resulting in higher predicted thresholds at 125 Hz. The same three subjects gave thermal thresholds that fell within the range of normal values (i.e. within the mean plus one standard deviation).

The absence of clear effects of age indicates that other factors had a greater influence on thresholds than age. The influence of other subject charcteristics (including general health, ethnicity, use of alcohol, smoking and profession) on thermal and vibrotactile thresholds merit more attention.

Conclusions

Similar distributions of normal values can be assumed for the vibrotactile thresholds of healthy males and healthy females. However, for thermotactile thresholds young healthy females are more sensitive heat and than young males.

In healthy persons aged between 20 and 65 years, the present results suggest that an age correction may not be needed when identifying whether thermal thresholds or vibrotactile thresholds are abnormal.

The size of the contact area has a systematic effect on thermotactile thresholds and should be controlled.

Acknowledgements

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References

Bartlett G, Stewart JD, Tamblyn R and Abrahamowicz M (1998) Normal distributions of thermal and vibration sensory thresholds. Muscle and Nerve, 21(3), 367-374.

Doeland HJ, Nauta JJP, Zandbergen JB van, Eerden HAM van der, Diemen NGJ van, Bertelsmann FW, Heimans JJ (1989) The relationship of cold and warmth cutaneous sensation to age and gender. Muscle and Nerve, 12, 712-715

Ekenvall L, Nilsson BY and Gustavsson P (1986) Temperature and vibration thresholds in vibration syndrome. British Journal of Medicine, 43 (12), 825-829

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

Hilz MJ, Axelrod FB, Hermann K, Haertl U, Duetsch M and Neundörfer B (1998) Normative values of vibratory perception in 530 children, juveniles and adults aged 3-79 years. Journal of Neurological Sciences, 159 (2), 219-225

Lindsell CJ, Griffin MJ (2002) Normative data for vascular and neurological tests of the hand-arm vibration syndrome. International Archives of Occupational and Environmental Health, 75, (1-2), 43-54

Lindsell CJ, Griffin MJ Standardised diagnostic methods for assessing components of the hand-arm vibration syndrome. HSE Books, 1998, CRR197/1998, ISBN 0 7176 1640 1.

Liou,J-T , Lui P-W, Lo Y-L, Liou L, Wang S-S, Yuan H-B, Chan K-C and Lee T-Y (1999) Normative data of quantitative thermal and vibratory thresholds in normal subjects in Taiwan: gender and age effect. Chinese Medical Journal, 62 (7), 431-437

Wild P, Massin N, Lasfargues G, Baudin V, Unlu D and Donati P (2001) Vibrotactile perception thresholds in four non-exposed populations of working age. Journal of Ergonomics, 44 (6), 649-657

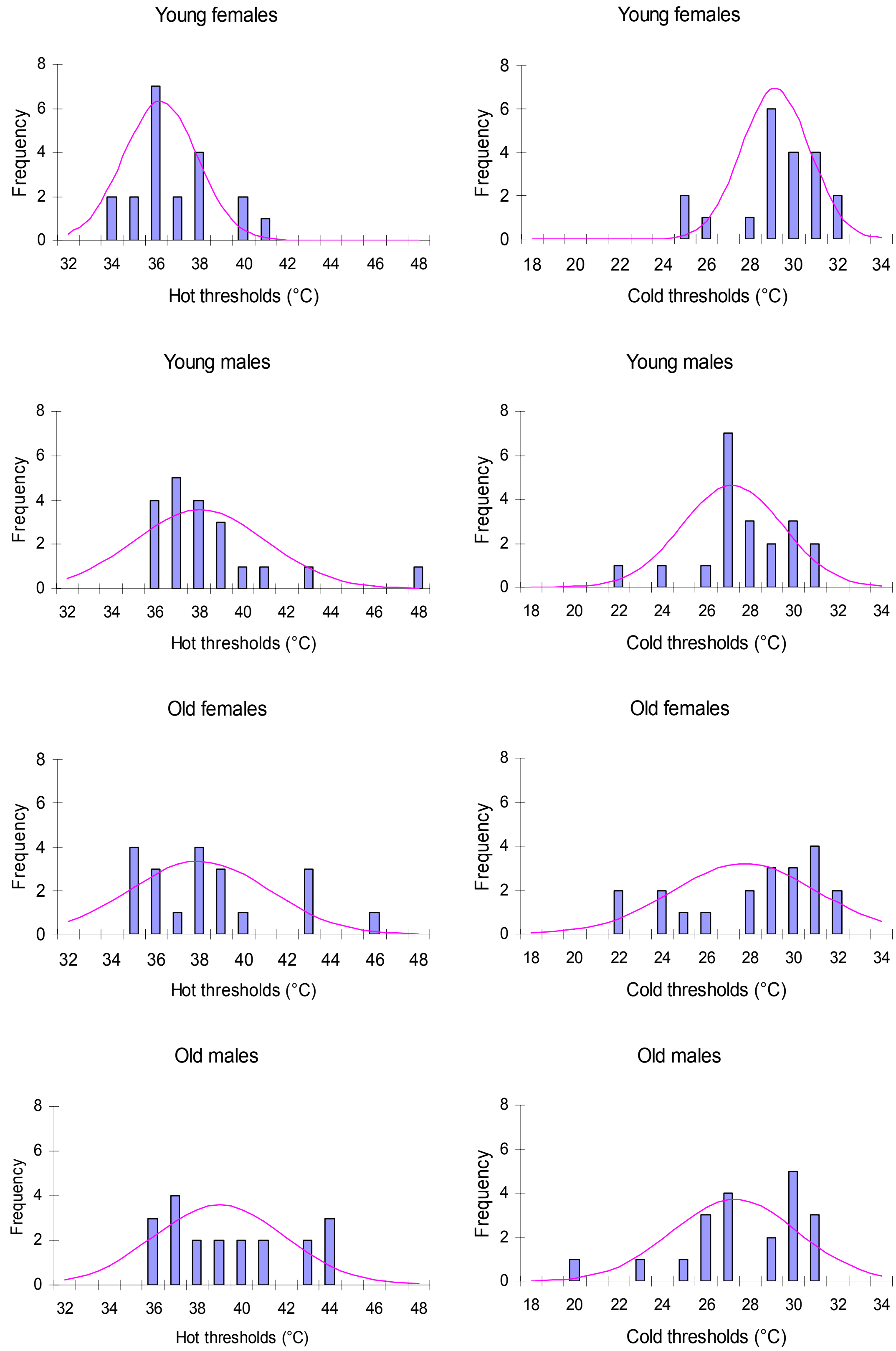

Figure 1 Distributions of hot and cold thresholds at the finger with fitted normal distributions.

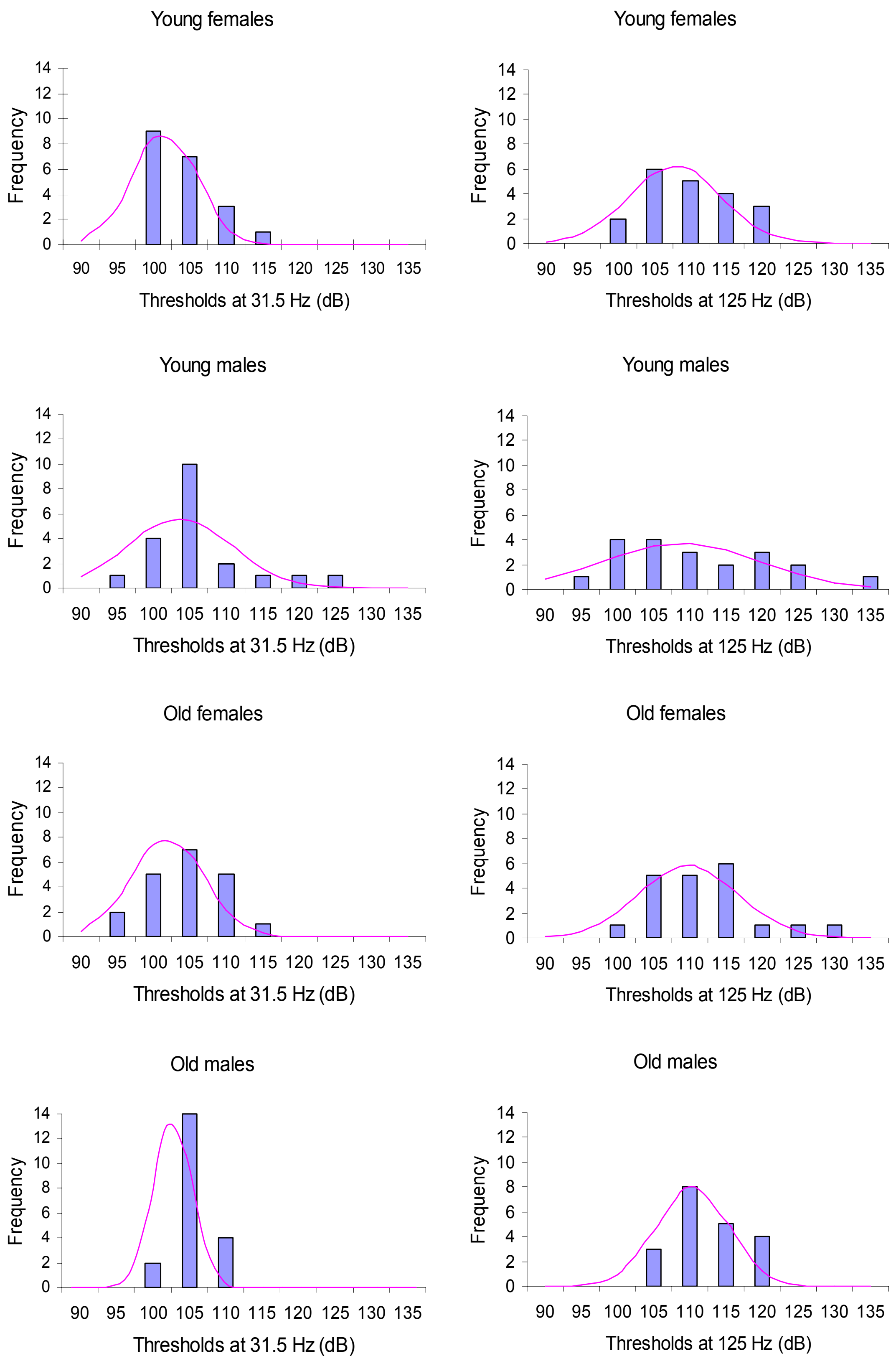

Figure 2 Distributions of vibrotactile thresholds at 31.5 Hz and 125 Hz at the finger with fitted normal distributions.