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Quantitative estimation of aesthesiometric thresholds for assessing impaired tactile sensation in workers exposed to vibration

Massimo Bovenzi[1] **and Antonella Zadini**[2]

[1]Institute of Occupational Health, University of Trieste, Centro Tumori, I-34129 Trieste, Italy
[2]Rehabilitation Center, National Health Service, Ospedale Maggiore, I-34129 Trieste, Italy

Summary. To evaluate the usefulness of aesthesiometric threshold testing in the quantitative assessment of peripheral sensorineural disorders occurring in the hand-arm vibration syndrome, two point discrimination (TPD) and depth sense perception (DSP) thresholds were measured by means of two aesthesiometers in the fingertips of 65 forestry workers exposed to chain saw vibration and 91 healthy males unexposed to local vibration or neurotoxic chemicals. Among the healthy subjects, divided into three age groups, there was no difference in the mean values of TPD and DSP thresholds. Assuming 1.28 or 2 standard deviations above the mean to be the upper limits of normality, in the present study the threshold values for TPD were 2.5 and 3.13 mm, respectively. Using the same assumptions, the normal threshold values for DSP were 0.36 and 0.49 mm. Among the 65 chain saw operators the prevalence of peripheral sensory disturbances was 70.8%. On the basis of the aesthesiometric results obtained for the group of 46 chain sawyers affected with sensorineural symptoms and a control group of 46 manual workers, the specificity of the aesthesiometric testing method was found to range between 93.4 and 100%, while the sensitivity varied from 52.2 to 71.7%. In its predictive value aesthesiometry had a positive accuracy of 84.6–96.0% and a negative accuracy of 42.8–50.0%. Aesthesiometric testing was able to differentiate between normals and vibration workers with sensory disturbances on a group basis ($P < 0.001$), but due to the high rate of false negatives among vibration exposed patients, it was unsuitable to confirm objectively sensorineural symptoms on an individual basis. We conclude that aesthesiometry may be used in field surveys for epidemiological purposes to assess peripheral sensory disorders in exposed groups at risk.

Key words: Aesthesiometry – Healthy subjects – Tactile function – Vibration exposure

Offprint requests to: M. Bovenzi

Introduction

Sensorineural disturbances, such as tingling and numbness in the fingers and hands, have been frequently reported by workers exposed to hand-arm vibration [2, 3, 11]. Symptoms and signs of sensory impairment as early manifestations of peripheral neuropathy may also occur in manual workers affected with nerve trunk entrapments (e.g. carpal tunnel syndrome) or in operators exposed to neurotoxic organic substances (e.g. n-exane) [1]. At present, only a few objective tests are available to assess quantitatively sensorineural function in worker groups exposed to physical or chemical agents involving the peripheral nervous systems. In some studies of the hand-arm vibration (HAV) syndrome, aesthesiometry (two point discrimination and depth sense perception) has been used to examine fingertip sensation in workers operating vibrating tools [5–9]. The results of these studies suggest that tactile dicrimination and sensory perception are reduced in the advanced stages of vibration induced neuropathy. These findings have been ascribed to the adverse effect of segmental vibration on the integrity or functional capacity of skin mechanoreceptors of slowly adapting (SA I) and, probably, fast adapting (FA I) types [2]. In order to evaluate the severity of the sensorineural component of the HAV syndrome, it is essential to quantify tactile sensation in vibration exposed patients by measuring aesthesiometric thresholds and comparing the observed threshold values with those from controls. Owing to differences in instrument design and testing procedures used by various researchers, the upper normal limits of aesthesiometric thresholds for healthy individuals vary widely. Hence, comparable data on tactile function of normal populations are needed. For this purpose, the present paper reports the results of depth sense and two point discrimination measurements performed on a large sample of healthy male subjects of working age by using the same apparatus and methodology employed by Carlson et al. [4, 5]. The reproducibility of the aesthesiometric measures was also tested. A further aim of this study was to assess the efficiency and accuracy of the aesthesiometric method to detect sensory afferent involvement in a group of forestry workers exposed to chain saw vibration.

Subjects and methods

One hundred male subjects of working age (mean age 39.3 years, age range 20–60 years), unexposed to local vibration or neurotoxic chemicals, were examined. Seventy were manual workers and thirty were white collar workers. No subjects had metabolic, neurological or circulatory abnormalities. Nine manual workers were excluded from testing because of finger traumas or fingertip calluses. The final sample, consisting of 91 healthy individuals, was divided into three groups according to age: 20–35 years ($n = 33$, mean age 28.7 years), 36–45 years ($n = 33$, mean age 40.3 years), 46–60 years ($n = 25$, mean age 52.0 years). Smoking and drinking habits were similar in the age groups ($P > 0.5$). An overall population of 65 forestry workers exposed to chain saw vibration was also investigated. Nineteen chain sawyers (29.2%) had no symptoms in the upper limbs and 46 (70.8%) suffered from sensorineural disturbances in the fingers and hands, such as tingling and/or numbness. Of these latter, 19 (41.3%) were also affected with vibration induced white finger (VWF).

Aesthesiometric threshold testing was performed in a laboratory room with an ambient temperature of 22–24°C. We used depth sense and two point discrimination aesthesiometers as designed by Carlson et al. [4]. These instruments are an improved design of Renfrew's original aesthesiometers [10]. A complete description of the instrumentation is reported in the paper by Carlson et al. [4]. Briefly, the depth sense aesthesiometer has a surface containing a step of varying height which slopes at a rate of 0.1 mm/cm horizontal distance. The total horizontal sensory length is 15 cm (tactile perception range 0–1.5 mm). The two point discrimination aesthesiometer has a surface containing a 5-mm deep double edged groove spreading at a rate of 0.4 mm/cm for 15 cm longitudinal length (tactile discrimination range 0–6.0 mm). Graduations in centimeters are engraved on the side of each aesthesiometer. A tunnel-shaped instrument, as devised by the NIOSH team [4], was also employed to maintain a constant finger pressure and position on the aesthesiometers (Fig. 1). The apparatus has been described in more detail elsewhere [4]. The testing procedure was explained individually to each subject and after trial runs three measurements of both two point discrimination (TPD) and depth sense perception (DSP) were performed by moving the aesthesiometers away from the finger of the subject. During testing, the subject was invited to look to one side. When the subject indicated verbally that he perceived a fingertip sensation of gap width or step height, the examiner read TPD or DSP threshold values on the graduated scales. In 63 healthy men aesthesiometric measurements were obtained for each fingertip of each hand, while in the remaining 28 normals and in the vibration-exposed forestry workers the index, middle and ring fingers of both hands were tested. In all subjects, fingertip skin temperatures (FSTs) were measured by means of copper-constantan termocouples (Ellab A-E5) and testing procedure was initiated only when FSTs were at least 28°C. As vibration exposure may induce a temporary sensory threshold shift, forestry workers were tested at least 16 h after cessation of exposure to chain saw vibration.

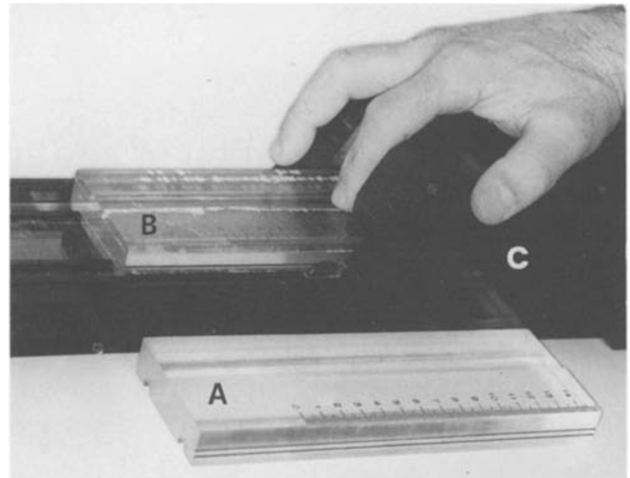

Fig. 1. Depth sense aesthesiometer *(A)*, two point discrimination aesthesiometer *(B)* and tunnel shaped device to maintain constant finger pressure and position *(C)*

Statistical analysis of data was performed by the Statistical Package for the Social Sciences (SPSS). Descriptive statistics showed that TPD thresholds were normally distributed, while DSP data were skewed. Normalization of DSP values was obtained by square root transformation. Student's *t*-test was used to compare two means. Differences among group means were tested by one-way analysis of variance and a multiple comparison test. Linear associations between two variables were assessed by bivariate correlation.

To evaluate the reproducibility of aesthesiometric testing, TPD and DSP measurements were repeated on five consecutive days in five healthy individuals and the coefficients of variation for the measurements of aesthesiometric thresholds were determined. Repeated measures analysis of variance was also performed. A significance level of 0.05 (two-sided) was chosen. The sensitivity, specificity and predictive values of TPD and DSP measures, were used as indices of the diagnostic accuracy of the aesthesiometric method.

Results

Aesthesiometric thresholds measured on each fingertip of each hand for the normal subjects are reported in Tables 1 and 2. Analysis of variance pointed out that among the age groups no differences in the mean values of TPD and DSP thresholds could be demonstrated for all the fingers of both hands. A similar result was also observed for the composite means of aesthesiometric threshold values for the 2nd, 3rd and 4th fingers (Table 3). No differences were found between the right and left hands. In the entire population, significant correlations were discovered between TPD and DSP values for both the right hand ($r = 0.74$, $P < 0.001$) and the left one ($r = 0.65$, $P < 0.001$). In all subjects, and within each age group, no relationships were found between alcohol and tobacco consumptions and aesthesiometric thresholds ($P > 0.1$)

Table 1. Two point discrimination threshold values (mm) measured on the fingertips of the right (R) and left (L) hands of healthy male subjects divided into different age groups. Data represent means (SD)

Age groups (years)	n	Two point discrimination thresholds (mm)									
		Thumb		Index		Middle		Ring		Little	
		R	L	R	L	R	L	R	L	R	L
20–35	33	1.58	1.76	1.30	1.19	1.21	1.18	1.21	1.22	1.55	1.47
		(0.64)	(0.64)	(0.81)	(0.72)	(0.76)	(0.72)	(0.78)	(0.78)	(0.75)	(0.59)
		(n = 27)								(n = 27)	
36–45	33	1.91	1.98	1.56	1.52	1.72	1.35	1.65	1.47	1.72	1.77
		(0.59)	(0.50)	(0.90)	(0.95)	(1.02)	(0.89)	(0.93)	(0.89)	(0.64)	(0.54)
		(n = 23)								(n = 23)	
46–60	25	1.94	2.05	1.52	1.50	1.51	1.51	1.45	1.52	1.55	1.67
		(0.63)	(0.71)	(1.08)	(1.16)	(1.10)	(1.12)	(0.94)	(1.06)	(0.55)	(0.60)
		(n = 13)								(n = 13)	
20–60	91	1.77	1.90	1.45	1.40	1.47	1.34	1.43	1.39	1.61	1.62
		(0.63)	(0.61)	(0.92)	(0.94)	(0.97)	(0.90)	(0.89)	(0.88)	(0.66)	(0.58)
		(n = 63)								(n = 63)	

Table 2. Depth sense perception threshold values (mm) measured on the fingertips of the right (R) and left (L) hands of healthy male subjects divided into different age groups. Data represent means (SD)

Age groups (years)	n	Depth sense perception thresholds (mm)									
		Thumb		Index		Middle		Ring		Little	
		R	L	R	L	R	L	R	L	R	L
20–35	33	0.15	0.18	0.12	0.12	0.12	0.13	0.17	0.16	0.18	0.16
		(0.17)	(0.18)	(0.12)	(0.12)	(0.11)	(0.12)	(0.15)	(0.13)	(0.14)	(0.12)
		(n = 27)								(n = 27)	
36–45	33	0.16	0.17	0.17	0.18	0.17	0.16	0.22	0.20	0.20	0.18
		(0.15)	(0.11)	(0.18)	(0.15)	(0.15)	(0.15)	(0.24)	(0.18)	(0.12)	(0.12)
		(n = 23)								(n = 23)	
46–60	25	0.22	0.21	0.16	0.19	0.19	0.18	0.20	0.18	0.21	0.22
		(0.16)	(0.13)	(0.18)	(0.21)	(0.22)	(0.20)	(0.22)	(0.20)	(0.17)	(0.15)
		(n = 13)								(n = 13)	
20–60	91	0.17	0.18	0.15	0.16	0.16	0.16	0.19	0.18	0.19	0.18
		(0.16)	(0.15)	(0.16)	(0.16)	(0.15)	(0.15)	(0.21)	(0.17)	(0.14)	(0.13)
		(n = 63)								(n = 63)	

Among the five healthy men investigated with repeated aesthesiometric measures, a learning effect was noted for all but one subject. Nevertheless, no significant variability between tests performed on five consecutive days was observed for either TPD or DSP thresholds. The reproducibility of aesthesiometric testing was considered to be satisfactory as the mean values of the coefficients of variation for repeated determinations of two point discrimination and depth sense perception ranged from 5.2 to 8.0% (Table 4). However, DSP thresholds showed greater variation (range 5.0–11.4%) than TPD thresholds (range 2.3–7.8%).

Table 5 reports the results of aesthesiometric testing for 46 vibration exposed forestry workers affected with peripheral sensorineural disturbances and for 46 control manual workers comparable in age and drinking and smoking habits. The composite means of TPD and DSP threshold values for digits 2, 3 and 4 of the right and left hands were found to be significantly greater in the chain sawyers than in the controls ($P < 0.001$). Among the vibration exposed workers, aesthesiometric threshold means were lower in the individuals without symptoms than in those reporting tingling and/or numbness ($P < 0.001$), while no differences were observed between subjects with sensory disturbances alone ($n = 27$) and those with combined neurological and VWF symptoms ($n = 19$). The asymptomatic chain sawyers were not significantly different from the controls.

Table 3. Composite means (SD) of two point discrimination (TPD) and depth sense perception (DSP) threshold values for the index, middle and ring fingers of the right and left hands of healthy male subjects divided into different age groups

Age groups (years)	*n*	TPD (mm)			DSP (mm)		
		2nd, 3rd, 4th fingers			2nd, 3rd, 4th fingers		
		Right hand	Left hand	Both hands	Right hand	Left hand	Both hands
20–35	33	1.24 (0.77)	1.20 (0.69)	1.22 (0.72)	0.14 (0.11)	0.14 (0.12)	0.14 (0.11)
36–45	33	1.64 (0.90)	1.45 (0.88)	1.54 (0.87)	0.19 (0.18)	0.19 (0.14)	0.19 (0.15)
46–60	25	1.49 (0.99)	1.51 (1.09)	1.50 (1.00)	0.19 (0.19)	0.19 (0.19)	0.19 (0.19)
20–60	91	1.45 (0.89)	1.37 (0.89)	1.41 (0.86)	0.17 (0.16)	0.17 (0.15)	0.17 (0.14)

Table 4. Coefficients of variation of two point discrimination (TPD) and depth sense perception (DSP) thresholds measured on five consecutive days in five healthy subjects. For each individual, the composite means of TPD and DSP values (mm) for all fingers of the right and left hands were calculated. Data represent means ($\bar{x}$), standard deviations (SD) and ranges

Aesthesiometric parameters		Coefficients of variation (%)		
		$\bar{x}$	SD	Range
TPD	Right hand	5.8	2.6	3.0– 8.7
	Left hand	6.3	2.1	3.8– 8.7
	Both hands	5.2	2.3	2.3– 7.8
DSP	Right hand	8.0	2.6	5.1–11.3
	Left hand	6.9	1.5	5.2– 9.2
	Both hands	6.9	2.5	5.0–11.4

Table 6 displays data on the accuracy of aesthesiometric threshold testing to detect sensorineural disorders in the hand-arm vibration syndrome. Upper limits of normality for TPD and DSP thresholds were calculated as mean plus 1.28 or 2 standard deviations on the basis of the aesthesiometric results obtained from the above described population of 91 healthy men. Assuming the two different upper normal limits as diagnostic criteria to discriminate between healthy individuals and patients with sensorineural impairment, the specificity of the aesthesiometric method varied from 93.4 to 100% for the controls and from 68.4 to 94.7% for the asymptomatic chain sawyers. The sensitivity of aesthesiometric testing (i.e. positive results with disease) ranged from between 52.2 and 71.7%. To detect vibration induced sensory disorders among the forestry workers, the aesthesiometric method had a positive predictive value varying from 84.6 and 96.0% and a negative predictive value ranging between 42.8 and 50.0%.

Table 5. Composite means (SD) of two point discrimination (TPD) and depth sense perception (DSP) threshold values for the index, middle and ring fingers of the right and left hands of a control group of manual workers and a group of vibration exposed chain sawyers affected with peripheral sensorineural disturbances

			Control workers ($n = 46$)	Vibration exposed chain sawyers with sensorineural symptoms ($n = 46$)
TPD	(2nd, 3rd, 4th fingers):			
	Right hand	(mm)	1.61 (0.54)	2.87 (1.76)*
	Left hand	(mm)	1.49 (0.67)	2.96 (1.82)*
	Both hands	(mm)	1.55 (0.55)	2.91 (1.78)*
DSP	(2nd, 3rd, 4th fingers):			
	Right hand	(mm)	0.19 (0.11)	0.53 (0.53)*
	Left hand	(mm)	0.18 (0.12)	0.49 (0.51)*
	Both hands	(mm)	0.19 (0.11)	0.52 (0.51)*

Student's *t*-test, * $P < 0.001$

Discussion

The findings of this study indicate that among healthy males in the range of 20–60 years old, tactile function is not significantly influenced by age, even though young people (20–35 years) showed lower aesthesiometric threshold values than older individuals (36–60 years). Furthermore, in our subjects alcohol and tobacco consumptions do not seem to be related to tactile sensation. The upper normal limits for TPD thresholds derived from the present study are consistent with those reported by other investigators. Assuming a plus one standard deviation as the upper limit of normality, Carlson et al. [4, 5] quoted TPD threshold values of 2.4 and 2.84 mm in a group of 56 manual workers and in ten male students, respectively. Using different instrument design and methodology, Renfrew [10] suggested an upper normal limit of 3.0 mm for TPD. Threshold values for our subjects were 2.5 mm (mean + 1.28 SD) and 3.13 mm (mean + 2 SD).

Depth sense perception data from published studies show differences in the upper limits of normality. Some authors [9, 10] have suggested a normal sensitivity threshold of 0.25 mm for DSP. Studying two groups of male controls, Carlson et al. [4, 5] reported DSP thresholds ranging from 0.43 to 0.47 mm (mean + 1 SD). In the present study, the normal threshold values for DSP were 0.36 mm (mean + 1.28 SD) and 0.49 mm (mean + 2 SD). The upper limit of normality (mean plus two standard deviations) reported by Brammer et al. [2] for 248 manual workers not ex-

Table 6. Specificity, sensitivity, positive and negative predictive values of aesthesiometric threshold testing to detect peripheral sensorineural (SN) impairment in the hand-arm vibration syndrome. TPD is two point discrimination and DSP is depth sense perception. Upper normal limits for aesthesiometric thresholds are derived from a control group of 91 healthy male subjects (age range 20–60 years)

Diagnostic criteria			Control workers (n = 46)	Chain sawyers		Specificity		Sensitivity (%)	Predictive values	
				No symptoms (n = 19)	SN symptoms (n = 46)	Control workers (%)	Asymptomatic chain sawyers (%)		Positive (%)	Negative (%)
TPD (mm)	> 2.50[a]	Positive	3	4	26	93.4	78.9	56.5	86.7	42.8
		Negative	43	15	20					
	> 3.13[b]	Positive	0	1	24	100	94.7	52.2	96.0	45.0
		Negative	46	18	22					
DSP (mm)	> 0.36[a]	Positive	3	6	33	93.4	68.4	71.7	84.6	50.0
		Negative	43	13	13					
	> 0.49[b]	Positive	0	4	31	100	78.9	67.4	88.5	50.0
		Negative	46	15	15					

Upper normal limits: [a] (mean + 1.28 SD)
[b] (mean + 2 SD)

posed to vibration was similar in magnitude to that found in this study.

The present investigation indicates that among the control workers the specificity of aesthesiometric threshold testing was high, varying from 93.4 to 100% according to the diagnostic criteria used. Among the exposed "controls" (i.e. asymptomatic chain sawyers), false positive results occurred in 5.3 to 31.6% of the subjects examined. This finding may be due to vibration induced subclinical damage to skin mechanoreceptors and/or their associated nerve fibers. The sensitivity of the aesthesiometric method was found to be lower than the specificity and this is in agreement with the findings of other studies [7]. The sensitivity of depth sense threshold testing (67.4–71.7%), however, was higher than that of two point discrimination (52.2–56.5%) and this is also consistent with the opinion of most authors [7].

Our data pointed out that vibration exposed forestry workers suffering from paraesthesias showed, on the average, a significant loss in fingertip sense perception when compared with control manual workers. Nevertheless, aesthesiometric results revealed that in the chain sawyer group the rate of false negatives was high, so that in its predictive value aesthesiometric testing had a negative accuracy of only 0.4–0.5. It follows that aesthesiometry may be considered a useful testing method to differentiate between healthy controls and vibration exposed patients on a group basis, but it is unsuitable to confirm objectively sensorineural symptoms on an individual basis. We conclude that aesthesiometry may be used in field surveys for epidemiological purposes to assess peripheral sensory disorders in exposed groups at risk.

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