Vibrotactile Perception Thresholds: The Tactile Equivalent Of Audiometry

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1. INTRODUCTION

Grasping, holding and controlling an object in the hands is part of everyday experience at work, at home and in many leisure activities. These functions together with tactile exploration of surface features and textures by the fingers are critically dependent on the sensory input, which is mediated by populations of mechanoreceptors. Disturbances in sensory acuity, such as occurs in some peripheral neuropathies, from repeated flexing of the wrist, or from use of vibrating hand-held tools, can influence hand function.

For over a century, the perception of vibration has been employed as a test of sensory function. As methods of stimulation and test procedures have become more refined, it has become apparent that the vibrotactile perception threshold (VPT) depends on details of the measurement procedure.(Maeda et al.) The lack of broadly accepted methods for determining VPTs, together with a lack of appreciation of the need to establish the acuity of specific mechanoreceptor populations, appears to have impeded acceptance in clinical medicine of this modality for quantitative sensory testing.

Efforts to rectify this situation have been underway for several years, principally within the International Organization for Standardization (ISO), building on research conducted at several laboratories including those of the National Research Council. The purpose of this paper is to summarize the information that has led to international acceptance of two, closely-related methods of measurement together with normative threshold values that may be used to identify changes from the VPTs of healthy persons. It is to be expected that the publication of standards for the measurement and assessment of VPTs will rekindle interest in, and the development of, products designed to be used in an analogous manner to audiometric instruments for determining hearing thresholds.

2. MECHANORECEPTOR PROPERTIES

The tactile performance of the hand is known to depend on neural activity in four populations of specialized nerve endings, which are commonly described by their response to mechanical indentation of the skin surface, namely: SAI - slowly adapting, type 1; SAII - slowly adapting, type 2; FAI - fast adapting, type 1, and; FAII - fast adapting, type 2.(Johansson et al., 1983) The acuity of SAI receptors is primarily responsible for the resolution of the spatial features of a surface, such as ridges or edges, while the acuity of FAI and FAII receptors is primarily responsible for distinguishing surface texture, such as silk from sandpaper, and for detecting the motion of objects in contact with the skin. The SAII receptors signal skin stretch. It is also known that the process of holding an object in the hand is controlled by the detection of micro-slips by the FAI and FAII receptors.(Srinivasan et al.)

This information has been derived from neural action potentials produced by single tactile units in response to externally applied skin displacements. When sinusoidal displacements of different magnitudes and frequencies are applied to single units of the four mechanoreceptor populations in the fingertips, the frequency ranges of maximum neural activity may be established.(Johansson et al., 1982) It is possible from the results of these experiments to define contours expressing the same rate of neuronal discharge per stimulus cycle, which have been shown in animal studies to characterize the physiological response. If the onset of a given rate of neuronal activity is combined with knowledge of the innervation density of different mechanoreceptor populations, an estimate for the threshold of the perceived response to a stimulus at the fingertip may be obtained. Contours of physiologically-based "perception" thresholds so derived are shown in Fig. 1 as a function of frequency, by solid lines of different width for the SAI, FAI, and FAII receptors. The neuronal thresholds have been constructed from the data of Johannson et al. (1982) by defining contours corresponding to one action potential per two stimulus cycles, and have been adjusted for the relative numbers of receptive units per unit skin area at the fingertip.(see Johansson et al., 1983) Note that each mechanoreceptor population responds to less stimulus than the other populations in certain contiguous, but different, frequency ranges. Appropriate stimulation at specific frequencies should thus result in vibrotactile perception being mediated by a *single* mechanoreceptor population, namely that requiring least stimulus.

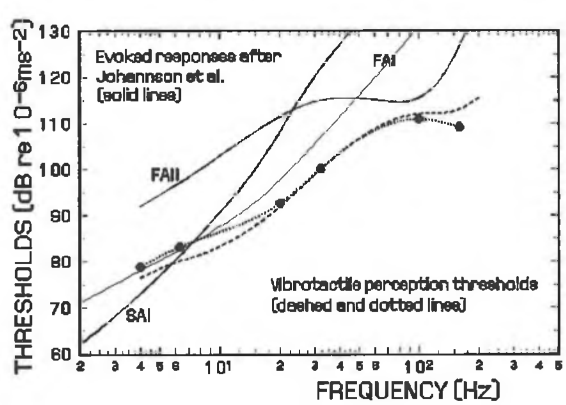

Figure1: Evoked responses and VPTs in healthy subjects

3. DETERMINATION OF VPTs

There have been two studies that attempt to mimic the essential characteristics of the stimulation conditions employed for the physiological experiments described in the previous section, in order to determine psychophysically the VPTs mediated by individual receptor populations. The thresholds obtained at the fingertips of healthy persons are shown by the dashed and the dotted lines in Fig. 1 (Löfvenberg et al., and Brammer et al., respectively).

From these studies, of the parameters most influencing the VPT at the fingertip, the indentation of the skin surface by the stimulating probe or, equivalently, the static force with which the probe contacts the skin, would appear to be the most important. Also, support is required for the forearm and hand to reduce motion between the subject and stimulator caused by environmental vibration or natural physiological processes, such as hand tremor, blood pulsation and breathing.(Piercy et al.) In addition, the rate of stimulus magnitude change within the psychophysical algorithm needs to be restricted to avoid forward masking. (Morioka) Of lesser importance is the probe diameter (a 3 mm, and a 6 mm, diameter probe was used in the two psychophysical studies cited) and the presence, or absence, of a surround, i.e., a static annular plate around the probe to support the fingertip being stimulated.(Verrillo et al.)

The essential requirements are specified in a recent international standard, ISO 13091-1 (2001), where contact conditions are provided for determining VPTs at the fingertips either with, or without, a surround.

4. DISCUSSION AND CONCLUSIONS

The extent to which the provisions of the international standard unify the VPTs recorded using alternate measurement methods may be inferred from an examination of the thresholds for healthy persons obtained in studies employing apparatus and procedures complying with, or almost complying with, its requirements. There have been four studies conducted with a surround, and two without a surround, that may be included in such an analysis (see Table 1). The mean VPTs reported at frequencies common to most studies can be seen from the Table to be similar in magnitude. Indeed, the variability in mean VPTs obtained using nominally the same method (involving a 6 mm probe and 10 mm surround) appears to be as great as the differences in thresholds between the different methods (identified in column 1). Moreover, this similarity remains, and the agreement between studies is improved, after adjusting the results to a common age for the subjects and indentation for the stimulating probe, and for differences between the algorithms used to calculate the VPT. A detailed report of this analysis will be published elsewhere.

It would thus appear that when measurements are performed according to the international standard: 1) essentially apparatus independent VPTs can be obtained, and; 2) a single set of normative values may be constructed for males.

5. REFERENCES

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Table 1: Mean values of VPTs for healthy males reported in studies using methods in, or close to those in, ISO 13091-1.

Probe/Surround (mm/mm)	Source	Mean Age (years)	Mean VPT (dB re 10^{-6} ms^{-2}) 16-20 Hz	31.5 Hz	125 Hz
6/10	Bovenzi et al.,1997	30.1	94.4	101.8	106.8
6/10	Lindsell et al., 1999	36		102.9	108.6
6/10	Maeda et al., 1994	28.8	91.6	100.7	103.9
6/10	Wild et al., 1999	30		99.8	107.5
6/no surround	L}fvenberg et al., 1984	~25	92.0	100.0	113.0
3/no surround	Brammer et al., 1993	30	92.7	100.2	110.1