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Research paper

Psychophysical estimate of plantar vibration sensitivity brings additional information to the detection threshold in young and elderly subjects

Yves Jammes [a,*], Julia Guimbaud [b], Rémi Faure [b], Patricia Griffon [b], Jean Paul Weber [b], Bruno Vie [b], Regis Guieu [a]

[a] UMR MD2, Faculty of Medicine, Aix Marseille University, France
[b] School of Podiatry, Marseille, France

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ABSTRACT

Objective: Vibration detection threshold of the foot sole was compared to the psychophysical estimate of vibration in a wide range of amplitudes in young (20–34 years old) and elderly subjects (53–67 years old).

Methods: The vibration detection threshold was determined on the hallux, 5th metatarsal head, and heel at frequencies of 25, 50 and 150 Hz. For vibrations of higher amplitude (reaching 360 μm), the Stevens power function ($\Psi = k * \Phi^n$) allowed to obtain regression equations between the vibration estimate (Ψ) and its physical magnitude (Φ), the n coefficient giving the subjective intensity in vibration perception. We searched for age-related changes in the vibration perception by the foot sole.

Results: In all participants, higher n values were measured at vibration frequencies of 150 Hz and, compared to the young adults the elderly had lower n values measured at this frequency. Only in the young participants, the vibration detection threshold was lowered at 150 Hz.

Conclusion: The psychophysical estimate brings further information than the vibration detection threshold which is less affected by age.

Significance: The clinical interest of psychophysical vibration estimate was assessed in a patient with a unilateral alteration of foot sensitivity.

1. Introduction

An electrophysiological study in humans (Kennedy and Inglis, 2002) reported the presence of both slow (Merkel and Ruffini corpuscles) and fast (Meissner and Pacinian corpuscles) adapting receptors in the foot sole, with far greater numbers of the latter (71% of tested units). These cutaneous mechanoreceptors detect the changes in the application of mechanical loads on the plantar surface during gait and standing. Skin mechanoreceptors can be classified into four groups based on their afferent firing properties [fast adapting (FA) vs. slow adapting (SA)] and receptive field size [type I (small defined boundaries), vs. type II (large undefined boundaries)]. Johansson et al. (1982) found that SAI and SAII skin afferents were activated by low vibration frequencies between 2 and 32 Hz whereas FAI were activated between 8 and 64 Hz and FAII between 64 and 400 Hz. Electrophysiological studies have shown that the cutaneous afferents from the plantar surface project on the somatosensory cortex leading to a perceptual representation (Kandel et al., 2012). There are several studies indicating that plantar cutaneous load receptors contribute to controlling the standing balance and postural reflexes in healthy subjects (Wu and Chiang, 1997; Meyer et al., 2004). Indeed, balance problems are often related to cases where reduced plantar sensitivity occurs.

Examination of the vibration sense is widely used as a clinical examination in neurology and it is usually done at the medial or lateral malleolus. Many studies also measured the vibration detection threshold of the sole in healthy subjects in an attempt to compare normal values to those measured in aged individuals and diabetic patients (Kenshalo, 1986; Kekoni et al., 1989; Kowalzik et al., 1996; Wells et al., 2003; Lin et al., 2005; Perry, 2006; Hennig and Sterzing, 2009; Gu and Griffin, 2011; Schlee et al., 2009; Strzalkowski et al., 2015). On the other hand, very few data are found on the magnitude of the vibration estimate of the foot sole in response to the increased amplitude of the vibratory stimulus. To determine the estimate of vibrations delivered to the skin of the hand, Verillo et al. (2002) already used a

* Corresponding author at: UMR MD2, Faculty of Medicine, Bd Pierre Dramard, 13916 Cedex 20 Marseille, France. Tel.: +33 491692924; fax: +33 491698927.
E-mail address: yves.jammes@univ-amu.fr (Y. Jammes).

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psychophysical approach based on the method of Absolute Magnitude Estimation (AME). They showed that the subjective magnitude of vibration was substantially lower at all intensities in the older group. But these authors did not compare their data to the vibration detection threshold. Kenshalo (1986) proposed a method of single ramp-and-hold skin vibrations to explore the vibration perception at the level of the thenar eminence and the plantar foot. The methods cited above give an approach of the global gain of the sensory detection but no information on the threshold of perception.

The main objective of the present study was to propose a psychophysical approach of the relationship between the estimate (Ψ) of vibratory stimuli applied on the foot sole and the physical magnitude of the stimuli (Φ) using the Stevens power function, $\Psi = k * \Phi^n$. The n coefficient measured the gain in perception. Independently, the vibration detection threshold was determined in each participant. The second objective was to compare values of n and detection threshold in two groups of young (20–34 years old) and elderly subjects (53–67 years old) to identify significant age-related changes in the perception of a mechanical stimulation by the foot sole. This approach could be useful to the diabetologists and the podiatrists who have to diagnose patients at risk of diabetic neuropathy.

2. Methods

2.1. Subjects

Twenty healthy female and male subjects were explored. All were free of foot pain and had no antecedent of trauma or surgery of the feet and legs. None were involved in an exercise program. They were separated into two groups of 10 individuals according to their age range (20–34 years old/53–67 years old). Their characteristics are shown in Table 1.

This research adheres to the principles of the latest revision of the *Declaration of Helsinki*. The protocol was submitted to and approved by our institutional committee (CPP Sud Mediterranée 1). The procedures were carried out with the adequate understanding and written consent of the subjects.

Table 1
Characteristics of subjects.

	Sex	Age Year	Weight kg	BMI kg/m^2
Group I: 20–34 years old				
CF	M	20	65	21
TG	M	21	104	30
EF	F	21	62	22
RF	M	21	74	23
JG	F	22	48	20
VD	M	22	71	20
LM	F	22	57	20
VR	F	33	61	21
CC	F	34	57	21
DL	M	22	68	21
Group II: 53–67 years				
BV	M	53	70	23
JMG	M	53	70	24
PG	F	53	78	30
GL	M	57	90	28
MF	F	57	48	18
RG	M	59	105	33
JPW	M	62	75	25
JGS	M	64	98	31
SR	F	64	49	20
YJ	M	67	100	30

BMI: body mass index.

2.2. Vibration sensitivity

The participants sat comfortably with their eyes closed and wore head phones to eliminate auditory cues associated with the onset of the vibration.

Skin sensitivity was evaluated using vibration testing at three frequencies (25, 50, and 150 Hz) at each one of three foot plantar locations (hallux, fifth metatarsal head, and heel). The vibration frequencies were chosen to target the activation of three different skin receptors in the glabrous skin of the foot (25 Hz for SAI, 50 Hz for FAI, and 150 Hz for FAII) based on the frequencies known to best recruit individual mechanoreceptors in the foot sole (Johansson et al., 1982; Lowrey et al., 2014). Sinusoidal vibrations were applied to the foot sole via a plastic probe (width: 2 mm; length: 5 mm) attached to a minishaker (model 201, Ling Dynamic Systems, Royston, UK). As recommended by Lowrey et al. (2014), prior to the onset of each trial the probe of the minishaker was placed in contact with the foot sole and a preload force of 2N was applied, manipulated by a vertical adjustment of the shaker and confirmed with a force transducer (model K13 – 0.02 kN, Scaime, Annemasse, France). Fig. 1 gives a schematic representation of the device.

Our vibrator device allowed to deliver different amplitudes of vertical motions of the probe and seven levels were retained (1, 2, 5, 10, 15, 20 and 25 arbitrary units). The vibration motion expressed in μm was measured using an accelerometer attached to the probe (model EOAS S114 D2500, MAES France, Les Clayes-sous-Bois, France) when applying a force of 2N on the probe. Fig. 2 shows the values of the vibration amplitudes measured at the three vibration frequencies. The vibration magnitude depended on its frequency and varied in a range of 10–360 μm at 25 Hz, 10–330 μm at 50 Hz, and 10–180 μm at 150 Hz. The three frequencies were tested at one site before moving on to the next site to minimize the total testing time. The testing frequencies were randomized at each foot sole location. The testing order of the foot sole location was also randomized across the participants. Both feet were tested in each participant.

First, the vibration detection threshold in each plantar location was determined by considering the lowest detectable load at each vibration frequency.

Second, a step increase in the vibration amplitude was performed at each of the vibration frequencies, the lowest amplitude corresponding to the detection threshold. Two trials were performed at each frequency. Judgements of increased stimuli intensity were recorded on a 1–10 cm visual analog scale. The participant's specific standards for 1 and 10 on this scale were established in pilot tests in which the lowest and the highest detected vibration stimuli were presented twice in order to acquaint the subjects with the full range of loads. After this

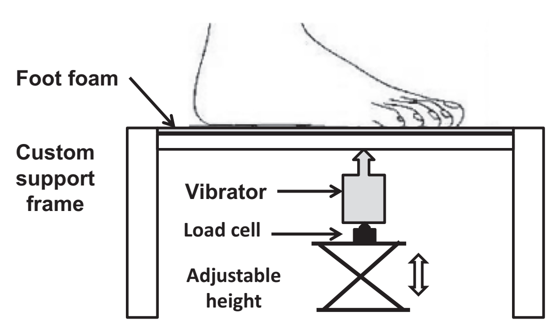

Fig. 1. Schematic representation of the vibration device including the foot support frame, the vibration probe and the load cell measuring the force applied on the foot sole.