Vibration thresholds and equal vibration levels at the human fingertip and palm

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Abstract

This study investigate the perception of vibrations at two different parts of the human hand, the fingertip and the palm. Vibration thresholds (VT) and equal-vibration levels (EVL) are measured at these locations from 16 to 315Hz, covering the frequency range of three mechanoreceptors, the Merkel and Meissner receptors and the Pacini corpuscles, in the human hand.

The VT, EVL and just-noticeable-differences (JND) in frequency for sinusodial vibrations are measured with an electro-dynamical shaker at the finger tip and in the palm. Skin-contact is made with a metal probe tip with 6 and 8 mm diameter respectively. The hand is resting on a wooden handtable with 10 mm diameter hole surround of the probe. The measurement method is an AFC method.

These results are related to the known properties of the mechanoreceptors of the human hand.

1. Introduction

Tactile Stimuli are perceived in several ways. For tactile or in this special case vibratory stimuli the somatosensory system is the responsible perceptive system with its mechanoreceptors in the skin. There are four receptor types located in the glabrous skin which react on mechanic deformation of the skin. These receptors have different features [1] and densities [2], depending on receptor type and location [3]. The properties of the receptors are neurologically already investigated but relations to the subjective perception are partly unknown.

Basic psycho-physical properties to be investigated are VT, EVL and JNDs in level and in frequency. The receptors react to different cues of a vibration stimulus (table 1) and serve for different functions. The Merkel receptor system (SA-I) is responsible for the overall touch feeling, it has a relative high density giving a good lateral spatial resolution. The Meissner receptors (RA-I) are responsible for perception of the velocity of the skin deformation, used to control the strength or pressure with which a certain part of the skin touches a surface or grabs an object. The Pacini Corpuscels (RA-II/ PC) are responsible for accelerations in the skin deformation with highest sensitivity at about 100-200 Hz and serve for the perception of roughness (even when touching a surface with a tool). The SA-I receptors have a very flat and broad frequency sensitivity curve along the frequency axis. The RA-I and the PC sensitivity curves are more narrow and quite steep. All receptors contribute to the sensation of vibration perceived through the skin of the hand. By choosing different stimuli conditions like contact area and size, surrounding, frequency and amplitude it is possible to differentiate between these different channels.

Table 1: Mechanoreceptors in the human hand

Receptor	Recept. Field/ Density	Cue
Merkel SA I	2 mm/ ~100/cm^2	Skin Indention, Vibrations ~4 Hz
Ruffini SA II	8 mm/ ~20/cm^2	Stretching
Meissner RA I	5 mm/ ~150/cm^2	Velocity, Vibrations <~80 Hz
Pacini RA II (PC)	Palm/ Finger/ ~20/cm^2	Acceleration, Vibrations ~40 to 500 Hz

Measured sinusodial vibrations for VT and EVLs are 16, 31.5 63, 80, 125, 160, 210 and 315 Hz. EVL contours are measured by comparing each frequency in level with a reference level of 3 m/s^2 and 6 m/s^2 at 80 Hz. Reference levels for JND measurements are derived at 31.5, 80 and 160 Hz from the averaged EVL contours at 3 m/s^2 and 6 m/s^2. The JND for vibrations will be presented at the ICA (not in this paper).

2. Measurements

2.1. Measurement conditions

Measurements were made with an BK Shaker driven by an Yamaha P3200 Amplifier, which were controlled by an MatLab script running on a PC generating the signals with a DIGI96/8 PAD soundcard. The shaker was mounted on a heavy weight, to provide a stable base, on a balance which was in balance. A contact forced was provided with a small weight add to the counterweight. The hand was resting an a small wooden table with a 10 mm hole. The experiment was conducted in a quiet room, where the subject was seated and had the arm resting on an arm support. The subject wore additionally a hearing protection. The skin temperature was above 34.0°C.

2.2. Experimental procedure

VT and ELV were determined at two locations with a psycho-physical AFC method: the center of the whorl on the distal phalanx of the right finger and at the center of palm of the right hand.

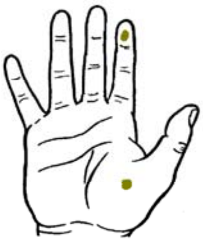

Figure 1: Hand locations.

The probe diameter of 6 mm and 8 mm were applied on both locations (table 2).

Table 2: Experimental conditions

Parameter	Set
Locations	Finger/Hand
Probe diameter	6 and 8 mm
Surround/hole diameter	10 mm
Probe to finger contact force	2.5 N
Finger to table/surround contact force	Not controlled
Frequency	16, 31.5, 63, 80, 125, 160, 210, 315 Hz
Measurement Method VT	3 AFC 1up/1down
Step size	8, 4, 1, 0.5 dB
Measurement Method EVL	2 AFC 1u/1dwon
Step size	8, 4, 1, 0.5 dB
Duration per interval	0.5 s
Reversals	4

2.3. Results

The figures 2-4 show the EVL contours and VT of 4 subjects measured for different hand locations and probe diameters. The results can be related to the physiological properties of the mechanosensors in the human skin. The VT given by the receptor sensitivity which is most sensitive in the respective frequency region and the amount of receptors which are stimulated. The different systems have an overlapping frequency spectrum. The density at the fingertip of the hand is higher for the SA-I and RA-I system than at the palm. Thus a lower threshold at the lower frequencies is rather expected at the fingertip than at the palm. The PC receptors are evenly distributed around the skin of the hand, so no noticeable differences are expected at higher frequencies for different hand locations. Due to the different cues to which the receptors react and the different sizes of the receptive fields, different contact conditions are expected to lead also to different VT. A larger gap (surround of probe) should lead to lower VT for frequencies better detectable for the RA-II system (10-80 Hz), but a larger contact surface to a lower threshold for frequencies (>80Hz) and is better detectable by the PC system.

2.3.1. Different contact conditions

In opposite to the expectations there is no overall noticeable difference in the threshold for different contact conditions at the finger tip (Figure 2, lowest two contours). At high frequencies (80, 125, 160, 210, 315Hz) the PC system with its highest sensitivity at around 125–160 Hz is clearly identifiable in the VT.The two different contact conditions show slight differences. The SA-I system determines the VT at low frequencies in both conditions. Though the RA-I system with its highest sensitivity at around 40-80Hz overlaps the SA-I and PC system, the VT is dominated by the SA-I due to the fact that the gap size (1 mm – 2 mm gap) is too small for the RA-I system to be detected. The difference in probe size (6 and 8 mm) is therefore not reflected in different VTs.

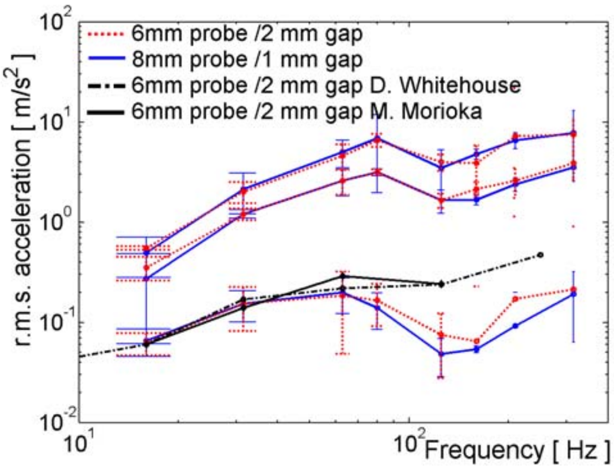

Figure 2: Median VT and EVL 6 mm and 8 mm probe diameter at the fingertip and data from D. Whitehouse [5] and M. Morioka [6].

The data from Whitehouse [5] was obtained by using a 6 mm diameter contact probe with an 2 mm gap, with an contact area force (from the finger to the surround) of 2 N different to the present study (contact probe force from tip to finger 2.5 N). The data by Morioka were obtained by the same measurement setup and condition as the data from Whitehouse. At lower frequencies both VTs fit very well together but at higher frequency the sensitivity curve of the PC system is better distinguishable in our own measurements than in the VT of Whitehouse and Morioka.

The EVL shown in figure 3 are as expected to follow the VTs roughly in parallel. No significant differences are expected between the two probe diameters due to the fact that all three receptors systems are answering at a high stimulus level. Note the increase in reproducibility towards higher frequencies.

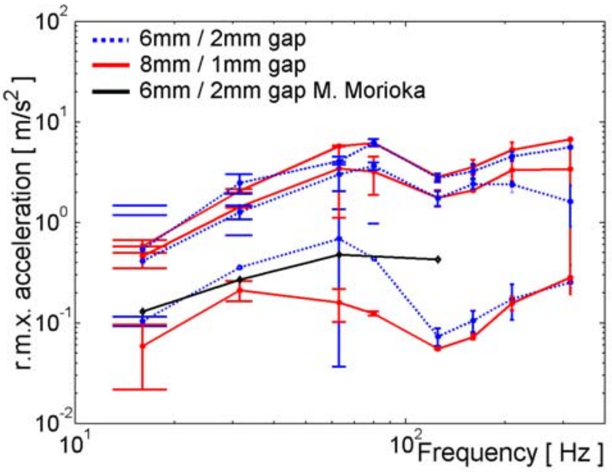

Figure 3: Median VT and EVL 6 mm and 8 mm contact condition at the hand palm and data from M. Morioka [6].

In contrast to the fingertip location (fig. 2) there is a significant difference between the VT for the 6 mm and the 8 mm probe diameter for the palm (fig. 3). As expected, the overall VT is higher for frequencies where the SA-I and RA-I system are dominant (below 80 Hz). At high frequencies (>125 Hz) the VTs converge again, reflecting the more evenly distributed receptors of the PC system. No significant difference is measured for the EVL for under the two contact conditions.

2.3.2. *Different hand locations*

For different hand locations we expect in total a higher VT for the palm than for the finger, due the fact that the density of the receptors for the SA-I and RA-I is much higher at the fingertip. At high frequencies, where the PC system is dominant no differences due the evenly distribution of the PC receptors and their large receptive field is expected.

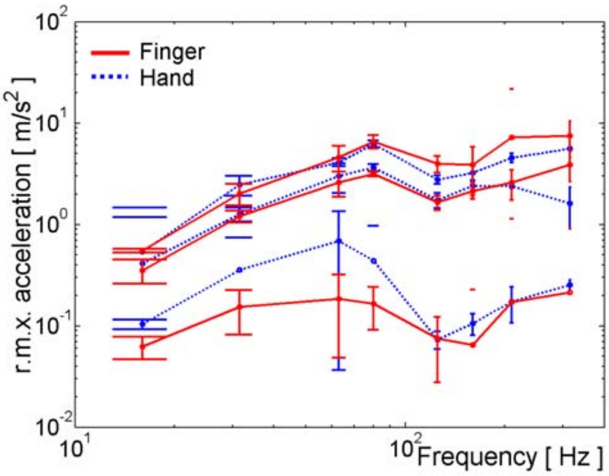

Figure 4: Median VT and EVL for 6 mm probe diameter; comparison of finger tip to palm.

The difference between the locations is clearly visible for the 6 mm probe diameter at the palm of the hand (fig. 4). The VT of the palm at frequencies from 10 to a 80 Hz is significant higher than at the finger tip, which can be related to the lower density of the SA-I and RA-I receptors. Towards higher frequencies (>125 Hz) the thresholds approach each other again because the PC system is the most sensitive system of the three receptor systems.

No significant difference is observed in the EVL in contours between the two hand locations.

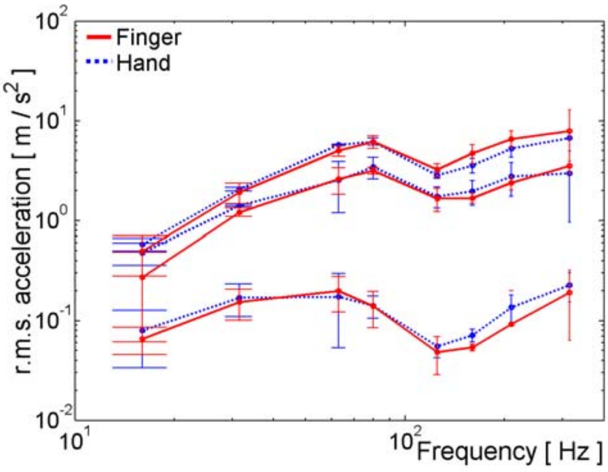

Figure 5: Median VT and EVL for 8 mm probe diameter; comparison of finger tip to palm.

In contrast to fig. 4 (6 mm probe) there is no significant difference for the 8 mm probe diameter between the two hand locations (fig. 5).

Because of the lower density of the SA-I and RA-I receptors at the palm a higher VT is expected compared to finger tip. This is not the case in fig. 5. No explanation can be given at present.

Since the gap for the 8 mm probe is smaller than for the 6 mm probe we expect the VT at higher levels than the VT in fig. 4. The sensitivity of the RA-I system decreases with the decreasing gap size. But the comparison with the dotted VT curve in fig. 4 shows an increase in sensitivity.

The EVL remain roughly the same, as in all other conditions.

2.4. Summary

The SA-I and the PC system can be assigned to a certain frequency range. The frequency-dependant sensitivity is clearly identified in the VTs. The PC system has its highest sensitivity in the range 125 - 160 Hz independent of probe diameter or hand location.

The RA-I system is most sensitive at 40 to 80 Hz but is difficult to identify in the VTs because it is masked by the SA-I and PC system in the experimental conditions presented.

VTs for 6 mm and 8 mm probes were measured at finger and palm, but only the 6 mm probe gives significant differences between the locations.

This VT was significant higher than the others (as expected) due to the lower receptor density for the palm

This expected loss in sensitivity is not observed for the 8mm probe diameter.

The expected difference between the 6 mm and 8 mm probe would result from the different receptive fields of the SA-I and RA-I receptors and should be visible in the frequency range 31.5 to 80 Hz. This is not observed.

The EVL remain almost the same, regardless of contact location and probe diameter.

3. Discussion and Conclusions

The results are in the same order as literature data from Whitehouse [5] and Morioka [6] but show a frequency dependence in accordance with the different receptor sensitivities.

The data from Whitehouse [5] were measured by controlling the downward force of the finger to the contact area, while in this experiment the upward force of the probe is controlled. This might be the reason for the observed differences at higher frequencies, because the PC system is better stimulated.

Systematic variation of probe diameter and shape, surrounding gap and contact force in connection with a reliable psycho-physical method of measurement will provide additional data for a physiologically motivated functional model of the vibration perception with the hand.

4. References

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