The Shape of the Tactile Detection Curve for Rotary Vibrations at Threshold Level

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Abstract. Single channel vibrotactile devices offer a limited communication bandwidth. Multi-channel displays are an attempt to overcome this limited data transmission rate. Evaluation of multi-channel devices suggests that the performance of multi-channel displays developed for the deaf are not superior to single channel devices. The present work examines the possible contribution of surface wave interaction of mechanical waves to this lack of performances. This paper describes the development of a novel rotary vibrator and presents the measurement of detection threshold of human to rotary oscillation at threshold level. The results show that at threshold, the shape of curve (as a function of frequency) is different for the rotary vibrator compared with the conventional longitudinal vibrator, although not greatly so.

Keywords: wave interaction, tactile displays, deaf, VR, rotary, detection threshold

1 Introduction

Multi-channel vibrotactile displays have been used for over 80 years to assist the ear and visually impaired individuals. These devices were intended to improve the limited data communication bandwidth available from single channel displays. Multi-channel displays vary in the choice of stimulation site, signal-processing strategies, number and size of the vibrators. Evaluations of these devices show little or no improvement in performance compared to single channel devices [1-7]. Previous research suggests that there is a high level of interaction within the nervous system path, which carries tactile information to cortex. The present work examines the rule of the surface wave interactions of mechanical waves in the performance of multi-channel displays. This paper explains the development of the rotary vibrator and presents results in regards to the shape of the human detection threshold to rotary oscillation.

2 Background

Skin is an intermittent layer between applied mechanical stimuli and tactile receptors. These receptors are engulfed within different anatomical layers of skin. Each layer appears to posses a different viscoelastic property with an overall non-linear

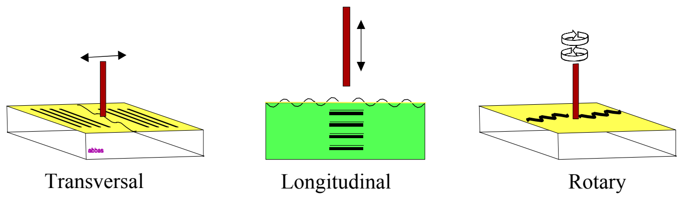


Fig. 1. Waves generated by different displacement modes, travelling in different planes in a medium.

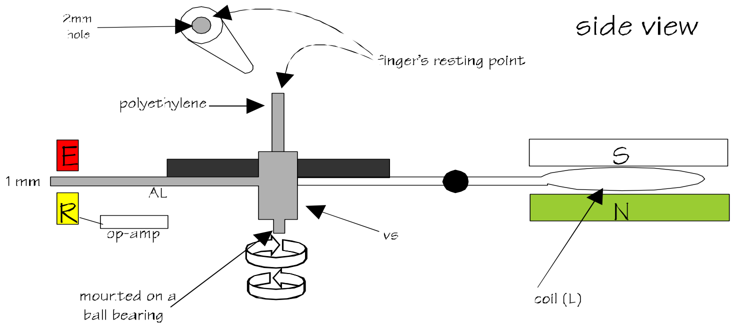
mechanical response [8-10]. Mechanical stimulation passing through these layers is expected to be filtered by the property of intermittent layers and the property of the receptors. Existing vibrotactile devices stimulate the skin by applying a transversally or longitudinally oscillations to the skin. *Transversal oscillation* is when the displacement of the object is tangential to the surface of the skin and *longitudinal oscillation*, is when the displacement is perpendicular to the surface of skin (see figure-1). For the development of vibrotactile devices and likewise virtual reality we examined the detection threshold of human tactile sense to rotary oscillations.

3 Equipment

For the purpose of this study a rotary vibrator and a longitudinal vibrator was built. The data from longitudinal vibrator served as a control against which the shape of the detection threshold from the rotary vibrator will be compared.

3.1 Vibrators

Design of the rotary vibrator based on electromagnetic force. Figure-2 illustrates sections of the rotary vibrator. The building blocks of a rotary vibrator consist of a stable shaft (A) which can rotate along its long axis, with a loop of conductor connected perpendicular to the axis (A). The loop is located in the gap of a permanent magnet. The velocity of the coil and subsequently the angular velocity of the axis (ϖ) is proportional to the voltage across the coil. To maintain a balanced and equal movement to the right and to the left with the positive and negative edge of the input waves respectively, the coil starts its movement from the centre of the U-shape magnet. This has been achieved by dividing the U-shape magnets into two sections, whilst two opposite poles of each magnet meet in the central line. A piece of ferromagnetic material mounted on the coil holds the coil in the middle of the magnet. An extension to axis (A) made from Polyethylene provides a resting point for the subject's finger. The chosen dielectric assures the safety of the device. The finger's resting point on the polyethylene extension has a diameter of 4mm (ϕ = 4) with a 2mm hole in its centre to reduce the contact area.



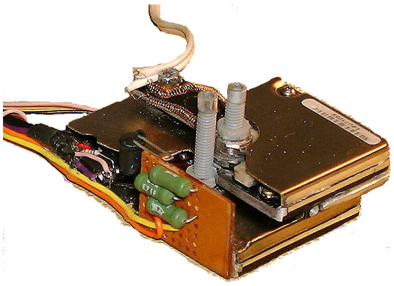


Fig. 2. Design concept of the rotary vibrator (top) and the assembly of the rotary vibrator (left).

3.2 Calibration

To calibrate the rotary vibrator a pair of photometric displacement measuring device (PMD) was built [11]. Following calibration the PMDs serve two main functions: 1) measuring the frequency response of the system and, 2) measuring the actual displacement under psychophysical test conditions.

The applied mechanical stimuli can be contaminated by both electrical and mechanical noise. To assess the level of each type of noise, the level of harmonics within the applied signal and the PMD and also the cross-talk between the rotary actuator and PMD were estimated.

The level of the harmonics were measured at 0dB SL, with the vibrator being driven by the same signal used for the psychophysical tests (a computer-generated sine wave). Measurements showed that the level of the harmonic components reached their highest value at 250Hz and never exceeded -15.6dB SL. The total level of mechanical and electrical noise was slightly higher than this value, approaching -11.8dB SL at 200Hz. The main source of the noise was components from the electrical mains.

Cross-talk is another cause of contamination of the output from the PMD. The main sources of cross-talk are the electric and magnetic fields around the vibrators. These two sources induce currents in all conductive sections of the neighbouring PMD circuits, resulting in errors when measuring output voltages. The induced current is inversely proportional to the square of the distance between the source and the induced section and is highly dependent on the length and orientation of the

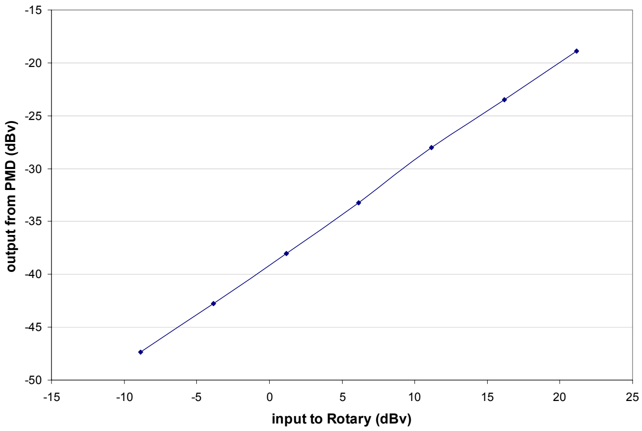


Fig. 3. Testing the linearity of the PMD where both input and output voltages are expressed in dB. Data collected from the rotary vibrator stimulated with 500Hz digitally generated sine-wave signal. The peak of the input voltage is equivalent to about 50dB SL rotary at 500Hz.

section. This effect is quantified by measuring the ratio of the input voltage (to the vibrator) to the output voltage across the PMD while the light path was blocked. This value was greater than 55.6dB, having its lowest value at 200Hz (measured at 40dB SL).

In the next series of tests that were carried out at some predetermined frequencies, the intensity of the signal was varied whilst the output from the PMD was recorded. There were two very closely related reasons for these tests 1) they provide an estimate of the input-output response of the system and, 2) providing that they response is linear, they provide evidence for the linearity of the PMD. Figure 3 shows an example of the results obtained at 500Hz. In this figure, the maximum input voltage corresponds to approximately 50dBSL (at 500Hz for the rotary vibrator). The graph in Figure 3 is consistent with the power law formula $V_{out}= 1.188\times10^{-2}\ V_{in}^{\ 0.96}$, which approximates the curve across an intensity range of more than 30dB. The values of the power and scale factor were obtained from the graph and, allowing for experimental error, it is possible that the true value of the power is actually 1.0, which would indicate that the output voltage was directly proportional to the input voltage.

These tests suggest that, over the tested range of intensities both the behaviour of the rotary vibrator and the PMD can be approximated by a linear system.

The procedures followed to measure response of the longitudinal vibrator were similar to those discussed for the rotary vibrator. Figure-4 shows the frequency response of the longitudinal vibrator measured by the spectrum analyser. The longitudinal vibrator shows much flatter response compared with the rotary vibrator. In a similar manner to that of the rotary vibrator, during the “system calibration” stage, an inverse filter based on these data was applied to input signals to the vibrator in order to correct its frequency response.

4 Methods

Three subjects – two females, one male- aged between 26-37 participated in the test. Subjects had no known history of peripheral or central nervous system disorder or skin conditions. This study was approved by the Committee on Ethics of Experimental Procedures Involving Human Subjects, School of Medicine, University College London.

During the psychophysical tests neither temperature nor initial force was controlled and no surround was used. Signals applied were computer-generated sine waves sampled at 10kHz. The order of presentation was randomised and the response rate of subject was not considered important. Subjects always wore earplugs and headphones supplied with white noise band-passed between 70-5000Hz. When the noise was switched on, its level was raised gradually (over a period of 10 s) from 50dB SPL to 92dB SPL to improve the comfort of the subject. Subjects were requested to relax and remove their finger from the vibrator in the intervals between tests at each frequency, and to feel comfortable to leave the test room whenever they liked. In addition, all tests were performed at the same time of day (10 AM ± 1 hour) and always with one to three days interval between each test to prevent fatigue. These three precautions were expected to reduce the variation in the threshold measurement

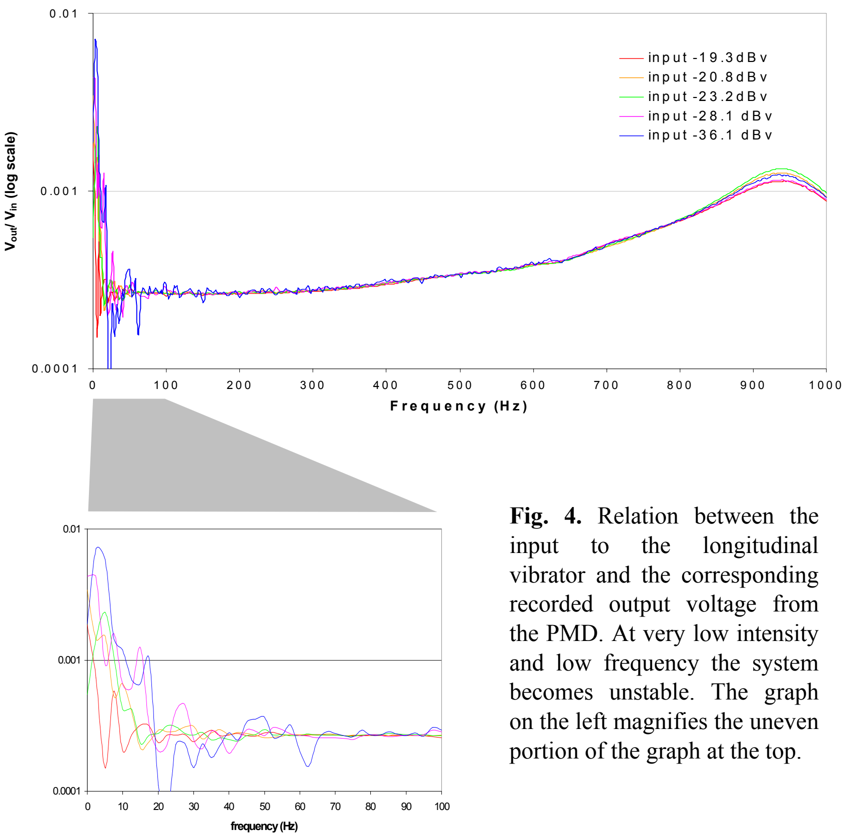
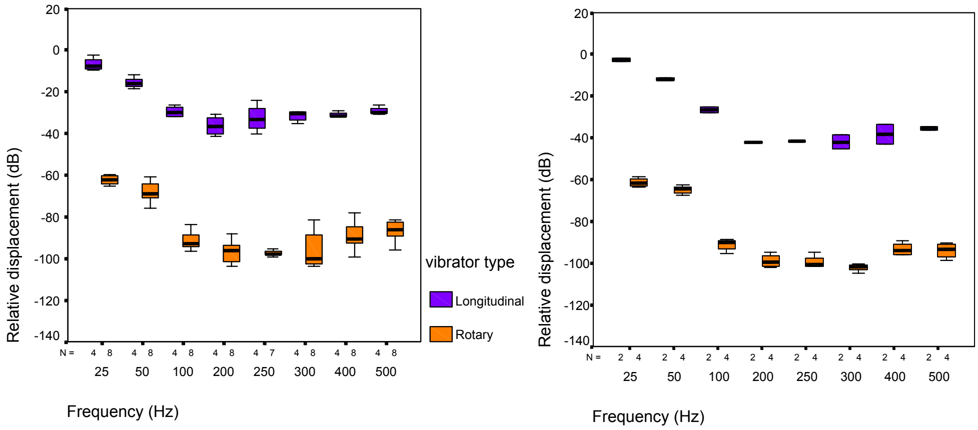


Fig. 4. Relation between the input to the longitudinal vibrator and the corresponding recorded output voltage from the PMD. At very low intensity and low frequency the system becomes unstable. The graph on the left magnifies the uneven portion of the graph at the top.



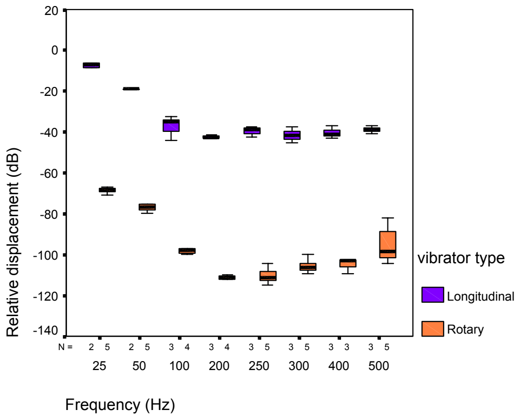


Fig. 5. Boxplots showing the absolute threshold data for both types of vibrators from subject “A”- (top-left), subject “B”-(top-right) and subject “C” -(bottom-left). Numbers on the x-axis indicate the number of observations that were used to make each “box”. Smaller numbers at some low frequencies are due to responses being out of the dynamic range of the system at those frequencies.

due to viscoelasticity of the skin and tiredness. They were always provided with writing tools during each session to note any comments (*e.g.* quality of stimuli). These comments proved valuable (at least) in tuning the details of the psychophysical test. Note also that the reported values in the frequency range are the result of interpolation of measurement at eight set frequencies (25, 50, 100, 200, 250, 300, 400 and 500Hz) which henceforth will be referred as a “complete set” of tests. The rise/fall time of these stimuli was kept constant at 120ms.

The threshold of vibration for sinusoidal waves for both the Longitudinal and rotary vibrators was established using two- interval, two-alternative forced-choice adaptive paradigm to estimate the 79% point on the psychometric function. Levitt’s [12] transformed up and down procedure was used with an initial step size of 10dB, which was reduced to the final size of 2dB over the first 3 reversals. The value of the threshold at each frequency was calculated by averaging the result of the last six reversals at the final step size. The time waveform of the stimuli consisted of a 1000ms steady-state portion and 120ms raised-cosine onsets and offsets. This length of time was considered adequate to provide both a sufficient period of presentation of stimuli and to minimise adaptation. The stimulation site was the anterior distal part of the right hand index and middle fingers (first phalanx).

The entire procedure was controlled by a software which could generates a sine wave with a predetermined raise and fall time and provides control over various parameters. At termination, the software generates a log file stamped with date and time, detailed information regarding the presented stimuli and the corresponding responses of the subject followed by the estimate of the threshold. The initial intensity of the generated stimuli was always higher than threshold and corrected according to the measured frequency responses of that particular device. Upon the completion of the threshold measurement at each frequency, the program paused and waited re-starting by the subject– this provided a rest period for the subject.

5 Results and discussion

A total of twenty-six complete sets (each with an estimated time of 25 minutes) were performed by the three subjects to evaluate their absolute threshold. The number of tests was not equal for all subjects and was determined by the consistency of their results. Figure-5 summarises the results of these measurements for the three subjects. The number of tests using the longitudinal vibrator were limited and performed for a sole reason to compare the shapes of the absolute threshold curves from the two types of vibrator.

The results were subject to an ANOVA with fixed factors of frequency and vibrator type, and subjects as a random factor. Only the highest order interaction was not significant, but all second order interactions were ($p \le 0.035$). All main effects were also significant, although the effect of subject was relatively weak ($F(2, 3.578)=10.960$, $p=0.030$). Both main effects of frequency ($F(7,14.51=82.39$, $p<0.001$) and vibrator type were highly significant ($F(1,2.041)=1999.5$, $p<0.001$). The relationship between factors (vibrator type, frequency and subject) appears complicated. The present of a significant "frequency × vibrator type" interaction indicates that the shape of the curves from the two types of vibrator are not the same (although as shown in Figure-7 they are not widely different). The present of a significant "subject × frequency" interaction indicates that the shape of the curves are not the same for all subjects. This effect had the lowest significance level of all the second order interactions ($F(14,14)=2.727$, $p= 0.035$) and as shown in Figure-7 they are not greatly different either. Finally, the existence of a "subject × vibrator type" interaction shows that subjects performed differently for different types of vibrator. Note that none of the observed dissimilarities confirm or reject the possibility of the graphs to be similar at some frequencies.

This will not be examined here for two reasons. First, to be able to specify at which frequency these two graphs are similar, a greater number of observation and better-controlled testing conditions are necessary to eliminate the variability in the data. Second, the real Operation Voltage Difference (OVD) between the two vibrators is needed to be known. Estimating the OVD by the method used here (*i.e.* from the mean difference between the two curves) is not considered appropriate for answering such a question. In brief, the OVD estimated from the mean difference can

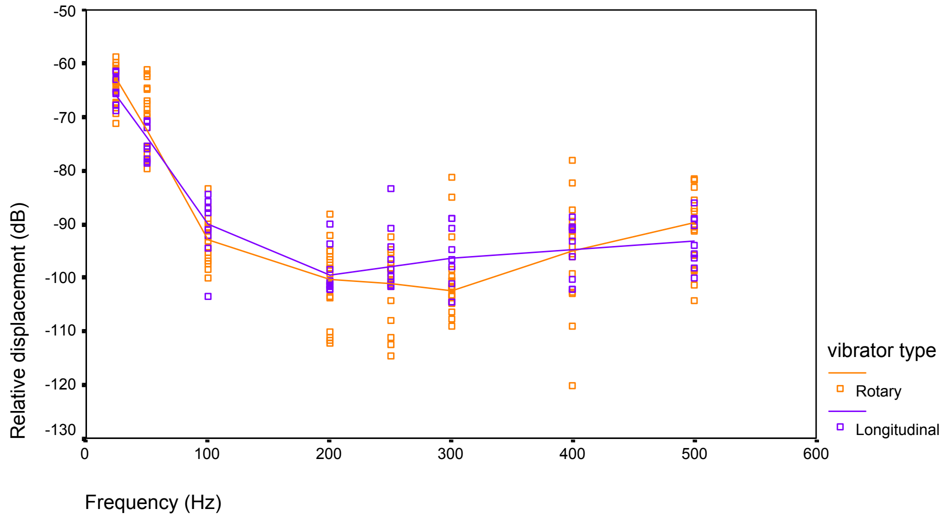


Fig. 6. The relationship between absolute threshold from the two types of vibrator. The lines are the best fit lines (regression lines) drawn by the least squares method (LOWESS) fitting to 50% of data points. Data are from all three subjects with those from the perpendicular vibrator shifted down by 59.4dB (the mean difference between the curves) to facilitate the comparison.

be affected by the weight of data comprising the two sections of the curve, which are considered dissimilar.

Similarities between the absolute threshold from the rotary vibrator and that of the longitudinal vibrator could in fact suggest that these two types of vibrators are stimulating similar types of tactile receptors.

To enable visual comparison of the threshold curve from each type of vibrator, the average difference between them was removed and data from all subjects presented in Figure-6. The result of absolute threshold measurement can be summarised as follow:

- Subjects differ in their absolute threshold.
- The shape of curve (as a function of frequency) is different for the two types of vibrator, although not greatly so.
- The shape of curve (as a function of frequency) is different for different subjects

6 Future directions

The aim of this project is to quantify the effect of the plane of vibration in surface wave interaction. The results from interaction test will be presented in the papers to follow.

References

1. Carney, A. E. and Beachler, C. R.: Vibrotactile perception of supra-segmental features of speech: a comparison of single-channel and multi-channel instruments. *J. Acoust. Soc. Am.*, vol. 79, no. 1 (1986) 131-140
2. Carney, A. E.: Vibrotactile perception of segmental features of speech: a comparison of single –channel and multichannel instruments. Journal of speech and hearing Research, vol. 31 (1988) 438-448
3. Boothroyd, A. and Hnath, T.: Lipreading with tactile supplements. Journal of Rehabilitation Research and Development, vol. 23, no. 1 (1986) 139-146
4. Weisenberger, J. M., Broadstone, S. M. and Kozma-Spytek, L. K.: Relative performance of single-channel and multichannel tactile aids for speech perception. Journal of Rehabilitation Research and Development. vol. 28, no. 2 (1991) 45-56
5. Reed, C. M. and Delhorne, L. A.: Current results of a field study of adult users of tactile aids. Seminars in Hearing, vol. 16 (1995) 305-315
6. Galvin, K. L., Mavrias, G., Moore, A., Cowan, R.S.C., Blamey, P. J. and Clark G. M. : A comparison of Tactaid II+ and Tactaid 7 use by adults with profound hearing impairment. Ear & hearing, vol. 20, no. 6 (1999) 471-482
7. Waldstein, R. S. and Boothroyd, A.: Speechreading supplemented by single-channel and multichannel tactile displays of voice fundamental frequency. Journal of speech and hearing research, vol. 38 (1995) 690-705
8. Payne, P. A.: Measurment of properties and function of skin. Clin. Phys. Physiol. Meas. vol. 12, no. 2 (1991) 105-129
9. Cua, A. B., Wilhelm, K.-P. and Maibach H. I. : Elastic properties of human skin: relation to age, sex, and anatomical region. Arch Dermatol. Res, vol. 282 (1990) 283-288
10. Finlay, B.: The torsional characteristics of human skin in vivo. Biomedical Engineering, vol. 6 (1971) 567-573
11. Haydari A., Rosen S. M.: Construction of a Rotary vibrator and its application in human tactile communication. Sixth international conference on tactile aids, hearing aids and cochlear implant, ISAC’00 (2000) Exeter
12. Levitt H.: Transformed up-down methods in psychoacoustics. J. Acoust. Soc. Am., vol. 49, no. 2 (1970) 467-477