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Construction of a rotary vibrator and its application in human tactile communication

Abbas HAYDARI and Stuart ROSEN

Department of Phonetics and Linguistics
UNIVERSITY COLLEGE LONDON

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Abstract
A major problem in the use of multichannel tactile communication devices is the extent to which multiple sites of stimulation interact and interfere with one another. In an attempt to minimise this interaction, we describe the design and construction of a novel rotary vibrator, based on the application of torsional oscillations to the skin. Preliminary psychophysical experiments are reported which compare the properties of rotary vibration to the more commonly used perpendicular vibration.

Introduction
Previous research on the possibilities of tactile communication has shown that a single stimulator is capable of transferring only limited information (*e.g.*, Summers *et al.*, 1996). Multichannel devices are an attempt to overcome this limitation. However the major problem of using more than one stimulator site is the interaction across sites. Interaction can take place on the surface of the skin, as well as in the layers of tissue beneath the skin surface.

Here we investigate the use of torsional oscillations on the skin in an attempt to minimise vibratory interaction. We begin by describing the concept, design and construction of a pair of rotary and perpendicular vibrators, along with a photometric calibration device for measuring the physical behaviour of both sets of devices. This is followed by a description of the behavioural tests that have been planned to compare the degree of interaction between two rotary vibrators and two perpendicular vibrators. The last section presents data from preliminary tests, and discusses the future direction of the project.

Concept
In general, waves propagate in the bulk of an elastic solid by two wave modes, longitudinal and transverse. The direction of motion of a tactile vibrator in respect to the skin specifies the mode of wave propagation in each direction. Figure 1 illustrates possible wave travelling modes for three methods of motion, including tangential, perpendicular and rotary motions. In any of these modes of oscillation, only the waves travelling in the same plane can affect each other.

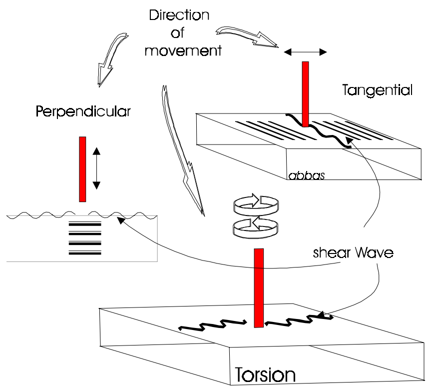

Figure 1: *Propagation of waves generated by three methods of oscillations*

[1] A version of this paper was presented in Exeter, England at the 6th International Conference on Tactile Aids, Hearing Aids & Cochlear Implants (April 2000).

Apparatus

1. Rotary vibrator

As Figure 2 shows, the core component of a rotary vibrator consists of a rigid shaft (**A**) which can rotate on its long axis. Connected perpendicularly to the main shaft is an aluminium extension which supports a coil of wire located in the gap of two permanent magnets. 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-shaped magnet. This has been achieved by means of two helical springs **SP1** and **SP2**.

Since the force on the coil is proportional to the current through it and to the extension of the spring, the velocity of the coil and subsequently the angular velocity of the axis in this structure is proportional to the rate of change of current passing through the coil. The force applied by a spring for a given extension is proportional to the spring constant. This force has been minimised by the use of springs with a small spring constant. An extension to axis (**A**) made from polyethylene provides a resting point for the subject's finger. Its dielectric properties assure the electrical safety of the device. The finger's resting point on the polyethylene extension has a diameter of 4 mm with a 2 mm hole in its centre to reduce the contact area. The photometric device illustrated on the rotary vibrator Figure 2 (**E** and **R**) has been used in both perpendicular and rotary vibrators and will be described below.

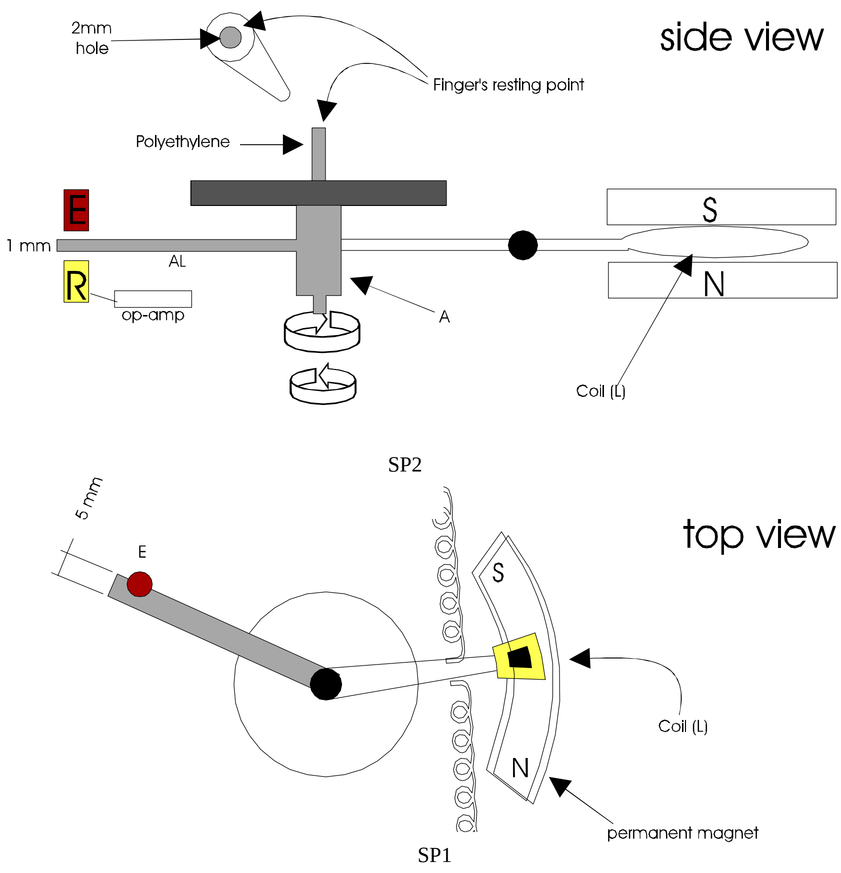

Figure 2: *The components of a rotary vibrator (not to scale).*

2. Perpendicular vibrator

The perpendicular vibrator serves as a reference against which the efficiency of the rotary vibrator will be measured, as it is the type of vibrator most commonly used in previous research. A pair of perpendicular vibrators have been built, each with a resting point for the finger identical to that used in the rotary vibrator (including centre hole).

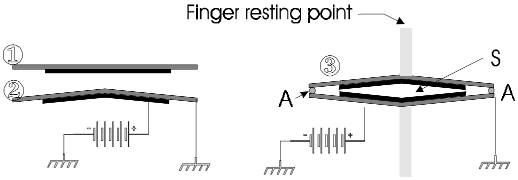

Figure 3: *Piezo-electric benders. (1) Relaxed (2) Activated and (3) assembly of a perpendicular vibrator (not to scale).*

Each perpendicular vibrator (figure 3) consists of a pair of piezoelectric benders electrically connected in parallel and jointed together by means of pivots (**A**). A perpendicular rod mounted on each bender provides an axis along which the vibration takes place. The piezo crystals face each other with wiring passing through the cavity (**S**) between them. The limited gap between the two piezo benders secures the piezo crystals against possible mechanical overloading while the grounded outer layer improves the electrical safety of the device.

3. Displacement measuring device

To measure the frequency response and the real displacement of the vibrators under test conditions, an optical measuring device was incorporated in the design of both vibrators.

This *photometric device* was composed of an infrared emitter and receiver (**E** and **R** in Figure 2) placed at both sides of the vibrating object on the same axis. To minimise the effects of ambient light, the photodiode and appropriate emitter were mounted on a black pipe. The signals from the photodiode feed into an op-amp wired as a simple inverting amplifier with two de-coupling capacitors. The power to the emitter and the op-amp are supplied by different power sources via shielded wires. The photometric device and vibrator were mounted on the same high-mass reference frame to eliminate the effect of external forces on the measurements.

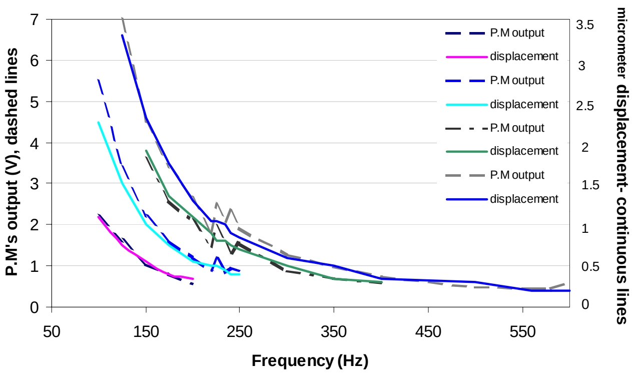

Figure 4: *Relationship between the displacement of the vibrator and read-out voltage across the photometric device (P.M) for the rotary vibrator.*

A microscope with a magnification of 50x with a graded ocular was used both to attest the linear response of the photometric device, and to calibrate the rotary vibrator. This was done by exciting the rotary vibrator sinusoidally at a variety of frequencies and levels. Simultaneous measurements were then made of the output of the photometric device and the actual displacement of the vibrator. The results of these measurements are shown in Figure 4.

4. Set-up for psychophysical tests

Figure 5 illustrates the set-up of the equipment for the behavioural tests. All aspects of stimulus control and experimental procedure were controlled by computer. Stimuli were digitally generated sinusoids (25 Hz - 500 Hz) with durations varying from 300 ms to 2 s, and were played through 16-bit digital-to-analogue converters. Subjects responded on a specially-constructed button box which could be readily held in one hand. Note particularly the use of ear defenders through which masking noise was presented so as to prevent the subjects from using any auditory cues in responding to the tactile stimulation.

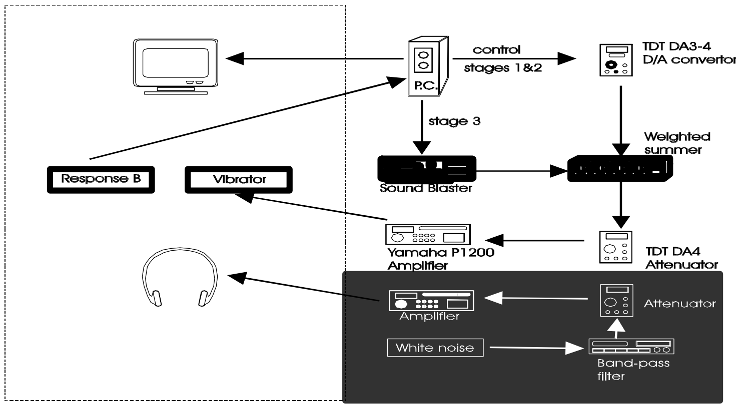

Figure 5: *Layout of the equipment used in the psychophysical*

Methods

Each subject participated in two main types of behavioural test. First, the absolute threshold of detection for a single vibrator of each type applied to the anterior distal part of the right-hand index finger was determined using a two-interval two-alternative forced-choice adaptive method (Levitt, 1971). Stimulus durations were always 300 ms.

Of more significance is a test used to determine the degree of interaction between vibrators of the same type. This test is based on stimulating the skin by two vibrators in close proximity to each other, but which differ slightly in their frequency. If there is no interaction between the two sites of vibration, it can be expected that the subject would not distinguish any difference between this pair and a pair of vibrations having the same frequency (as long as the difference in frequency between the two vibrators is small). On the other hand, if there is interaction between these two sites, the subject will feel the "beat" of a frequency equal to the difference between the two frequencies used. In interpreting the results of this test, a higher degree of error in the detection of beats indicates less interaction between the two vibrators.

The method was implemented by using a pair of vibrators of the same type placed 10 mm from each other. Each pair of vibrators was supplied by 2-s sinusoids that either differed in their frequency by 2 Hz or were equal. Subjects were required to indicate whether they felt the beat frequency or not. The stimulation sites were the lateral sides of the anterior distal part of the right hand index finger. The overall incidence of "equal" and "different" trials was identical in each test, with presentation of signals otherwise in random order.

Results and discussion

Only preliminary results from the two psychophysical tests are available at this time. Figure 6 shows that the absolute threshold curve for a rotary vibrator has almost the same shape as that obtained with a conventional perpendicular vibrator (no surround is used during these experiments).

Subjects also report different sensations from rotary compared to perpendicular vibration, especially at frequencies lower than 50 Hz. The sensation from the rotary vibrator is described as having a "clearer frequency" in comparison to the perpendicular vibrator. The reason for this difference may lie in the relative movement and direction in which the receptors are stimulated. We hope further investigation will clarify this issue.

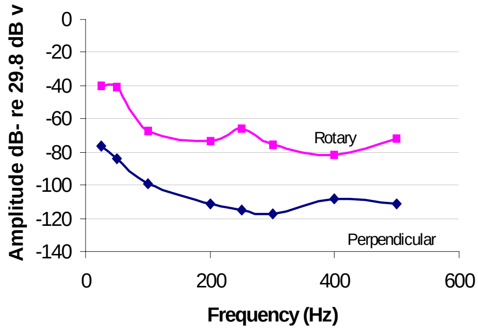

Figure 6: *Absolute thresholds for perpendicular and rotary vibrators. The ordinate is input voltage to the vibrator in dB referred to the maximum voltage available.*

Figure 7 depicts an initial result from the interaction test, showing almost the same degree of interaction for both vibrators. Further studies of interaction are currently underway.

These experiments show that the present rotary vibrator is a successful prototype which allows the investigation of rotary stimulation to be carried out up to 500 Hz and 20 dB SL.

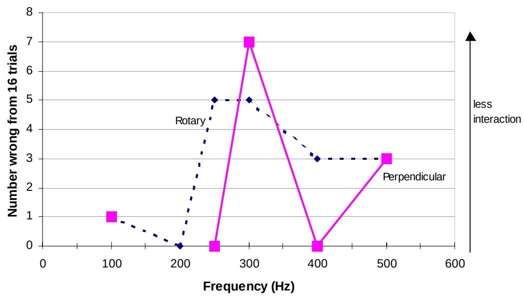

Figure 7: *Performance of a single subject on the interaction test. The level of the rotary vibrator was set to 10 dB SL, and that of the perpendicular vibrator to be subjectively equal.*

Future directions

The present prototypes allow the distance between two vibrators to be varied from 50 mm to 10 mm. In order to ensure practical utility, it is essential to carry out further experiments with smaller distances between vibrators. To this end, the design of a smaller rotary vibrator is in progress.

In previous experiments on perpendicular vibration, researchers used a ring (surround) around the vibrator to prevent the propagation of waves along the skin. It will be interesting to investigate the effect of a surround on the interaction between two rotary vibrators.

Acknowledgement

This work is supported by my parents and I wish to express my gratitude to them (AH).

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