The Influence of Frequency on the Integration of Auditory and Tactile Information

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Abstract

In the present study, a psychophysical experiment was conducted to investigate the influence of frequency on the integration of auditory and tactile information in virtual environments. In this experiment, sinusoidal sound and vibration were used. The auditory stimuli were presented to the subjects via headphones and the tactile stimuli were presented through a force-feedback mouse. In order to measure the sensitivity to frequency differences, stimuli were presented with different frequencies. The influence of frequency on the multi-modal integration is discussed on the basis of the results of the psychophysical experiment.

1. Introduction

In our daily life, in many situations, such as drilling a hole, playing a guitar, driving a car etc., we are exposed simultaneously to auditory and tactile information. There is a strong physical relationship between sound and vibration. Vibrating objects cause the disturbance which moves through the medium and this disturbance generates sound waves. Therefore, physical properties of sound, e.g. sound pressure level, frequency etc. and the physical properties of vibration, e.g. vibration magnitude, frequency, etc., are coupled with each other by physical laws. This relationship plays an important role in our integration mechanism of auditory and tactile information [1,2]. The goal of this study is to investigate the influence of frequency on the integration of auditory and tactile information.

Multi-sensory integration was defined as the synthesis of information from two or more sensory modalities such that information emerges which could not have been obtained from each of the sensory modalities separately [2]. The influence of the synchronicity between auditory and tactile modalities on the multi-modal integration was investigated by Altinsoy [3]. Two recent studies discussed the integration of information in the specific context of haptic-audio texture perception [4, 5]. McGee, Gray and Brewster suggested that the frequency of haptic and audio stimuli may have influence on multi-modal roughness perception, but they did not provide any experimental results related to the sensitivity to frequency differences between auditory and tactile information [5].

In order to measure the thresholds of multi-modal integration related to frequency, different experimental methods can be applied. In a response method, a subject is asked whether two stimuli (e.g. auditory and haptic information) caused by the same product or not. For this type of experiment, it may be useful to define a context or product (e.g. imagine a razor etc.) for the test subjects. It must be explained to subjects very clearly that they should imagine an event or a product and judge whether multi-modal information are caused by the same event (the same product) or not, and while evaluating this multi-modal event or product should be taken into account.

Another measurement method consists in evaluating a multi-modal attribute which may be influenced by the content of sensory modalities which contribute to the multi-modal event. For example roughness is such a multi-modal attribute, related to surface texture evaluation. The frequency of haptic and visual stimulus as well as the pitch of the auditory stimulus carry an influence on the roughness perception. For electrical products (e.g. drill, electric razor, hair-dryer), the performance of the product can be used as the multi-modal attribute. The disadvantage of this method is the difficulty in analyzing the measurement results to determine the level of multi-modal integration.

2. Experiment

In the current study, an experiment was conducted to investigate the influence of frequency on the integration of auditory and tactile information.

2.1. Set-up

The Saitek tactile feedback mouse was used to present the tactile information (vibrations) to the subjects. This mouse contains a motor that relates the vibration or the force-feedback sense to the hand guiding it. The participants were instructed to hold the mouse in their hand and lift it from the table to avoid unwanted structural vibrations which can be generated from the

contact between the mouse and the table and also to minimize the noise generated by the mouse.
The auditory stimulus was presented from a PC. It was amplified and delivered diotically through Sennheiser HDA 200 closed-face dynamic headphones which have a very high sound isolation level and therefore mask the background noise of the mouse when it generates the signal. The experiments were conducted in a sound-attenuated room.

2.2. Subjects

The same nine subjects, four men and five women, aged between 20 and 29 years, participated in the experiment. The subjects were undergraduate students and paid on a hourly basis. All subjects had normal hearing and were right handed, with no known hand disorders. They used their right hand for the experiment.

2.3. Stimuli and Procedure

The tactile stimuli were sinusoidal vibrations varying in frequency (4, 10, 50, 63, 80 and 100 Hz). Auditory stimuli were pure tones at fifteen different frequencies (31.5, 40, 50, 63, 80, 100, 125, 160, 200, 250, 315, 500, 630, 1000 and 2000 Hz).
In this experiment, subjects should imagine that the vibration and auditory information are produced by any device (or product) which they want to imagine.
Tactile and auditory stimuli pairs were presented simultaneously in a random order. Each condition was presented four times. The subjects were asked to report whether the auditory and tactile information caused by same product (same event) or not (yes/no answer option).
Human sensitivity to vibration is highly frequency and also magnitude dependent. To eliminate the effects of magnitude on the experiment, all tactile stimuli were filtered according to ISO 5349 (frequency weighting for hand-transmitted vibration). All auditory stimuli were also filtered using the A filter. The peak-to-peak level of vibration displacement was 0.05 mm (at 80 Hz) and the sound pressure level was 56 dB(A).
Level differences between vibration intensity and loudness may cause dominance of one modality on the other modality, or masking of some perceptive aspects (Forthergill, 1972). In selecting the amplitude of the vibrations and loudness of the sounds, it was hoped to avoid masking effects between the modalities.

3. Results and Discussion

The percentages of positive responses are shown in Fig. 1 to 5 as a function of the auditory frequency (Fig. 1: Vibration frequency 10 Hz, Fig. 2: 50, Fig. 3: 63, Fig. 4: 80 Hz).
The maximum of the responses curve (Point of Subjective Equality, PSE) for a 10 Hz vibration is found at 40 Hz pure tone, and the 75 % thresholds (Just Noticeable Differences, JNDs) are 30 and 55 Hz (Fig. 1). Fundamental frequency and second harmonics of 10 Hz are assumed not to be audible for normal hearing subjects , therefore, it is possible that participants try to match the 10 Hz vibration with a 40 Hz pure tone (fourth harmonic).

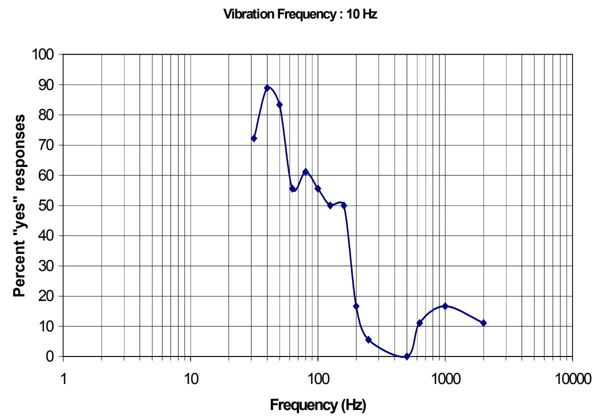

Figure 1: The percentage of positive responses for 10 Hz vibration as a function of the auditory frequency

The PSE value for a 50 Hz vibration is a 50 Hz pure tone, and also the second harmonic of 50 Hz (100 Hz) shows an increase of the percentages of positive responses as neighboring 1/3 octav band frequencies. The 75 % thresholds are 30 and 75 Hz for first harmonic and 90 and 130 Hz for the second harmonic (Fig. 2).

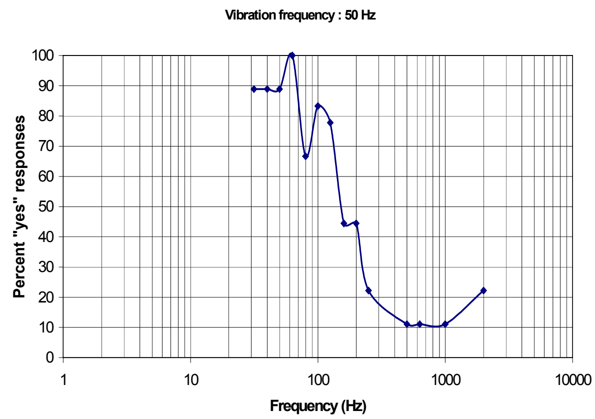

Figure 2: The percentage of positive responses for 50 Hz vibration as a function of the auditory frequency

The PSE value for a 63 Hz vibration is found at a 63 Hz pure tone, and also the second harmonic of 63 Hz (125 Hz) has a local maximum of positive responses. The 75 % thresholds are 30 and 150 Hz (Fig. 3).

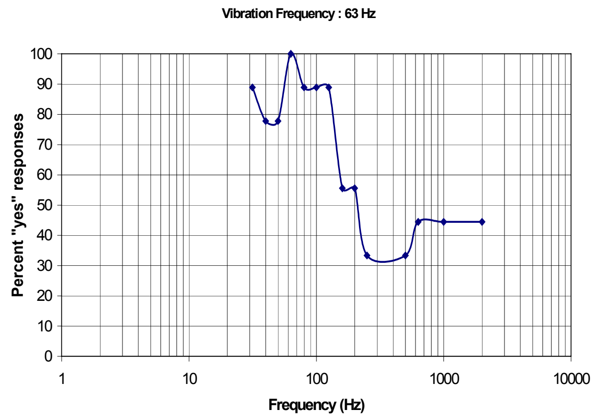

Figure 3: The percentage of the positive responses for 63 Hz vibration as a function of the auditory frequency

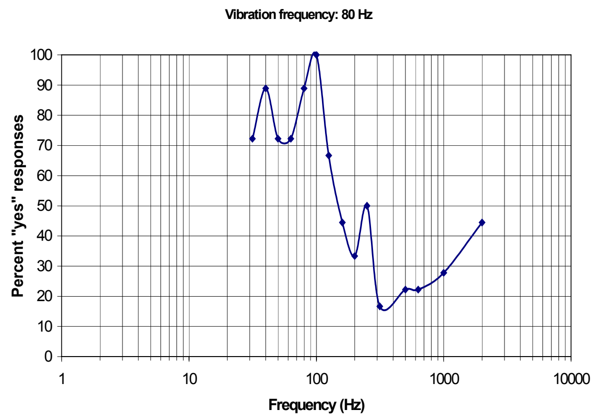

Figure 4: The percentage of the positive responses for 80 Hz vibration as a function of the auditory frequency

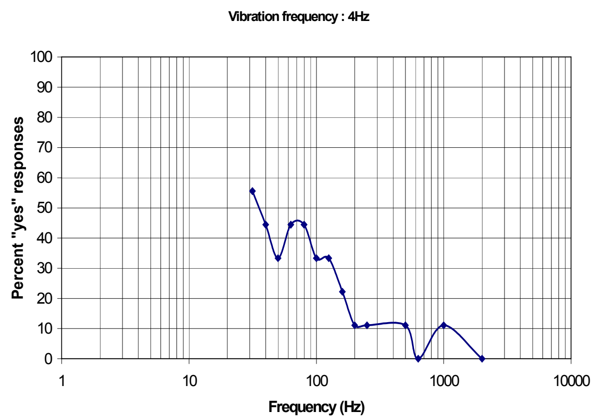

Figure 5: The percentage of the positive responses for 4 Hz vibration as a function of the auditory frequency

The PSE value for a 80 Hz vibration is found at a 100 Hz pure tone, and also at 40 Hz an increase of the percentages of suit responses is observed. The 75 % thresholds are 30 and 115 Hz (Fig. 4).The subjects could not match any suitable pure tone for a 4 Hz vibration (Fig. 3). An explanation may be that 4 Hz is more similar to an impact type tactile stimulation, and sinusoidal tone may not integrate with an impact type vibration.

4. Conclusions

The results of this study suggest that frequency is an important cue for the integration of auditory and tactile information. To find the most suitable multi-modal stimulus combination for the multi-modal integration, the subjects tend to prefer pairs having the same frequency for the auditory and tactile stimuli. In most cases, subjects judge also the second harmonic of the vibration frequency to be suitable for the auditory frequency, in order to integrate the two information. They could not integrate an impact type tactile stimulus with a high frequency auditory stimulus. The results show that physical relationship between multi-modal information plays an important role in our integration mechanism.

5. Acknowledgment

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6. References

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