Assessing the Effectiveness of Vibrotactile Feedback on a 2D Navigation Task

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Abstract. The effect of vibrotactile parameters were investigated on a 2D navigation task. Participants performed a simple navigation task reproducing directional information presented by a series of vibrotactile stimuli consisting of different levels of amplitude and frequency. Task completion time and degree of annoyance were measured. The results demonstrated that both frequency and amplitude had a significant effect on the responses. In addition, interaction effects between the two parameters were found on the responses. It was concluded that user performance and comfort are significantly affected by frequency and amplitude. The results give some insight into designing navigating information presented by vibrotactile display for visually impaired people. More studies with people with visual impairment and manipulation of other vibrotactile parameters are recommended to be applicable to the potential research.

Keywords: Tactile display, vibrotactile, haptic, navigation.

1 Introduction

Most traditional computer-based machines have relied on visual presentation to deliver information to users. However, there are cases in which visual displays are inappropriate. For example, when interacting with in-vehicle systems, the visual sensory channel can be pressured from the constant information in the traffic scene itself. This can result in the cognitive capacities that drivers have at their disposal being overloaded (Van Erp & Van Veen, 2004). Another possible case in which non-visual communication is required is for people with a visual impairment. Therefore, it is important to consider using alternative modalities through which information can be presented. The use of the auditory sense as an alternative channel for communication has been widely investigated (Blattner, Sumikawa, & Greenberg, 1989). An alternative modality which might be beneficial in these cases is the sense of touch.

The sense of touch, referred to as haptics, has been used to aid communication for people with visual impairments. For example, one use of the sense of touch by people with visual impairment is the Braille system, which enables them to read text. Another method with potential for communication via haptics is vibration. It was proposed that vibrotactile stimuli could be used to present information by manipulating differ-ent parameters of vibration (Geldard, 1960).

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Vibrotactile displays have recently been common in a variety of devices, such as mobile phones, handheld PCs and game console controllers. However, the types of vibration used in such devices are generally very simple and does not provide much information as a means of communication. Researchers have recently begun to explore the possibility of implementing vibrotactile displays for presenting more complex information, such as in navigation (Van Erp & Van Veen, 2001; Van Erp & Van Veen, 2004). However, most research uses vibrotactile displays/feedback as secondary information channel in a specific application and only tests whether it is applicable and whether the user per-formance is enhanced. Little research has been conducted to investigate the effect of vibrotactile feedback as primary modality information on enhancing users' spatial orientation.

Vibrotactile navigation systems have been developed and investigated by many studies to aid navigation for a variety of fields including car drivers, pilots, and people with visual impairment. Van Erp and van Veen (2001) designed vibrotactile icons for an in-vehicle navigation system, using vibrotactile devices mounted in a car seat. In addition, Van Veen and Van Erp (2000) have investigated the use of a vibrotactile vest to provide navigation information for airplane pilots. It was found that tactile display would be particularly useful when pilots are in harsh conditions, and tactile information might be more readily received. In addition to aiding navigation in vehicles, vibrotactile feedback has also been used to help blind or visually impaired people to navigate. For visually impaired people, Ross and Blasch (2000) designed a wearable tactile display, which indicated whether the user was walking in the right direction or if a change of direction was needed (Ghiani, Leporini, & Paternò, 2008).

Ghiani et al. (2008) developed mobile museum guide which provides vibrotactile feedback for blind users. It was designed to be easily plugged into PDAs to assist blind users in orientation. Geldard (1960) proposed that the main parameters of vibration are intensity (am-plitude), frequency, signal (waveform) duration, rhythm, and spatial location. This study investigated intensity and frequency as vibrotactile parameters for communi-cating navigation information. Intensity refers to the square of the amplitude of the signal. Since the terms intensity and amplitude are often used interchangeably, the term amplitude is mainly used in this study. Frequency refers to the rate of vibration and is expressed in Hertz (Hz). Simple navigation tasks were proposed with manipulation of these two parameters. We were interested in examining how the vibrotactile parameters affected user per-formance and annoyance on 2D navigation task.

2 Methodology

2.1 Participants

Twelve participants were recruited from the student population at a local University. Their ages ranged from 19 to 23 years (M = 21.9, SD = 2.4). None of subjects had prior experience with a similar type of the experiment.

2.2 Apparatus

A computer-controlled system was designed to generate vibrotactile information on a vibrotactile array. The computer controlled the trial conditions, manipulated parameters, and logged response data. The tactile display consisted of an elastic belt that subjects wore around their abdomen, on which the vibrotactile tactor array was attached. The tactor array was composed of four (C2 tactors (Engineering Acoustics, Inc). The C2 tactor incorporates a moving contactor that is lightly preloaded against the skin. When an electrical signal is applied, the contactor oscillates perpendicular to the skin, while the surrounding skin area is shielded with a passive housing. Four tactors contacted the left, right, front, and back of abdomen, to represent four directions (left(L), right(R), up(U), and down(D)) in the navigation task.

2.3 Task Design

The proposed navigation task was performed with the vibrotactile array belt which conveys direction information. The vibrotactile array belt has four tactors, each producing an independent vibration. A navigation task has a series of four vibrotactile stimulus. After the sequence of stimuli was presented, participants were required to mark a path in a grid paper with pencil. Each stimulus would represent one movement in the grid paper with specific direction. For example, if the sequence of vibrotactile stimulus is D-L-U-R and the participant correctly perceived the stimuli, a participant should draw a navigation path which is Down (D) first, Left (L), Up (U), and finally Right (R) from the starting point. Participants were asked to draw the path as quickly as possible and let the experimenter know when done with drawing.

The proposed navigation task needs participants' memory recall. The responses may be affected by a limited working memory capability. To this end, a screening test was designed to measure the participant's vibrotactile working memory capability. In the screening test, the number of stimulus in each sequence increased from 2 to 6. Based on the results from the screening task, participants with vibrotactile working memory less than 4 were removed from the data analysis.

2.4 Experiment Design and Variables

The experiment followed a factorial combination within-subject design. Amplitude and frequency were the independent variables. There were two levels of amplitude in the study. The amplitude level was created by choosing the gain value provided by the tactor controller: large amplitude (A_1 = 4.1), and small amplitude (A_2 = 1.0). Since only sinusoidal stimuli were available, frequency was the number of cycles of sinusoidal stimuli occurring in one second. There were three levels of frequency in the study: high frequency (F_1= 349 Hz) (highest frequency available provided by the controller), medium frequency (F_2 = 200 Hz), and low frequency (F_3= 50 Hz). Task completion time and the degree of user's annoyance were measured in terms of milisecond and rating scale 1(small) though 7(large) respectively.

2.5 Procedure

The participants received instructions describing the experiment. They were asked to read and sign an informed consent. After the belt was fastened, they were asked whether they could distinguish vibration with different levels of parameters. The experiment started with a screening test. The screening test included 15 trials with the number of vibrotactile stimuli varying from 2 to 6. Five minutes break was provided after the screening test. The experiment session was composed of 36 trials, with 4 vibrotactile feedback in each trial. Rest was provided every 10 trials and whenever requested by the participant. In both the screening test and the following experiment session, the trials were completely randomized to avoid the sequence effect. During the second half of the trials, the participants were asked to mark a degree of annoyance between 1 and 7 for each trial. The whole experiment lasted around 45 minutes.

3 Result

Each dependent variable was analyzed using an ANOVA with amplitude (high, low) x frequency (high, medium, low) factors. Post hoc analyses were completed using the Tukey HSD test with the alpha level set at .05. Table 1 summarizes the significant effects for the responses.

Table 1. Significant effects for performance parameters

Parameter	Effect	F-Value	p-value
	Frequency	$F_{2,426} = 99.15$	<0.0001
Completion Time	Amplitude	$F_{1,426} = 45.72$	<0.0001
	Frequency*Amplitude	$F_{2,426} = 14.12$	<0.0001
	Frequency	$F_{2,426} = 33.03$	<0.0001
Annoyance	Amplitude	$F_{1,426} = 31.55$	<0.0001
	Frequency*Amplitude	$F_{2,426} = 9.20$	0.0001

Result showed that frequency had a significant effect on task completion time ($F_{2, 426} = 99.15$, p = <0.0001). Post analysis of frequency showed that participants had significantly shorter completion time in medium frequency (M = 7686, SD = 4972) than high frequency (M = 10410, SD = 10239), which also had significantly shorter completion time than low frequency (M = 23625, SD = 15478). Amplitude ($F_{1, 426}$ = 45.72, p < 0.0001) was also found to have significant effect. Post analysis of amplitude showed that participants had significantly shorter completion time in large amplitude (M = 10565, SD = 10426) than small amplitude (M = 17250, SD = 14551).

A significant interaction effect between frequency and amplitude was found, ($F_{2, 426}$ = 14.12, $p < 0.0001$). As Fig. 1 showed, the task completion time decreased as amplitude increased at all frequency levels. But, the decrease rate was much greater at low frequency than medium and high frequency.

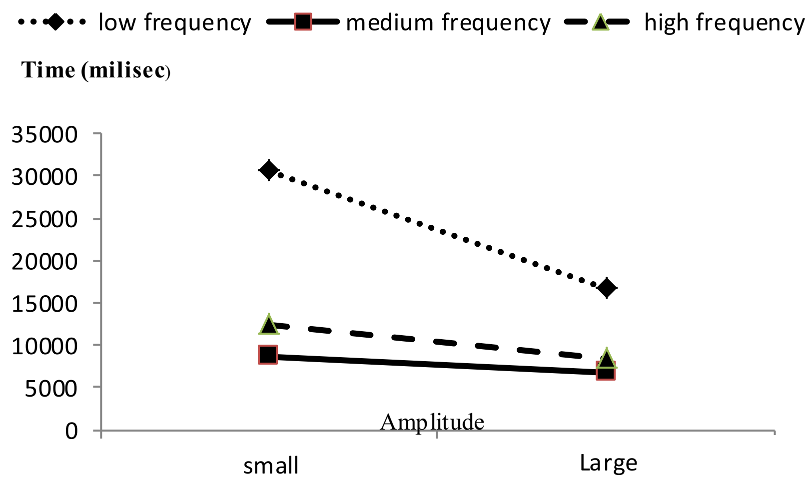

Fig. 1. Interaction effect between frequency and amplitude on task completion time

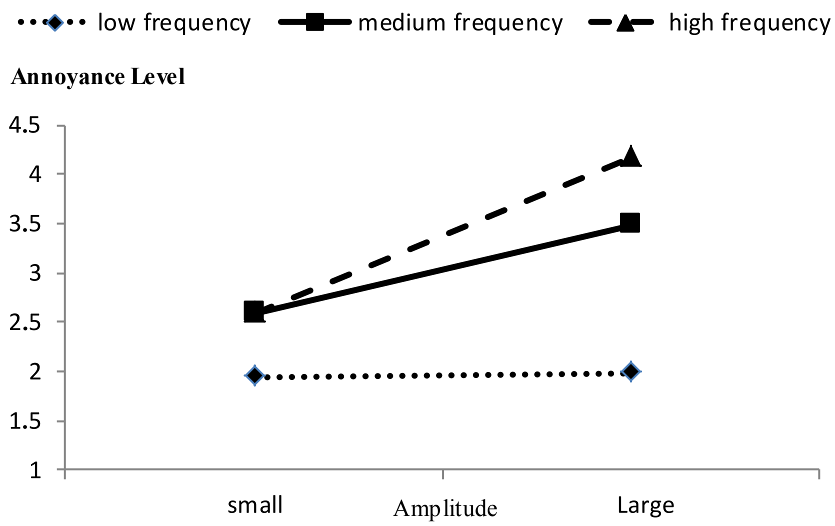

Fig. 2. Interaction effect between frequency and amplitude on annoyance

In addition, frequency had a significant effect on the annoyance level ($F_{2,\ 426} = 33.03$, $p < 0.0001$). Post analysis of frequency showed that participants had a significantly lower annoyance level in low frequency ($M = 1.96$, $SD = 1.65$) than medium ($M = 3.03$, $SD = 1.54$) and high frequency ($M = 3.38$, $SD = 1.68$). Amplitude ($F_{1,\ 426} = 31.55$, $p < 0.0001$) was also found to have significant effect. Post analysis of amplitude showed that participants had a significantly lower annoyance level in small amplitude ($M = 2.37$, $SD = 1.67$) than in the large amplitude ($M = 3.20$, $SD = 1.69$).

A significant interaction effect between frequency and amplitude was found ($F_{2, 426} = 9.20$, $p = 0.0001$). As Fig. 2 showed, the user annoyance level increased as amplitude increased at all frequency levels. However, the increase rate also increased as frequency level increased. In other words, the increase rate was largest at high frequency, and smallest at low frequency.

4 Discussion

The results of the study illustrated the effect of the parameters of the vibrotactile display in a navigation task. A significant effect of the two parameters on task completion time and user annoyance was found.

Amplitude is the most direct measure of whether the stimulus is strong or weak. Therefore, it is self-evident that vibrotactile stimuli with larger amplitude are easier for participants to perceive than those with smaller amplitude. In terms of annoyance, vibrators can generate sufficient heat to cause a painful sensation of heat on the user's skin. In addition, tactile stimuli are hard to ignore if the user does not want to sense them (Van Erp & Van Veen, 2001). However, in the study, participants felt moderately annoyed in the large amplitude condition. Since the on-time duration of the tactile display was short (shorter than 2 seconds) users may not have been annoyed regardless of amplitude levels. To better understand how the participants' annoyance level changes, a time series analysis of annoyance level may help. To improve the task performance without sacrificing user friendliness, more levels of amplitude should be tested in future research.

5 Conclusion

This study investigated the effect of vibrotactile feedback on a navigation task. Vibrotactile amplitude and frequency were manipulated to present different patterns of vibrotactile stimuli. The participants performed 2D navigation tasks with vibrotactile stimuli conveying the moving direction. The results showed that all the parameters have a significant effect on user performance (task completion time) and comfort (the degree of annoyance). These results should provide insight to the real-world applicability of the vibrotactile feedback as a primary modality information provider.

In the present study all subjects were healthy people without any visual impairment. It is expected that vibrotactile would be a significant aid to those with visual impairment. Therefore, more studies with the participants having visual impairment are needed to ensure that the results of the study will be applicable to those potential users. In addition, other vibrotactile parameters, such as on-time duration or rhythm, should be investigated.

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