Vibration Perception in Mobile Contexts

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ABSTRACT

Human sensitivity to vibration declines in mobile contexts. Designers of wearable haptic systems need to compensate for the effects of movement and distraction so that tactile display information is perceived consistently. Our objective is to compare the sensitivity of seven body sites in typical mobile contexts. We show that the thigh is least sensitive and the wrists are the most sensitive of the body sites tested.

KEYWORDS: Vibration, Sensitivity, Mobile Contexts, Movement, Distraction, Wearable Haptics.

INDEX TERMS: H.5.2 [**Information Systems**]: User Interfaces – *Haptic IO*.

1 INTRODUCTION

Different body sites have been considered for wearable tactile displays, such as the waist or wrists, and haptic information has improved the performance of pilots and drivers. But it is well known that some body sites, such as the back, are less sensitive than other areas, such as the wrist. However, when a body part is in motion, it becomes less sensitive to stimuli [1] and vibration patterns may be misinterpreted or undetected. For wearable haptic systems, this is especially troublesome, since the systems will commonly be used in mobile situations. Crudely increasing the vibration intensities is unsatisfactory since portable tactile displays should be powered by minimal energy and the vibrations should be comfortable on the skin. In this paper we tackle unpredictable vibration sensitivity by finding body sites that are less susceptible to changes in sensitivity.

2 RELATED WORK

Wearable tactile systems have been the focus of many papers in the last decade because of its variety of applications. Ertan et al. introduced a wearable navigation system for guidance of blind users in unfamiliar indoors areas [2]. They used a vibrotactile display consisting of a 4-by-4 array of micromotors embedded in the back of a vest to communicate stop signal or the four cardinal directions to the user. Bosman et al. developed a wearable haptic guidance system that could be attached to both wrists of a pedestrian to guide him inside unknown buildings [3]. Tsukada and Yasumura developed a belt with eight vibrotactile haptic displays to guide a pedestrian towards destinations, predefined locations, or valuables left behind [4]. Subjects could feel vibrations when stopped but often failed to recognize vibrations when walking but they could stop for a moment to recognize the direction of the vibration. This suggests that the effect of movement on detection of tactile stimuli which has been studied in the field of neural psychology [5][6] is in fact significant and ignoring it will harm the effectiveness of tactile user interfaces.

3 METHODS

16 volunteers (8 male) took part. Half the male and half the female participants first sat in a chair and subsequently walked on a treadmill, while the other half walked on a treadmill first and subsequently sat in a chair. A tall chair was chosen in an attempt to keep the participants' view of the screen consistent between the sitting and walking conditions.

During half of the walking and half of the sitting trials, participants directed their attention to the scene, which was approximately four meters wide and three meters high. The scene showed twenty-five blocks bouncing slowly around a three-dimensional room. One block was highlighted and participants were asked to count how many times the highlighted block hit any of the walls of the room. The task was chosen as a controllable continuous workload characteristic of everyday attention and memory tasks, but was not so distracting that participants were liable to fall off the treadmill. Participants reported their collision count at the end of each workload condition.

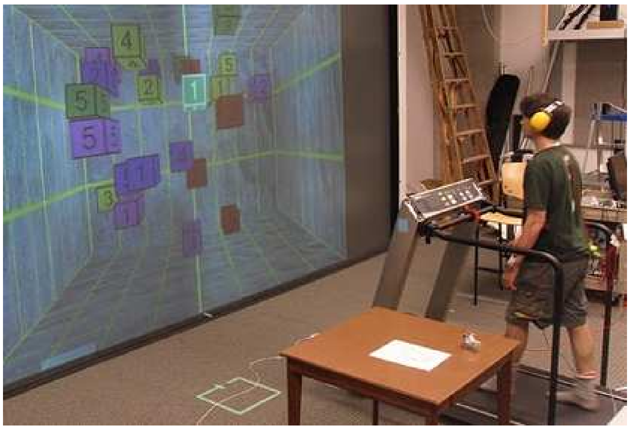

Figure 1: Experiment Setup

We chose seven different body sites for the tactors corresponding to common wearable haptic sites: chest (left and right, directly below the collar bone), spine, outer thighs, stomach (left and right, halfway between navel and hip bone), feet (on the top surface of the foot), wrists, upper arms. During all the conditions, participants had to press right button on a modified computer mouse when they detected vibration from a single tactor. We recorded detections discarding any reactions later than 3500 ms. The time between tactor vibrations was randomized between four and six seconds. Tactors where energized for 500 ms. Vibrations were presented in randomized sites. Vibration intensities were presented in randomized order.

4 RESULTS

As the dependent variable is dichotomous, logistic regression is an appropriate statistical test. We include 5 factors: Intensity, Task, Movement, and Body Site are within-subject factors, and Gender is a between-subject factor. Gender, Task, Movement, and Body Site are categorical variables; the spine was used as the reference point for Body Site. As expected, the omnibus test of the model coefficients is highly significant, $p < 0.001$.

Table 1: Results of logistic regression

	B	S.E.	Wald	df	Sig.	Exp(B)
Gender(1)	.215	.064	11.158	1	.001	1.240
Intensity	1.692	.036	2195.889	1	.000	5.429
Task(1)	.054	.064	.700	1	.403	1.055
Movement(1)	1.778	.071	625.023	1	.000	5.919
BodySite			649.684	6	.000	
BodySite(1)	-1.186	.121	96.079	1	.000	.305
BodySite(2)	.878	.125	49.060	1	.000	2.407
BodySite(3)	-.972	.121	64.962	1	.000	.378
BodySite(4)	-2.086	.125	279.697	1	.000	.124
BodySite(5)	.096	.121	.622	1	.430	1.100
BodySite(6)	-.102	.121	.715	1	.398	.903
Constant	-2.651	.117	511.428	1	.000	.071

We then turn to the results of the regression, listed in Table 1. The factors Gender, Intensity, Movement, and Body Sites are statistically significant; their coefficients in the regression equation are significantly different than zero. Task, however, does not have a coefficient significantly different from zero. We now explore Body Site in more depth. The six Body Site levels in the table are Foot, Wrist, Stomach, Thigh, Chest, and Arm; Spine is the reference level. We see that Foot, Wrist, Stomach, and Thigh are significantly different than the Spine; this is also apparent in Figure 4, where we note that the wrist is more sensitive than the spine, and the Foot, Stomach, and Thigh are less sensitive.

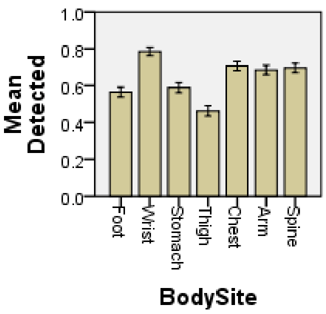

Figure 4: Detection rates at different body sites.

We now report the other main effects. For Gender, males show a slightly higher detection rate of 65.3% compared to 63.0% for females. The Movement factor showed an important result: participants detected 73.9% of stimuli when sitting, but only 54.4% while walking. As hinted at by the regression results, Task did not show significant differences; the detection rate with and without the visual distraction task was 64.4% and 63.8%, respectively. There were strong results for Intensity, as expected. 0 was the weakest intensity level and 4 was the strongest level. At intensity 4 almost all stimuli were detected, while at intensity 0 only 16.7% were detected.

Interaction effects are difficult to analyze using regression, so we will present these results graphically rather than with tests of significance. There is a strong interaction between movement and intensity, as shown in Figure 5. At the highest intensity there is no difference between movement conditions, while at lower intensities the detection rate is much lower while walking.

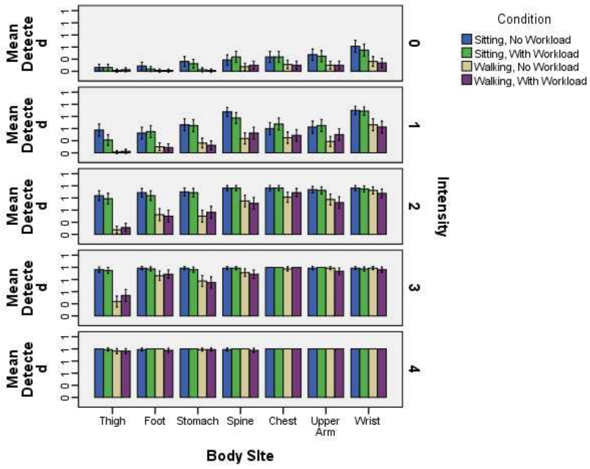

Figure 5: Sensitivities for five intensities across the four conditions.

All body sites are negatively affected by movement, but some sites are affected more than others, as illustrated in Figure 5. Thighs are particularly strongly affected. The feet and stomach also appear to be strongly impacted. These are also areas of motion: the feet move linearly and can feel heel strikes on the treadmill surface, while the stomach undergoes twisting motions as the arms swing.

5 CONCLUSION

The results of our experiment confirm the affect of body motion on detection of vibrations. We discovered that movement in a typical mobile context (i.e. walking) affects detection of vibrations on the thighs more than other body sites. Also, reaction times to vibrations are significantly reduced during walking. However, it appears that visual distraction in a mobile context may not have a significant effect on detection of vibration on any body site. In general, the thigh is not suited for applications that require discriminating among vibration patterns in everyday wearable haptics. This may be of interest to cell phone users who typically receive vibration notifications on the site most susceptible to movement effects. On the other hand, the data suggest that the chest, upper arm, and wrist are sufficiently sensitive to lower energy vibrations while the body is in motion.

6 REFERENCES

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