Vibration Perception in Mobile Contexts

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ABSTRACT

Human sensitivity to vibration declines in mobile contexts. Designers of wearable haptic systems must account for the effects of movement and distraction so that tactile display information is perceived consistently. We compared the sensitivity of seven body sites in simulated mobile contexts, and found that the thigh is least and the wrists the most sensitive of the sites tested.

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

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

1 INTRODUCTION

Many body sites have been considered for wearable tactile displays, and vibratory information has improved performance of pilots and drivers. It is well known that some body sites are less sensitive than other areas, e.g. back versus wrist – a function of skin type and sensor density and composition. 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, often used in ambulatory situations this is especially troublesome. Merely increasing vibration intensity is unsatisfactory due to concerns of power and comfort. In this paper we tackle unpredictable vibration sensitivity by seeking body sites that are less susceptible to changes in sensitivity, comparing diverse sites (a few studied elsewhere) in a single study.

2 RELATED WORK

Wearable tactile systems have been the focus of many papers in the last decade due to 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 a 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; 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.

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3 METHODS

16 volunteers (8 male) took part. The participants (counterbalanced for gender and condition) sat in a chair in one condition, and walked on a treadmill in the other. A tall chair maintained a consistent view of the screen between conditions. We attached thirteen vibrotactile displays to seven body sites corresponding to wearable sites based on past studies and potential practicality: 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, and upper arms.

During half of the trials in each condition, participants performed a workload task targeting vision, memory, and attention as shown in Figure 1. A screen four meters wide and three meters high displayed twenty-five blocks bouncing slowly around a three-dimensional room; one block was highlighted and participants counted the times the highlighted block hit any of the walls. The task was chosen for its controllable continuous workload typical of normal pedestrian activity, with distraction adjusted so that participants would not fall off the treadmill. Participants reported their collision count at the end of each workload condition.

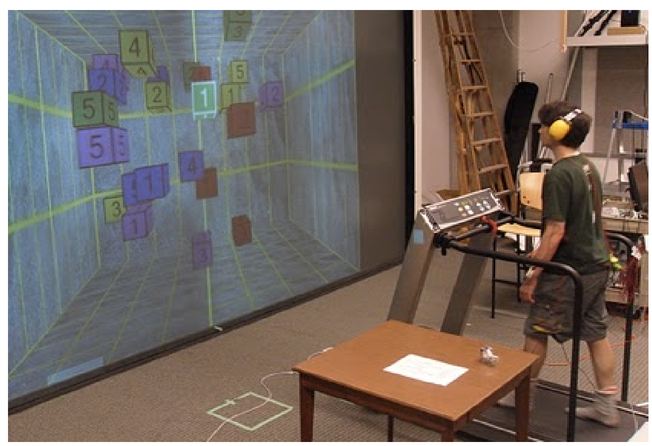

Figure 1: Experiment setup. Subject responds to vibrations while walking on the treadmill and doing the visual task.

During all conditions, participants pressed the right-hand button on a modified computer mouse when they detected vibration from any tactor. Vibrations were presented in randomized sites, intensities in randomized order, and the interval between 500 ms-duration tactor vibrations was randomized between four and six seconds. Reactions later than 3500 ms were discarded.

4 RESULTS

As the dependent variable (detection rate) is dichotomous, we performed a logistic regression on five factors: Intensity, Task, Movement, Body Site (within-subject) and Gender (between-subjects). Gender, Task, Movement, and Body Site (with spine as a reference point) are categorical variables. The omnibus test of the model coefficients is significant ($p < 0.001$). The regression results are listed in Table 1, where main effects Gender, Intensity, Movement and Body Sites are seen to be statistically significant.

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

The six Body Site levels in the table are Foot, Wrist, Stomach, Thigh, Chest, and Arm; Spine is the reference level. Foot, Wrist, Stomach, and Thigh are significantly different than Spine; Figure 2 further shows that the Wrist is more sensitive than the Spine, and the Foot, Stomach, and Thigh are less sensitive.

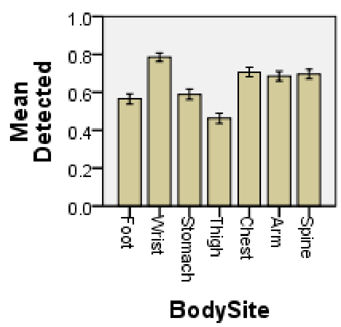

Figure 2: Detection rates at different body sites.

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 suggested 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. Predictably, there were strong results for Intensity: at intensity 4 (the strongest) almost all stimuli were detected, while at intensity 0 (weakest) 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 3. At the highest intensity there is no difference between movement conditions, while at lower intensities the detection rate is much lower while walking.

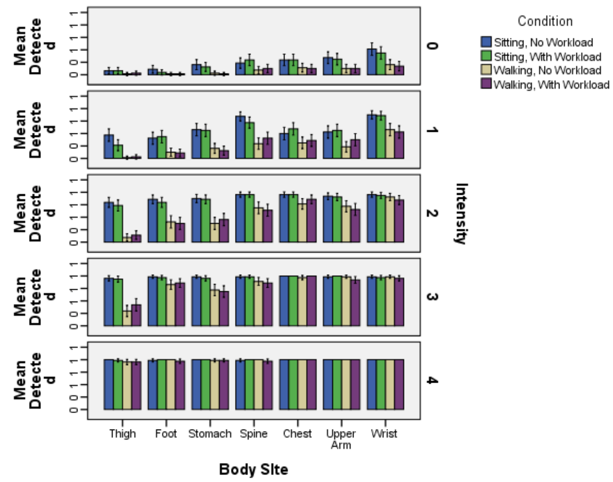

Figure 3: Sensitivities for five intensities across the four conditions.

All body sites are negatively affected by movement, but some sites more than others, as illustrated in Figure 3. Thighs, and to a lesser extent feet and stomach are particularly strongly affected. These are also areas of motion: the feet 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 effect 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.

References

[1] C. E. Chapman, M. C. Bushnell, D. Miron, G. H. Duncan, and J. Lund. Sensory perception during movement in man. In *Experimental Brain Research*, vol. 68, pages 516-524, 1987.

[2] S. Ertan, C. Lee, A. Willets, H. Tan, and A. Pentland. A wearable haptic navigation guidance system. In *Digest of the Second International Symposium on Wearable Computers*, pages 164-165, 1998.

[3] S. Bosman, et al. GentleGuide: An exploration of haptic output for indoors pedestrian guidance. In *Lecture Notes in Computer Science*, pp. 358-362, 2003.

[4] K. Tsukada and M. Yasumura. Activebelt: Belt-type wearable tactile display for directional navigation. In *Lecture Notes in Computer Science*, vol. 3205, pp. 384-399, 2004.

[5] R. W. Angel and R. C. Malenka. Velocity-dependent suppression of cutaneous sensitivity during movement. In *Experimental neurology*, vol. 77, pp. 266-274, 1982.

[6] L. Post, I. Zompa, and C. Chapman. Perception of vibrotactile stimuli during motor activity in human subjects. In *Experimental Brain Research*, vol. 100, pp. 107-120, 1994.