Comprehension of Vibrotactile Route Guidance Cues

Andre Garcia[1], Jesse Eisert[1], Carryl L. Baldwin[1], and Victor Finomore[2]

[1] Department of Psychology, George Mason University, United States
[2] Human Effectivness / Battlespace Acoustics Branch, Air Force Research Lab, United States
agarciagmu@gmail.com, {jeisert,cbaldwi4}@gmu.edu,
victor.finomore@wpafb.af.mil

Abstract. Two experiments with 24 participants each evaluated comprehension of vibrotactile route guidance instructions via a tactile seat in a driving simulator. Vibrotactile patterns were presented from an array of 8 tactors arranged in two rows of 4 tactors located in the seat pan. A faster pulse rate and a slower pulse rate as well as four distinct locations on the tactile seat (Front-Left, Front-Right, Back-Left, Back-Right) created 8 different combinations of stimuli. Across all participants, the most consistent interpretation was that the faster pulse rate played from the back two tactors was perceived as an instruction to make the next most immediate turn while a slow pulse rate from the front two tactors was interpreted as a cue directing the user to the direction of the next eventual turn. Results have direct implications for design of effective vibrotactile and multimodal route guidance systems.

1 Introduction

Vibrotactile technology for in-vehicle use has shown increasing promise and popularity of late (Scott & Gray, 2008; Mohebbi, Gray, Tan, 2009). General Motors currently offers a feature on their Cadillac XTS sedan where the seat pan vibrates if there is a potential rear-end collision while you are reversing. This is just one example among several other current production vehicles that come equipped with vibrotactile technology. The tactile modality offers a way to relay information that is privileged to only the user. Tactile collision warning systems have been shown to effectively reduce reaction time (Scott and Gray, 2008), and may be particularly effective in multimodal systems (Mohebbi, Gray, & Tan, 2009).

The tactile modality is a way to provide the user information without relying on visual or auditory attentional resources that are often in high demand in many operational settings. Recent studies investigating vibrotactile route guidance systems have shown great potential. Van Erp and Van Veen (2004) demonstrated how a tactile navigation system display can reduce a driver's perceived workload compared to a visual display, particularly in high workload settings. Van Erp, Van Veen, Jansen, and Dobbins (2006) investigated the efficacy and feasibility of a tactile navigation waist belt and found that directional information is easy, intuitive, and requires almost no training, although their results on how to map distance were inconclusive. Vibrotactile systems for in-vehicle technology have generally been limited to collision warning

D. Harris (Ed.): EPCE/HCII 2013, Part II, LNAI 8020, pp. 12–18, 2013.

systems or lane departure warning systems and relatively few studies have investigated the use of vibrotactile systems for in-vehicle route guidance.

Garcia, Finomore, Burnett, Baldwin & Brill (2012) conducted a study to investigate waypoint navigation via a visual, auditory, tactile, or multimodal route guidance system in dismounted soldiers. Participants were lead via the various uni- or multimodal route guidance system from waypoint to waypoint and were instructed to look for certain landmarks throughout the environment. For the tactile modality, a vibrotactile belt was used, which consisted of 8 tactors equally spaced around the waist (For more information on this belt see: Merlo, Duley, & Hancock, 2010; Cholewiak, Brill, & Schwab, 2004). Overall, the unimodal geocentric visual condition was the slowest and least accurate at guiding the user from waypoint to waypoint to complete a course through a virtual environment. Additionally, every multimodal condition was as fast as its fastest unimodal condition, i.e. there was no additive effect. This experiment provides evidence for tactile navigation and its effectiveness compared to other modalities to guide dismounted soldiers. The current experiment is intended to build on this knowledge and investigate how to best design a tactile navigation for in-vehicle use.

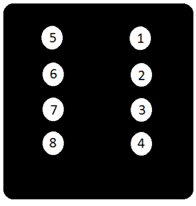
The goal of this investigation was to determine the most intuitive mapping of different vibrotactile patterns for use as route guidance instructions. It was predicted that a redundant mapping consisting of presenting a slower pulse rate from the front two tactors to represent a preliminary cue and a faster pulse rate played from the back two tactors to represent an immediate cue, indicating to turn at the next available location would lead to the most consistent interpretation relative to formats providing information using only tactor location or pulse rate.

2 Experiment 1

Procedure. After providing written informed consent, participants sat in a high fidelity driving simulator equipped with a tactile seat pan. A schematic of how the tactors are arranged on the seat pan is available on the right side of Table 1. The driving simulator was created by RealTime Technologies, Inc. The vibrotactile seat was custom designed and constructed by Engineering Acoustics, Inc and contained an array of 8 C2 tactors. Although no motion was used for this study, the simulator is capable of yaw and pitch motion. The yaw motion allows for 180 degrees of motion, 90 left and 90 right and the pitch motion allows for 1.5 degrees of pitch motion to simulate abrupt acceleration and braking. The simulator features 3 screens that allows for 180 degree forward field of view. The cab was built from a 2002 Ford Taurus and is operated similar to a real car with an automatic transmission.

Before the experiment began, a variety of vibrotactile patterns were presented to the participant to familiarize them with the seat. Participants were then shown an image of an overhead view of a street with a stationary car and six possible turn options. Each turn was labeled with a corresponding response choice (letters A-F). This can be seen in Figure 1. Eight combinations of stimuli (front or back, left or right, slow or fast pulse rate) were presented twice each in randomized order. For the two pulse rates the "slow" stimuli had an interpulse-interval (IPI) of 475 ms and the "fast" stimuli had an IPI of 118 ms. The properties of each of the stimuli are described in table 1. After receiving each stimulus participants were asked to identify which direction they would turn, for a total of 16 questions.

Table 1. Details of each condition and type of cue

Location	Slow	Fast	
Front	Pulse rate 3.69 Tactor 5+6 For Left Turn Tactor 1+2 for Right Turn	Pulse rate 7.87 Tactor 7+8 for Left Turn Tactor 3+4 for Right Turn	
Back	Pulse rate 3.69 Tactors 6+7 for Left Turn Tactors 2+3 for Right Turn	Pulse rate 7.87 Tactors 6+7 for Left Turn Tactors 2+3 for Right Turn	

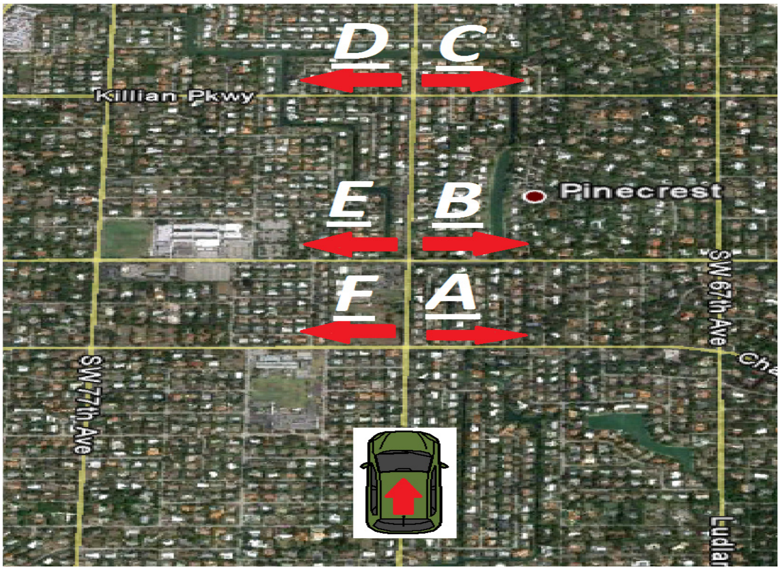


Fig. 1. Overhead view of Response Options

2.1 Results and Discussion

The results from experiment one suggest that the most agreed upon responses were that a slow pulse rate played in the front two tactors best represent a preliminary cue (45% Front-Right-"Slow", 37.5% Front-Left-"Slow") whereas a fast pulse rate played in the back two tactors best represent an immediate navigational cue (83% Back-Right-“Fast”, 83% Back-Left-“Fast”).

When the front right tactors were activated at the slow pulse-rate (tactors 1 and 2), 8 participants indicated they would turn at option A, 5 at option B, and 11 at option C. When the front left tactors were activated at the slow pulse rate, 8 participants indicated they would turn at option F, 9 indicated they would turn at option E, and 7 responded with option D. This suggests that there is no clear consensus on what participants perceived as a slow pulse rate vibrating on either side of the front half of the seat meant. When the back two tactors on the right side (tactors 3 and 4) were activated at a slow pulse rate, 13 participants indicated they would take turn A, 6 participants indicated turn B, and 5 participants indicated turn C. When the back two tactors on the left side (tactors 5 and 6) were activated at a slow pulse rate, 4 participants indicated they would turn at option D, 8 at option E, and 12 indicated they would turn at option F.

When the front right tactors (tactors 1 and 2) were activated at a fast pulse rate, 11 participants indicated they would make turn A, 4 indicated they would turn at option B, and 9 indicated they would turn at option C. For the back-right-fast pattern, 20 participants indicated they would make turn A, 3 indicated they would turn at option B, and 1 indicated they would turn at option C. For the front-left-fast pattern, 8 participants indicated they would turn at option D, 7 indicated they would turn at option E, and 9 indicated they would turn at option F. For the back-left-fast combination, 2 participants indicated they would turn at option D, 2 participants indicated they would turn at option E, and 20 indicated they would turn at option F. These results can be seen in Table 2.

Table 2. Participant responses indicating which turn location they thought each stimulus represented

Turn	Front Left		Front Right		Back Left		Back Right	
	Fast Pulse Rate	Slow Pulse Rate	Fast Pulse Rate	Slow Pulse Rate	Fast Pulse Rate	Slow Pulse Rate	Fast Pulse Rate	Slow Pulse Rate
A			11 (46%)	8 (33%)			20 (84%)	13 (54%)
B			4 (17%)	5 (21%)			3 (12%)	6 (25%)
C			9 (37%)	11 (46%)			1 (4%)	5 (21%)
D	8 (33%)	4 (17%)			2 (8%)	4 (17%)		
E	7 (30%)	8 (33%)			2 (8%)	8 (33%)		
F	9 (37%)	12 (50%)			20 (84%)	12 (50%)		

The results of experiment one suggest that a slow pulse rate on the front half of the seat indicates a preliminary cue giving the participant a “heads-up” as to which direction the next eventual turn will be, but not necessarily when that turn will be. Conversely, a fast pulse rate to either side on the back half of the seat most clearly indicated an immediate instruction to make the next possible turn.

3 Experiment 2

Experiment two followed the same procedure as experiment one except the perspective of the image with the response options was changed to a third-person view instead of a birds-eye view. The viewing angle was manipulated to give the participants a more realistic point of view compared to the overhead view of experiment 1, as shown in figure 2 below.

3.1 Results and Discussion

The results from experiment two are consistent with experiment one in that, the most agreed upon responses were that a slow pulse rate played in the front two tactors best represent a preliminary cue whereas a fast pulse rate played in the back two tactors best represent an immediate turn instruction. The results from experiment two are summarized in table 3 below. In sum, there was no difference in how participants responded between a birds-eye view and a third person view. Table 3 shows results on which turn a participant indicated they would make, regardless of pulse-rate.

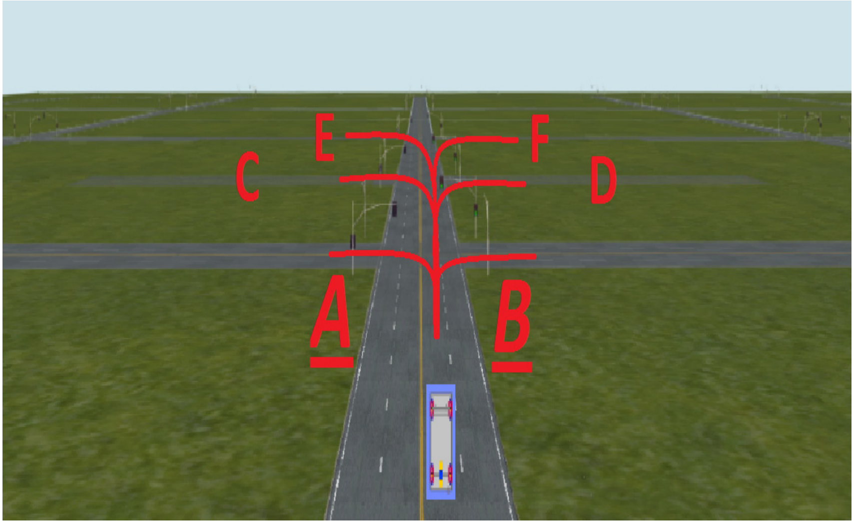


Fig. 2. Birds Eye View of Response Option

4 General Discussion

As new technology based systems begin to trickle into modern vehicles, attention should be paid towards seamlessly integrating these systems. The goal of this study was to better understand how to design a route guidance system using a tactile seat. The results suggest that both pulse rate and location and potentially the interaction between the two can affect perception of route guidance instructions. Results indicated that without training mappings between tactors located in the seat and navigational instructions are not consistent. Results of the current investigation demonstrate that depending on the location and pulse rate of the cue, the perceived meaning will differ. Some people intuitively perceive a vibration towards the front of the leg to mean make an immediate turn while others perceive the same location to map to a more distal turn. Further research is currently being conducted to examine how quickly users may learn to comprehend a designed mapping and if they can use this mapping during simulated driving as a a navigation system. Future research should also strive to increase fidelity and assess the additive effect of multimodal route guidance systems. It is also suggested that these systems be assessed concurrently with the simultaneous use of other types of in-vehicle technology such as infotainment systems and collision warning systems.

Table 3. - Results by Location from Experiment 2

Turn	Front Left		Front Right		Back Left		Back Right	
	Fast Pulse Rate	Slow Pulse Rate	Fast Pulse Rate	Slow Pulse Rate	Fast Pulse Rate	Slow Pulse Rate	Fast Pulse Rate	Slow Pulse Rate
A	6 (30%)	5 (25%)			16 (80%)	17 (85%)		
B			9 (45%)	4 (20%)			16 (80%)	11 (55%)
C	8 (40%)	9 (45%)			3 (15%)	3 (15%)		
D			6 (30%)	8 (40%)			3 (15%)	4 (20%)
E	6 (30%)	6 (30%)	1 (5%)		1 (5%)			
F			4 (20%)	8 (40%)			1 (5%)	5 (25%)

Currently, our lab is conducting additional research extending these results to an examination of wayfinding performance and spatial memory. Another future direction of this line of research would be to investigate individual differences in wayfinding display preferences based on spatial abilities and sense of direction. Garcia et al. (2012) suggest that individuals differ in their ability to understand and use certain navigational display formats depending on their sense of direction. Additional individual differences research conducted by Baldwin and Reagan (2009) suggests that individuals with low spatial abilities may rely on verbal working memory when learning a route while navigating where as those with a good sense of direction rely more on visuospatial working memory. They assessed this by having participants learn a route while performing either a concurrent verbal task (articulator suppression) or a visuospatial tapping task. They found that those with a poor sense of direction had more difficulty while having to perform a concurrent verbal task, suggesting an interference with their verbal working memory. Conversely, those with a good sense of direction experience more interference while attempting to learn a route while performing a concurrent visuospatial tapping task, suggesting that the two tasks - navigation and the tapping task - were both fighting for visuospatial working memory resources at the same time. Vibrotactile stimuli may induce an egocentric mapping since they require direct contact with the touch receptors. However, coding via location may induce a visuospatial code. Individual differences in navigation strategy may be able to predict the preferred or most effective way to display navigational information to the user based on individual spatial abilities. However, it will also be important to examine the effectiveness and potential impact of vibrotactile navigational systems if vibrotactile stimuli are being used to present other forms of time critical information like collision warnings. Future systems must ensure that tactile overload does not supplant visual or auditory overload.

References

1. Baldwin, C.L., Reagan, I.: Individual Differences in Route-Learning Strategy and Associated Working Memory Resources. Human Factors 51(3), 368–377 (2009); Garcia, A., Finomore, V., Burnett, G., Baldwin, C.L., Brill, C.: Individual Differences in Multimodal Waypoint Navigation. In: Proceedings of the 56th Annual Meeting of the Human Factors & Ergonomics Society, Boston, MA (2012)
2. Cholewiak, R.W., Brill, J.C., Schwab, A.: Vibro-tactile localization on the abdomen: Effects of place and space. Perception and Psychophysics 66, 970–987 (2004)
3. Garcia, A., Finomore, V., Burnett, G., Baldwin, C.L., Brill, C.: Individual Differences in Multimodal Waypoint Navigation. In: Proceedings of the Human Factors and Ergonomics Society 56th Annual Meeting (2012)
4. Scott, J.J., Gray, R.: A comparison of tactile, visual, and auditory warnings for rear-end collision prevention in simulated driving. Human Factors 50(2), 264–275 (2008)
5. Merlo, J.L., Duley, A.R., Hancock, P.A.: Cross-modal congruency benefits for combined tactile and visual signaling. American Journal of Psychology 123(4), 413–424 (2010)
6. Mohebbi, R., Gray, R., Tan, H.Z.: Driver reaction time to tactile and auditory rear-end collision warnings while talking on a cell phone. Human Factors 51(1), 102–110 (2009)
7. Van Erp, J.B.F., Van Veen, H.A.H.C., Jansen, C., Dobbins, T.: Waypoint Navigation with a Vibrotactile Waist Belt. ACM Transactions on Applied Perception 2(2), 106–117 (2006)
8. Van Erp, J.B.F., Van Veen, H.A.H.C.: Vibrotactile in-vehicle navigation system. Transportation Research Part F 7, 247–256 (2004)