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Individual Differences in Perception and Performance of Advanced Navigation Systems

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INDIVIDUAL DIFFERENCES IN PERCEPTION AND PERFORMANCE OF ADVANCED NAVIGATION SYSTEMS

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We examined individual differences in use and preference for tactile route guidance formats. Participants drove a simulated vehicle through counterbalanced pairings of four distinct cities using one of four navigation systems (three tactile and one auditory control). One tactile system used only pulse rate, the second system used only tactor location, and the third used both pulse rate and location to convey guidance instructions. All navigation systems provided both a preliminary and an immediate cue indicating to take the next most immediate turn. Individual differences in sense of direction resulted in different preference ratings without any observed performance differences. The pulse-rate route guidance system was the most commonly preferred system, especially for those with a poor sense of direction. All four systems resulted in equivalent wayfinding performance and support previous literature indicating that tactile guidance systems can effectively support navigation in unfamiliar environments, even for individuals with poor sense of direction.

Tactile technology is becoming more prevalent in various new in-vehicle systems such as lane departure warnings and driver alertness warnings. The Ford Motor Company's "Lane Keeping System" informs the driver they are drifting out of their lane by vibrating the steering wheel. Mercedes Benz also uses a steering wheel vibration to alert the driver to pay attention to the road when the system senses the driver is fatigued or drowsy. For example, in the current Cadillac XTS, General Motors added a feature that vibrates the seat when the driver may be backing up into an object that cannot be seen. Tactile technology has also been used in a variety of settings for navigation purposes.

The sense of touch is generally an under-utilized modality and may be used to relay information to the user in an un-obstructive and minimally invasive way. Merlo, Duley, & Hancock (2010) used a vibrotactile belt at the waist to relay traditional Army hand signals to infantry who may not be within eyesight. Van Erp & Van Veen (2006) demonstrated that a vibrotactile waist belt can be an easy to learn and intuitive route guidance system in waypoint navigation. Garcia, Finomore, Burnett, Baldwin, & Brill (2012) found results consistent with Van Erp & Van Veen (2006) for dismounted soldiers traversing through a virtual environment of a Middle East war zone.

Van Erp & Van Veen (2004) investigated the use of a vibrotactile seat for in-vehicle navigation in normal and high workload conditions. They found that a tactile navigation display can help reduce the workload involved with driving, particularly in high workload settings. Yet few of these studies have investigated the individual differences that may exist with the use of tactile technology for navigation purposes.

Individual differences in navigation strategy based on sense of direction or spatial abilities have been extensively investigated. Garcia, et al. (2012) demonstrated that individuals with a good sense of direction (GSD) based on the Sense of Direction Questionnaire (SDQ) (Kato & Takeuchi, 2003) were significantly faster and more accurate navigators traversing through a virtual environment. Individuals with a good sense of direction are better at maintaining their heading in relation to their cardinal heading, whereas those with a poor sense of direction tend to use a verbal approach to navigation and benefit most from egocentric route guidance instructions (Baldwin & Reagan, 2009). Individuals with a good sense of direction benefit most from allocentric visual based route guidance systems which allow them to build a better, more global cognitive map of their environment (Furukawa, Baldwin, & Carpenter, 2004).

Due to these individual differences in navigation abilities, individuals may differ in the type of route guidance system they prefer. Individuals may subjectively prefer a certain type of navigation display based on the system's presentation modality characteristics and the type of information that is included in the system. This subjective preference may even conflict with the system design that they would perform best with. This experiment was intended to examine this research question. Specifically, we sought to examine whether individuals with different sense of direction abilities would differ in terms of which vibrotactile route guidance system format they most preferred and whether or not those preferences would also be reflected in navigation performance. Based on previous research (Baldwin and Reagan, 2009) we reasoned that individuals with a good sense of direction might be more likely to prefer a tactile system that did not disrupt their use of visuo-spatial working memory resources during route learning. Of the tactile systems examined, the system that uses tactor location to convey guidance information is the most likely to involve visuospatial working memory resources and therefore we predicted it would be the least favored system among individuals with a good sense of direction. It was further predicted that individuals with a good sense of direction would commit fewer turning errors than individuals with a poor sense of direction and that they would have relatively better overall route recall regardless of the navigation format used. Furthermore, it is predicted that the redundant route guidance system would be the most effective at conveying route guidance instructions overall.

Methods

Participants

57 undergraduate participants from George Mason University provided written informed consent and then participated in this experiment. All reported normal or corrected to normal vision and hearing and were recruited from the undergraduate population.

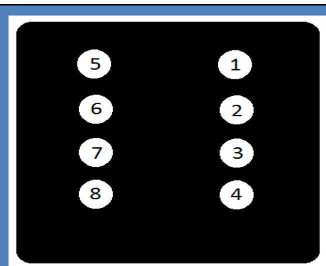
Apparatus

A driving simulator created by RealTime Technologies, Inc. was used for this experiment. 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. Virtual/physical rotating motion were decoupled to a .5:1 ratio, meaning that for every 90 degrees of motion in the virtual world, the simulator only turned 45 degrees in the physical world. The simulator features (3) 42" plasma high definition 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.

The simulator is equipped with a 5.1 surround sound speaker system and a vibrotactile seat that contains 8 tactors arranged in 2 rows of 4 $C2^{@}$ tactors. The vibrotactile seat was custom designed and constructed by Engineering Acoustics, Inc. Three different tactile route guidance systems were designed in addition to the more traditional auditory route guidance system. The first tactile route guidance system, known as the "redundant" system, gives a preliminary route guidance instruction by vibrating the front half of seat in the given direction of the next turn in a slow pulse rate, and a fast pulse rate in the back half of the seat in the given direction of the next turn for the immediate route guidance instruction.

In the "pulse rate" route guidance system, participants were given a preliminary route guidance instruction by vibrating the middle two tactors on the appropriate side at a slow pulse rate and for the immediate route guidance instruction the middle two tactors were activated at a fast pulse rate. In the "location" route guidance system, an intermediate intensity pulse rate was used in the front half of the seat for the preliminary route guidance cue and in the back half of the seat for the immediate route guidance cue.

This allows for systematic evaluation of the effects of pulse rate or location, or the additive combination of the location and pulse rate of a route guidance cue. This also allowed us to examine whether individual differences in route guidance design preferences based on sense of direction exist. The details of each tactile route guidance condition are summarized in Table 1, below. For further details on the tactile seat, see Garcia, Eisert, & Baldwin (2013).



Condition	Preliminary	Immediate
Auditory Equivalent	"Your next turn will be a [direction]"	"Make the next [direction]"
Redundant	Pulse rate 3.69 Tactor 5+6 For Left Turn Tactor 1+2 for Right Turn	Pulse rate 11.93 Tactor 7+8 for Left Turn Tactor 3+4 for Right Turn
Location	Pulse Rate 7.87 Tactors 5 + 6 for Left Turn Tactors 1+2 for Right Turn	Pulse Rate 7.87 Tactors 7+8 for Left Turn Tactors 3+4 for Right Turn
Pulse Rate	Pulse rate 3.69 Tactors 6+7 for Left Turn Tactors 2+3 for Right Turn	Pulse rate 11.93 Tactors 6+7 for Left Turn Tactors 2+3 for Right Turn

Table 1. *Details of each route guidance format condition and type of cue.*

Procedure

After signing an informed consent document, participants completed the Kato & Takeuchi Sense of Direction Questionnaire (SDQ, Kato & Takeuchi, 2003). Next, participants were escorted into the driving simulator and were given a demonstration of the various features of the simulator. Participants were then given a quick tutorial and training session of how the route guidance systems in general function, were informed on the order of the experiment and were shown a few sample images of the task they would be performing throughout the experiment.

Participants drove through four different cities, twice each (one city per route-guidance system) for a total of 8 experimental drives, and a practice drive before each city to help familiarize the participant with each route guidance system. After each drive, participants were asked to retrace each route they drove on a blank map of the city. They were given the starting locations for each drive before beginning the experimental task. Participants were shown three unique landmarks to attend to as they drove each experimental drive; they were asked to indicate on the map their locations after each pair of drives. Next, participants were given a blank compass to indicate where they thought the point of origin was in relation to their egocentric orientation at the end of each drive.

Experimenters recorded how many turning errors were committed by the participants during the drives as well as the type of errors committed. At the end of the experiment, once the participant was able to complete a pair of drives with each type of route guidance system, participants were asked which route guidance system they preferred. Last, participants were debriefed on the true purpose of the experiment and were given the contact information of the PI in case they had any additional questions.

Results

Due to data collection failures, user's route guidance system preference was collected for only 40 subjects. Overall, participants overwhelmingly preferred the "pulse rate" route guidance system (22), followed by the "redundant" route guidance system (12) and the "location" route guidance system (6). For the purposes of maximizing responses, sense of direction grouping for preference data was determined by simply grouping people as to whether they were above or below the sample mean on the SDQ. The results are organized in table 2 and figure 1.

	PSD	GSD
Redundant	4	7
Location	3	3
Pulse rate	12	9

Table 2. *Route Guidance System Preference Split by SOD*

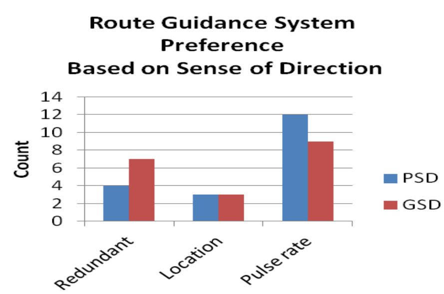


Figure 1. *Route Guidance System Preference Split by SOD*

For the performance data, sense of direction groupings was based on criterion of SSDQ score plus or minus one standard deviation from the mean of a larger sample containing 250 responses. In this grouping, individuals with a good sense of direction had an average score of 2 or below and those with a poor sense of direction had an average of 2.7 or higher. Note that an attempt to use a more stringent criterion would have maximized the potential to observe differences between the groups but at the cost of even further reduction in sample size and statistical power. A 2 (sense of direction X 4 (RGS format) mixed repeated measures ANOVA was used to assess the number of navigational errors (turning errors) committed by participants while using the various route guidance systems. Only 8 individuals met the criteria needed to qualify as a poor sense of direction individual. Overall, there was no statistically significant difference between the 4 route guidance systems in the amount of turning errors made by participants, F (1.3) = 1.24, $p > .05$, as well as no statistically significant interaction, F (1.3) = 2.27, $p > .05$.

Discussion

Tactile route guidance systems have shown great potential in a variety of settings and have begun finding their way into the modern vehicle. The purpose of this experiment was to assess participants' subjective route guidance system interface preference as well as the amount of navigational errors committed.

Overall, the pulse-rate route guidance system was the most preferred vibrotactile navigation system. When analyzing preferences based on sense of direction, the pulse-rate route guidance system was still the most preferred route guidance system. However, individuals with a good sense of direction picked the redundant route guidance system almost as often as the pulse rate route guidance system. We believe this is due to the ability of GSD individuals to understand and benefit from the added spatial information that the redundant route guidance system offers above and beyond the pulse rate RGS. That is, the pulse rate route guidance system distinguishes between a preliminary route guidance cue and an immediate instruction based on a slow or fast pulse rate coming from the same location. The redundant RGS adds the element of spatial location. Not only does it offer the same pulse rate information from the pulse-rate RGS, but the seat also vibrates in the front half (at a slow pulse rate) for a preliminary cue and in the back half on the appropriate side (at a fast pulse rate) for the immediate cue. The added spatial information may have been ignored or found to be an annoyance for those with a PSD, whereas those with a GSD may have experienced the addition of spatial information as a benefit.

There was no significant difference in the amount of turning errors committed between GSD and PSD individuals. There are a few potential explanations for this. Due to the extremely low rate of turning errors, it is a possible that the task was too simple, thus creating a ceiling effect. Furthermore, all four types of route guidance systems were egocentric in nature. This perspective is most intuitive for route guidance purposes, but may not lend itself best to route learning or building a cognitive map of the environment. Additionally, individuals with a poor sense of direction often perform best with interfaces with an egocentric perspective (Baldwin & Reagan, 2009; Garcia et al. 2012). Future investigations should include a condition from a geocentric perspective, similar to Garcia et al. (2012). A limitation of the current investigation is the small sample sizes obtained with our groupings based on the SDQ questionnaire. Small samples sizes resulted in low statistical power and likely contributed to the present non-significant findings. The convenience sample used made it difficult to find enough participants who scored more than one standard deviation above and below the mean on the SDQ. Data collection may continue in the near future to collect more data from individuals who meet the criteria to be classified as a GSD or PSD individual.

Ideally, a multimodal system may be most beneficial in a fully commercial route guidance system. Human factors design principles should be responsibly implemented in commercial multimodal systems so that the navigational cues are perceived as a single gestalt rather than cues being perceived each as a different message for each modality. Additionally, commercial route guidance systems should have the ability to be customizable based on an individual's spatial abilities and preferences.

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References

Baldwin, C. L., & Reagan, I. (2009). Individual Differences in Route-Learning Strategy and Associated Working Memory Resources. *Human Factors, 51*(3), 368-377.

Garcia, A., Finomore, V., Burnett, G., Baldwin, C.L., Brill, C. (2012). Individual Differences in Multimodal Waypoint Navigation. *Proceedings of the 56th Annual Meeting of the Human Factors & Ergonomics Society*. Boston, MA.

Cholewiak, R. W., Brill, J.C., & Schwab, A. (2004). Vibro-tactile localization on the abdomen: Effects of place and space. *Perception and Psychophysics, 66,* 970-987.

Furukawa, H., Baldwin, C. L., & Carpenter, E. M. (2004). Supporting Drivers' Area-Learning Task with Visual Geo-Centered and Auditory Ego-Centered Guidance: Interference or Improved Performance? In D. A. Vincenzi, M. Mouloua & P. A. Hancock (Eds.), *Human Performance, Situation Awareness and Automation: Current Research and Trends, HPSAA II* (pp. 124-129). Daytona Beach, FL

Garcia, A., Eisert, J., Baldwin, C.L. (2013). Comprehension of Vibrotactile Route Guidance Cues. *In Proceedings of 15th International Conference on Human Computer Interaction*. Las Vegas.

Garcia, A., Finomore, V., Burnett, G., Baldwin, C. L., Brill, C. (2012). Individual Differences in Multimodal Waypoint Navigation. In *Proceedings of the Human Factors and Ergonomics Society 56th Annual Meeting*.

Merlo, J.L., Duley, A.R., & Hancock, P.A. (2010). Cross-modal congruency benefits for combined tactile and visual signaling. *American Journal of Psychology, 123* (4), 413-424.

Van Erp, J.B.F., Van Veen, H.A.H.C., Jansen, C., Dobbins, T. (2006). Waypoint Navigation with a Vibrotactile Waist Belt. *ACM Transactions on Applied Perception*. 2(2), 106-117.

Van Erp, J.B.F., Van Veen, H.A.H.C. (2004). Vibrotactile in-vehicle navigation system. *Transportation Research Part F 7*, 247-256.