Driving by the Seat of Your Pants: A Vibrotactile Navigation Study  

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Vibrotactile navigation systems can provide drivers with directional information while reducing annoyance from a voice that interrupts on-going music and conversations. However, little is currently known regarding the working memory processes involved in utilizing vibrotactile navigation. Prior research has demonstrated that individuals differ in their sense of direction and ability to navigate and the working memory resources used to carry out the navigation task. Recent research has shown that vibrotactile cues can be used effectively to facilitate navigation while potentially reducing workload. The aim of this study is to examine impact of vibrotactile navigation systems on working memory. Specifically, the aim is to examine how they may differentially impact individuals based upon their sense of direction. It is predicted that the location based information provided by the vibrotactile navigation system may facilitate performance among individuals with a poor sense of direction – because it is not expected to rely on their verbal working memory. Conversely, vibrotactile systems are expected to hinder the performance of individuals with a good sense of direction since they may overload the visuospatial working memory processes. The results of this research will help in better understanding the differences between these individuals and help improve navigation system design to better navigational performance.

INTRODUCTION

Being able to navigate is an important facet of daily life, without it we would struggle simply to find our way around our own house. Many professions such as firefighters, professional drivers (taxi, semi-truck, limo, etc.), aviation, and UAV pilots all rely heavily on being able to navigate from one point to another. However, consistent individual differences are found in the way people navigate (Kato and Takeuchi, 2003; Baldwin, 2009; Baldwin and Reagan, 2009; Lawton, 1994). Understanding these differences is vital to understanding how to help facilitate navigational performance.

Primarily it is important to understand that individuals differ in their overall sense of direction. Kozlowski and Bryant (1977) thought of sense of direction as the awareness of location or orientation an individual has when moving around in his or her environment. They found that individuals are able to give an accurate self-assessment of their own sense of direction. Additionally, Kato and Takeuchi (2003) developed a questionnaire, the Sense of Direction Questionnaire-Short Form (SDQ-S), to assess an individual's awareness of orientation as well as memory for usual spatial behavior. Using the SDQ-S, Kato and Takeuchi (2003) found that individuals who had been categorized as having a good sense of direction were better able to re-navigate a route than those who were categorized as having a poor sense of direction.

Individuals who are considered as having a good sense of direction are more likely to use an orientation or survey strategy, which relies on the use of cardinal directions and Euclidian distances to build a mental map of their route (Kato and Takeuchi, 2003; Baldwin, 2009). However, individuals who have a poor sense of direction tend to use a route based strategy that primarily relies on sequential left and right verbal directions (Baldwin, 2009). While individuals who are reported as having a good sense of direction primarily use survey strategy they are also capable of using a route based strategy, however individuals with a poor sense of direction often find it impossible to utilize a survey based strategy (Saucier et al., 2002). Additional research has looked at gender differences in sense of direction and overall ability to navigate. Findings from this research have shown that males tend to use a survey strategy while navigating, while females tend to use a route based strategy (Lawton, 1994; Lawton and Kallai, 2002).

While individuals differ in their sense of direction and ability to navigate, research has looked at how these different navigational strategies may rely on different aspects of working memory. Saucier, Bowman, & Elias...
(2003) found that when females were engaged in an articulatory interference task their ability to navigate when receiving both Euclidean and landmark based instructions was impaired; however male performance was not impaired regardless of interference task. This lends some evidence to the role that the phonological loop plays in navigation for females. Garden, Cornoldi, and Logie (2002) found that while individuals who were high in spatial ability were navigating they were impaired more while performing a spatial tapping task than an articulatory suppression task and individuals low in spatial ability were more impaired by the articulatory suppression task. These findings were replicated by Baldwin and Reagan (2009) in a virtual environment navigation task. They found poor sense of direction individuals took longer to complete a route after learning it while engaged in an articulatory suppression task, relative to while engaged in a visuospatial tapping task. Conversely, good sense of direction individuals took longer to complete a route after learning it while engaged in the visuospatial tapping task versus an articulatory suppression task. These findings lend evidence towards the notion that different navigational strategies utilize different aspects of Baddeley’s working memory model (Baddeley, 1992), with good sense of direction individuals relying on the visuospatial sketchpad and poor sense of direction individuals relying on the verbal processes of the phonological loop (Garden, Cornoldi, and Logie, 2002; Baldwin, and Reagan, 2009).

While most research has examined navigating while using either a visual or auditory navigation system, limited research has examined the use of vibrotactile based navigation systems. Currently vibrotactile technology has begun to be more utilized due to the fact that the sense of touch is generally an underutilized modality while driving. Ford, Mercedes Benz, Cadillac, and Hyundai all have current vibrotactile systems in some of their car models. Van Erp and Van Veen (2006) demonstrated that a vibrotactile waist belt can be an easy to learn and intuitive route guidance system in waypoint navigation. Van Erp and Van Veen (2004) examined the use of a visual, vibrotactile and multimodal navigation system and found that using the vibrotactile navigation system resulted in a lower rating of mental effort without a decline in performance while workload was increasing. Vibrotactile cues offer a very promising avenue for presenting navigational information; however, little if any research has examined the type of working memory processes required by their use and virtually no work to my knowledge has examined potential individual differences in the use of vibrotactile navigation systems. The current study sets out to examine the type of working memory resource required by use of a vibrotactile navigation system and how this may impact individuals with different navigational strategies. It will examine the impact of potential individual differences in the ability to use a vibrotactile navigation system and its impact on perceived workload.

Previous research on vibrotactile systems has relied primarily on the manipulation of signal location for differing cues (Van Erp and Van Veen, 2004; Fitch, Kiefer, Hankey, and Kleiner, 2007; Cholewiak, Brill, and Schwab, 2004; Hogema, De Vries, Van Erp, and Kiefer, 2009). Additionally previous research by Garcia, Eisert & Baldwin, (2013) found that the location of a vibration impacted when participants believed they should make a turn, such that a cue played towards the knees was representative of a preliminary cue for an eventual turn and a vibration played towards the back of the legs was representative of an immediate cue to make the next turn.

We predict that similar to previous research individuals with a good sense of direction will have a degradation in performance (defined by committing more navigational errors and taking longer to traverse a route) when attempting to recall a route after learning the route while completing a concurrent visuospatial secondary task. Furthermore, we predict that the additional spatial information provided by the location based vibrotactile system will result in an even greater reduction in performance then when using the auditory navigation system. Since individuals with a poor sense of direction rely more on verbal working memory we predict that using an auditory based navigation system while completing a concurrent verbal secondary task during route learning will result in worse route recall performance than when using a vibrotactile navigation system for individuals with a poor sense of direction.

METHODS
Participants

We will be recruiting participants from the local University. Using the Kato and Takeuchi SDQ-S (Kato and Takeuchi, 2003) we plan to recruit thirty individuals who are classified as having a good sense of direction and thirty who are classified as having a poor sense of direction. Using Buzzell, Roberts, Baldwin, and McDonald (2013) survey results our cut off points will be 3.46 for good sense of direction and 2.52 for poor sense of direction. We will attempt to have equal amount of males and females in each group. All participants will be required to have a valid driver’s license and be at least 18 years of age or older.

Materials

This study will use a driving simulator created by RealTime Technologies, Inc. The simulator is capable of yaw and pitch motion, with the yaw motion allowing for 180 degrees of motion, 90 degrees left and 90 degrees right and the pitch motion allowing 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 will only turn 45 degrees in the physical world allowing for greater flexibility in scenario development, without having an impact on fidelity. 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 set up can be seen in figure 1.

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. The auditory based navigation system will provide participants with a preliminary cue alerting them to the direction of the next eventual turn and an immediate cue alerting them that they need to take the next turn. The vibrotactile navigation system will provide the same types of cues as the auditory system. The tactor seat can be seen in figure 2, the tactors are aligned in 2 columns with 4 tactors in each column. The tactile cues consisted of 6 250ms pulses, with 368ms between pulses (IPI), and were presented at 250 Hz using C2 tactors. For a preliminary left turn cue, the front two tactors on the left side column would vibrate, for a preliminary right turn cue the two front tactors on the right column would vibrate. For an immediate cue the only difference would be that the back two tactors would vibrate. These sequences are based off previous studies examining the same tactile seat (Eisert, Garcia, Payne, & Baldwin, 2013).

Participants will be navigating through four different routes. Each route consists of six turns that can occur at either a three or four way intersection. All routes have 14 points where the participant must make a decision to either continue going straight or make a turn. Participants will also be completing one of two different versions of a N-Back task. In one version participants will be asked to pay attention to the letter being presented and indicate if it matches the letter previously presented. In the other version participants will need to indicate if the current letter being shown is in the same location as the previous letter shown. Pilot testing revealed these two versions to be equal in difficulty with participants demonstrating equal performance on both versions. Participants will also be filling out the NASA-
TLX (Hart and Staveland, 1988) after using each navigation system to determine the workload associated with using each system.

**Procedure**

When participants arrive they will be asked to present their driver’s license while signing an informed consent form. Then participants will fill out the SDSQ-S in order to determine if they meet the criteria of having either a good or poor sense of direction. Once participants have completed the questionnaire they will be introduced to the simulator and given time to get comfortable with the mechanics of driving in it. Once they are comfortable participants will receive training on the two forms of the N-Back task alone, then they will also practice driving while performing the N-Back task. After participants are fully comfortable with driving while performing the N-Back tasks the actual experiment will begin. Before each drive participants will complete a training drive on the navigation system and N-Back task they will be using. The navigation systems and secondary task will be counterbalanced across the routes, such that they will only get each combination of the navigation system and secondary task once for only one city. After completing their first route with the combination of navigation system and N-Back task participants will be asked to re-drive the route without the navigation system and N-Back task. If participants make an error they will be corrected back to the correct path. Participants will re-drive each route until they complete the route without making any errors or a maximum of three re-drives has occurred. At the end of each route participants will be given the NASA-TLX and asked to fill it out for how easy it was to try and learn the route using that particular navigation system. Participants will repeat this process for all four routes.

**Measures**

For this study we will be recording total number of errors made while using the navigation system, total time taken to complete the route with the navigation system, number of errors made while re-driving the routes, time needed to re-drive the route, total number of re-drives needed in order to be able to perfectly re-drive the route, and NASA-TLX scores for use of navigation system.

**RESULTS/IMPLICATIONS**

Data collection is currently underway. Data will be analyzed using a 2(SDQ-S) x 2 (Navigation System Used) x 2 (N-Back Version) design. We expect to find that the vibrotactile navigation system will help individuals with a poor sense of direction, but actually hurt individuals with a good sense of direction in their navigational performance. This finding would be important for the design of future navigation systems. By understanding the differences in how these two types of navigators navigate we can then design systems that are tailored to help facilitate their ability to learn new routes.

**REFERENCES**


