The Effects of Acoustic Turn-by-turn Navigation on Wayfinding

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This study examined the impact of using an acoustic turn-by-turn navigation device on wayfinding. Participants used a driving simulator to traverse the same route twice. They either traveled both times without the guidance or used a turn-by-turn navigation on the first drive and then replicating the route from memory on the second drive. Wayfinding performance was assessed by using route travel time and an assessment of scene recognition Results show that using a turn-by-turn navigation system negates route learning and impairs scene recognition. These findings suggest that using a navigation system while driving creates inattention blindness, a failure to "see" elements in the environment.

INTRODUCTION

The negative impact of using modern navigational aids has been often publicized as anecdotes in a number of media outlets. For example, in 2009 the Salt Lake Tribune reported that a Swedish couple vacationing in Rome, Italy incorrectly entered the island of Capri into their car's Global Positioning System (GPS) as "Carpi." As a result they drove about 400 miles away from Capri winding up at the other end of the Italian peninsula from their desired destination. It was only then that they started asking for directions. What makes this report fascinating is that Capri is an island, and, while the couple entered the destination incorrectly they still never seemed to realize that they had not crossed any water (Associated Press, 2009).

Similar to the anecdotal report, a withdrawal of attention to the visual environment also occurs with cell phone conversations while driving (Strayer, Drews, and Johnston, 2003). Talking on a cell phone and driving diverts attention because of dual-task interference (Strayer & Drews, 2007), leading to inattentional blindness, a failure to "see" objects (Mack, 2003; Simon & Chabris, 1999). Inattention and perceptual errors are associated with nearly 40% of traffic accidents (Hendricks, Fell, Freedman, 1999). Furthermore, even talking on cell phone with a hands free device still caused enough inattention blindness that participants failed to recognize billboards they had passed earlier (Strayer et al. 2003). Based on the above anecdote and prior research on distracted driving, it is possible that using a GPS also produces inattentional blindness; therefore, it is feasible using a GPS may increase the likelihood of traffic accidents.

Surprisingly, research on the consequences of GPS use is limited. Qualitative field research suggests using a GPS results in a sense of disengagement from the environment, drivers report feeling detached (Leshed et al. 2008). In addition, using a GPS negatively affects driving performance, assessed using speeding and lane control (Jensen, Skov, & Thiruravichandran, 2010). Other research has shown representation of the environment, spatial knowledge, is impoverished with guided navigation (Bakdash, Linkenauger, & Proffitt, 2008; Burnett & Lee, 2005).

In this study, we hypothesize inattentional blindness occurs when a GPS is used while driving. To test this hypothesis, we used a driving simulator to investigate travel time, a direct measure of wayfinding performance, and memory for scenes in the environment. The same route in a virtual city environment was traveled twice. It was either navigated with a GPS device on the first drive, which was then removed for the second drive (GPS group), or navigated without any GPS device for both drives (No GPS group). Anecdotally, reliance on a GPS causes reductions or even failures to process environmental information. Therefore, in the context of GPS use, attention may be partially directed towards the guidance, impairing visual processing of the environment. Consequently, wayfinding performance for GPS used will likely be worse than navigation that is not guided.

Interestingly, Drews, Pasupathi, and Strayer (2008) examined how a conversation with a passenger in a vehicle is different than that of a cell phone, since both the passenger and the driver are able to see what the driver is experiencing. In the context of the above anecdote, it is possible that the passenger, like the driver was relying on the GPS device, also was not encoding any information about the environment. However, the situation could be even worse if there is only a driver and no passenger who could provide some critical assessment of the progress towards some destination.

Successful navigation has three stages; first a person needs to know their current location, second a person needs to plan a route using their knowledge of where the destination is, and third there is a need to execute the route (Ishikawa, Fujiwara, Imai, & Okabe, 2008). With the use of a GPS device, the second step is not necessary, since no explicit planning or knowledge of the location of the destination is required. See Ishikawa and Montello (2006) for conceptual frameworks on the stages of acquiring spatial knowledge

Ishikawa et al. (2008) compared wayfinding for GPS use, map use, and direct experience. They found that GPS users were focusing on the continuously updating screen of the device which hindered their ability to focus on their environment. This situation caused participants to pay only very little attention to their surroundings. The failure of the GPS systems to help participants move in a way that is similar to someone who traveled the route before, was attributed to the small screen of the cell phone, which was used as the GPS device (Ishikawa et. al 2008). However, one remarkable aspect of that study is that participants traveled the route by foot. Operating a vehicle while using a navigational aid may increase the cognitive demand and involve other mechanisms that result in a break down of performance. In the context of the present study we will use a driving simulator to examine the impact of the use of a GPS system on way finding performance. In addition to eliminate the added potential impact of a screen that required allocation of attention away from the driving environment, we will use an acoustic turn-by-turn navigation instead of visual guidance.

Another study examining guidance compared spatial knowledge for freely selected navigational route choices (e.g. where to turn, selected path to the destination) to verbally guided navigation (Bakdash et al. 2008). In this study, the ability to make spatial decisions was found to be critical to acquiring environmental knowledge. Making decisions during navigation requires creating and updating spatial representations (Garling & Golledge, 2000). Under guidance, such route choices are no longer made. This finding raises the important question if a GPS device giving turn-by-turn instructions has an impact on wayfinding performance when guidance is removed.

Burnett and Lee (2005) used a driving simulator to compare navigation with a paper map to a verbal navigation system. They found that participants who used the navigation unit drew less detailed maps with fewer landmarks and had lower scene recognition. In the studies by Bakdash et al. (2008) and Burnett and Lee (2005), wayfinding performance was not directly assessed in the environment.

We hypothesized that inattention blindness would reduce the processing of visual information when a GPS device was used on the first drive, leading to an impoverished representation of space. For the current study, participants navigated the same twice; consequently, performance for route wayfinding was directly assessed using travel time. GPS use on the first drive was hypothesized to lead to increased travel time on the second drive. When no GPS was used, travel time on the second drive would either stay the same or improve. Also, we hypothesized memory for scenes in the environment would be lower with GPS use because of diminished visual attention. Scene recognition was assessed after the first drive, using pictures of the virtual city used in the driving simulator and novel scenes that were not in the city.

METHODS

Participants

Fifty (29 male, 21 female) University of Utah undergraduate students participated in this study for course credit. Of the 21 female participants 10 were in the GPS group 11 were in the GPS group. Of the 29 male participants 15 were in the GPS group 14 were in the no GPS group. The average age of the participants was 20 years (range 18-44).

Stimuli and Apparatus

A PatrolSim high-fidelity driving simulator, manufactured by GE Capital I-Sim was used in this study. The simulator is composed of five networked microprocessors and three high resolution display providing a 180 degree field of view. The dashboard instrumentation, steering wheel, gas, and brake pedal are from a Ford Crown Victoria™ sedan with an automatic transmission. A governor was programmed into the car preventing it from traveling faster than 25 miles per hour. The simulator incorporates proprietary vehicle dynamics, traffic scenario, and road surface software to provide realistic scenes. Figure 1 shows the driving simulator.

Figure 1. View of simulator from behind a participant (left) and simulator display screens and controls (right).

A town database was used to create the scenario for the experiment. The town database simulated a typical town with cul-de-sacs, one way streets, large buildings in one section to represent a city, homes in another area to represent a suburb, two lane as well as one lane roads in both directions. All scenarios used daytime dry-pavement driving conditions with clear visibility. There was no other traffic on the roadway. The road signs were legible and consisted of letters running one direction (A-L) and the cross-streets being numbers (1-10). A Garmin Nüvi[tm] was used to model the acoustic turn-by-turn navigation through the town (e.g. "In 0.5 miles turn left"). Only acoustic directions were used, no visual GPS device was used. The layout of the town and optimal route from the start to the end locations is shown in Figure 2.

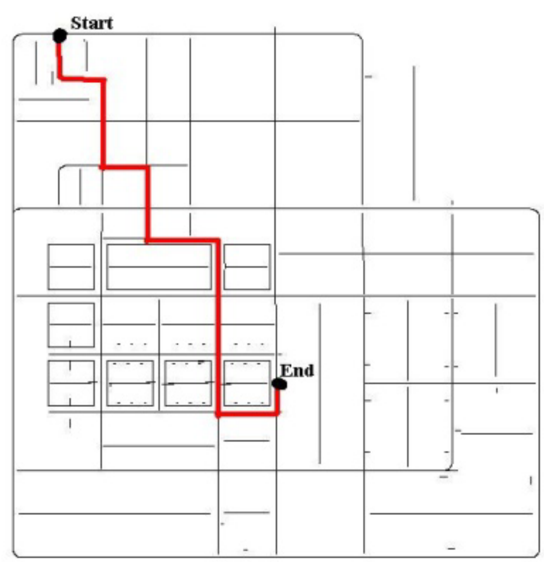

Figure 2. Town layout with the start and end locations. The red line depicts the optimal route.

Procedure

Participants were randomly assigned to a learning group, the GPS group (acoustic turn-by-turn navigation on the first drive, no GPS on the second drive) or the no GPS group (no GPS on either drive). Neither group was told that they would drive the same route twice nor were they instructed that there would be a scene recognition test.

General methods. First, both groups received practice by driving in a scenario, similar to, but separate from the town used in the experiment. This was done familiarize participants with the control and feel of driving in the simulator. Prior the first drive, the general makeup of the city was shown to participants for a maximum of 30 seconds using a map of the optimal route (see Figure 2 above).

Next, both groups began their first drive by starting at the same location ("B-Street" and "10th Ave") and received identical instructions to travel to the end location (The house on "E-Street" between "3rd and 4th Ave"). Following the first drive, all participants completed a spatial task which consisted of mentally comparing the angles between the hour and minute hands of clocks different time pairs (Paivio, 1978). After that, a scene recognition paradigm was administered to both groups to ascertain how much of the environment was encoded. This test consisted of a self-paced presentation of 22 scenes, 11 of these scenes could have been driven by participants and another 11 were not in present in the simulation. Participants were instructed to write down either "yes" they do remember the scene, or "no" if they are unsure or did not pass the scene. Lastly, both groups completed a second drive, beginning at the same start location, and were instructed to drive to the same ending location from before. Travel time was recorded for the first and second drives. However, if the simulation took longer than 10 minutes it was stopped.

GPS group. The GPS group received acoustic turn-by-turn navigation on their first drive. They were told that the goal of the study was to examine different vocal tones used within a turn-by-turn navigation device. The participants were informed that the turn-by-turn navigation would give them directions to a house located on "E-Street" between "3rd Ave" and "4th Ave." For the second drive, the acoustic GPS was absent and participants were told to replicate the route they had taken earlier.

No GPS group. The no GPS group served as a control, no auditory guidance was provided for either drive.

RESULTS

Travel Time

The hypothesis that using a turn-by-turn navigation device and then having it removed causes the driver to perform just as poorly second time as a driver who never had the device is supported by out findings. Travel time was evaluated using a 2 by 2 mixed-model ANOVA, with GPS use specified as a between-participants factor and drive specified as a within-participants factor. There was a reliable interaction between GPS device and drive, $F(1,48) = 12.38$, $p < .001$, $\eta^2_p = .21$, see Figure 3.

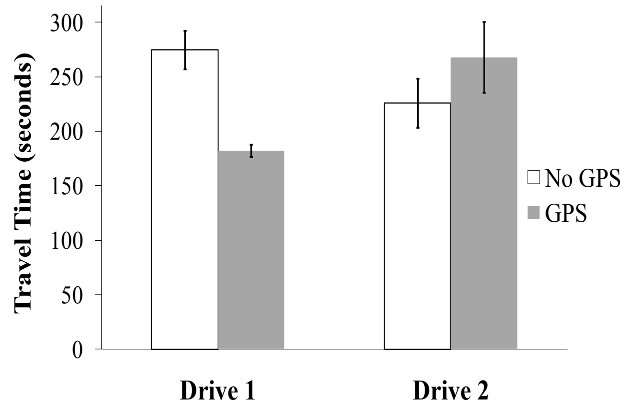

Figure 3. Mean travel time for drive 1 and drive 2 by No GPS device group and GPS device group. Error bars depict one standard error of the mean.

No main effects for GPS group or drive time were found, $ps > .30$, $\eta^2_p s \leq .02$. Note that although homogeneity of variance was violated, corrected values produced identical results.

Scene Recognition

Accuracy. Scene recognition accuracy was evaluated using a between-participants ANOVA with GPS group specified as a factor. When No GPS was used, it was possible that not all scenes would be viewed during the drive. Therefore, scene recognition accuracy was scored using the number of scenes actually viewed during a drive. The analyses revealed that drivers in the No GPS group recognized more scenes (M = 49.19%, SE = 3.91%) than drivers using the GPS (M = 37.39% , SE = 2.37%), $F(1,48) = 6.65$, $p = .01$, $\eta^2_p = .12$. This finding supports the hypothesis that using a turn-by-turn device impairs a driver's ability to encode the visual environment.

Signal detection. Signal detection (SDT) was used to determine if the difference in scene recognition was attributable to sensitivity (*d'*), the ability to distinguish between scenes viewed during navigation and novel scenes, or response bias (*c*), the propensity to state "yes" or "no." Six participants (3 in each condition), had hit rates or false-alarm rates of 0% or 100%. In order to perform SDT analyses for these participants, a value of 0.5 was added or subtracted from the frequency values of hits or false-alarms (Macmillan, 2002). Sensitivity to scenes in the environment versus novel scenes was higher for the No GPS group (M = 1.20, SE = .12) compared to the GPS group (M = .80, SE = .12), $F(1,48) = 5.44$, $p = .02$, $\eta^2_p = .10$. The decision criterion, response bias, did not differ between GPS (M = .57, SE = .09) and No GPS (M = .40, SE = .07), $p = .14$, $\eta^2_p = .05$. The SDT results indicate the difference in scene recognition was due to accuracy, not response bias.

Clock Spatial Task

To account for differences in how many items were attempted the clock task was scored by assigning a +1 to a correct answer and a -1 to an incorrect answer. A between-participants ANOVA with GPS use specified as a factor was conducted on the clock spatial task scores. There was no significant difference between GPS (M = 3.52, SE = 5.58) and no GPS (M = 3.64, SE = 5.00), $F(1,48) = .006$, $p = .94$, $\eta^2_p <$ .001. These results suggest that the increased travel time and lower scene recognition for the GPS group versus the No GPS group are unlikely to be attributable to individual differences in spatial ability.

DISCUSSION

The goal of this research was to examine the effect of using a turn-by-turn navigation system on wayfinding performance. Increased travel time and lower scene recognition after GPS use indicates that auditory guidance impairs wayfinding performance when the GPS is removed. Furthermore, impoverished environmental encoding with the GPS may be attributable to inattentional blindness, although future research is needed to determine the cognitive mechanism. In addition, these findings imply driving performance may also decline with GPS use, as Jensen et al. (2010) found.

In the present work, the drivers who had turn-by-turn guidance may be relinquishing decision-making during navigation to the GPS device causing them not to learn their environment (Bakdash et al. 2008). Increasing interactivity with the environment can ameliorate deficiencies in wayfinding performance with GPS use. For example, Olive and Burnett (2005) augmented GPS guidance by adding landmark descriptions to the turn directions. The augmented system led to better environmental learning then navigation with standard guidance. In addition, using aids that increase the saliency of landmarks and specify their locations during guidance improves wayfinding (Bakdash, 2010). Also, spatializing the auditory guidance for navigation without vision boosts wayfinding performance over non-spatialized guidance (Klatzky, Marston, Giudice, Golledge, & Loomis, 2006). Having users perform wayfinding tasks during guided navigation enhances spatial encoding (Parush, Ahuvia, and Erev, 2007). However, it also removes one the key benefits of a navigation system, automaticity. Thus, directing attention towards relevant environmental features, using aids to specifying environmental layout, and testing knowledge during learning can improve spatial representation with GPS use.

Although wayfinding performance can be improved for guided navigation using such aids, it is also possible augmentation or aids could increasedistraction, further exacerbating the potentially negative effects a GPS has on driving performance. In the current study, guidance was only auditory. Hence, it was in a different modality than environmental encoding, yet wayfinding performance was still deficient with GPS use. However, while talking on a cell phone, tactile lane change instructions have been shown to improve driving performance compared to auditory instructions (Medeiros-Ward, Cooper, Doxon, Strayer, Provancher, 2010). This finding suggests alternative modalities for guidance instructions may bypass the processing bottleneck. Nevertheless, additional research is needed to determine if driving performance decreases with GPS use, which is supported by the potential mechanism of inattentional blindness, and if augmenting guided navigation increases this potential detriment.

We theorize that using a GPS and driving may create a dual-task, producing inattentional blindness. Currently, we are running a study using eye-tracking to determine if a GPS does cause inattentional blindness. If this is the case, GPS use may constitute a form of distracting driving, perhaps resembling talking on a cell phone or texting while driving. Even though the cognitive mechanism for diminished wayfinding performance is not known, nor are the consequences using a GPS hason driving performance, there are clear human factors implications for automated navigation systems. If the couple who were searching for the island of Capri were more engaged in their environment they may have noticed that they did not cross any water or had been driving for longer than expected and corrected their misspelling before ending up 500 miles off course.

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