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GPS Reliance and its Effect on Working Memory and Spatial Ability

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As cell phone usage and technology is increasing in prevalence and its capabilities to the everyday user, the usage of tech-based navigational aids has also increased exponentially (specifically, the use of GPS maps on cellular devices). On the surface, this looks like a positive – electronic navigational assistance is faster than making a detailed plan from a physical map, requires less attention, and can be used on devices that are usually within reach of that individual most of each day. However, there are tradeoffs in effectiveness of physical compared to electronic navigational aids. While a physical map takes more time to plan out directions, it does not require battery life and allows users to remember cardinal information of an environment. Electronic navigational aids, while they are significantly faster, are constrained by requiring some sort of battery and service reception in order to function, and may not require learning cardinal information.

Several prior studies have investigated the trade-offs associated with GPS use on spatial learning. When comparing traditional GPS directions to a physical map or direct experience, those traveling with GPS performed more poorly when asked to sketch a map of a route previously learned, were slower in traveling, and made larger errors when asked to recall directions (Ishikawa, Fujiwara, Imai, & Okabe, 2008). While this study measured more short-term effects of the two aids, potential problems in acquisition of spatial knowledge (e.g. sense of direction, position in space, cardinal directions) can arise for users in long-term settings as well (Ishikawa, 2018). As relying on GPS to navigate throughout environments increases, the user's ability to actively encode the environment through a visual search (i.e. paying attention to surrounding buildings, street signs, or markers) consequently decreases, which can in turn hurt incidental learning of an environment (Munzer, Zimmer, Schwalm, Baus, & Aslan, 2006). As such, problems in learning environments in potential emergencies can occur (Steele, 2018), such as instances where the medium for the GPS is dead or there is no service in an area a user is unfamiliar with.

In addition to the spatial skills discussed above, potential problems can occur through reliance on GPS related to visuo-spatial working memory (VSWM) as well. Known initially as the visuo-spatial sketch pad (VSSP) by Baddeley (1981), this form of working memory relies on spatial and visual cues in encoding information, and differs from the more extensively-known articulatory loop (which relies on auditory cues). VSWM capacity has an influence on how people form spatial mental models (Gyselinck, De Beni, Pazzaglia, Meneghetti, & Mondoloni, 2007), which can in turn affect the way in which we create cognitive maps, as coined by Tolman (1948). Weisberg and Newcombe (2016) partially confirmed this, and found a relation between those who did poorly as a whole on a large-scale spatial ability task and low working memory capacity (there was no relation for any other group that did well in any other aspect of the task). Known sex differences exist (e.g. Padilla, Creem-Regehr, Stefanucci, & Cashdan, 2017; Vashro, Padilla, & Cashdan, 2016), as females traditionally perform worse on spatial tasks than men, creating more of a barrier for problems to arise in these areas. As such, there may be a disparity in how GPS is utilized and to what extent, which may have an effect on certain aspects of the population (i.e. women).

Studies have been done that tested GPS and its overall effect on spatial ability (e.g. Ishikawa, 2018; Steele, 2018; Gramann, Hoepner, & Karrer-Gauss, 2017; Bakdash, 2011; Leshed, Velden, Rieger, Kot, & Sengers, 2008); however, there has been a lack of research that examined the relationship among spatial ability, VSWM, and extensive GPS reliance rather than general usage (as users can utilize GPS for tasks other than navigation, e.g. traffic and time estimates). The purpose of this study is to determine if there is a relationship between a user's level of GPS reliance and their overall level of spatial ability, as well as VSWM capacity. As GPS devices are now fully integrated into society, measuring the long-term effects of reliance on current generations (i.e. those who have had access to GPS from a young age) will be useful in determining potential modifications to allow subsequent generations a better, more spatially-immersive device that will encourage better utilization of VSWM capacity. It is predicted that as participants' levels of GPS reliance become more extensive, overall spatial ability is going to show a decrease in performance, as well as VSWM capacity (i.e. a predicted inverse relation).

Method

Participants

Participants were primarily recruited through the University of Utah's participant pool, and voluntarily selected a timeslot out of several available. Participants were required to be at least 18 years of age, but there was no age limit past its minimum requirement. 43 participants were recruited in this experiment. 39.5% of participants were male, and 60.5% were female. Most participants were 18-24 years of age (88.4%), with only four being over the age of 30 (9.2%). The vast majority of participants were of Caucasian descent (72.1%), with a small minority being Asian/Pacific Islander (9.3%), Latino/Hispanic (14%), and Native American (2.3%).

Materials

Large-Scale Spatial Task. In order to test large scale spatial ability, the Virtual Spatial Intelligence and Learning Center Test of Navigation, or Virtual SILCton task (Weisberg, Schinazi, Newcombe, Shipley, & Epstein, 2014) was implemented, and participants were asked to do a within-route and between-routes pointing task post-navigating through a virtual environment of a college campus. In this task, participants learned the environment through a total of 4 paths. The first 2 routes contain 4 buildings each (8 total) that are separate of each other in both routes and buildings themselves. The last 2 routes are connecting routes between the original 2. Participants self-navigate, using a mouse to look around and arrow keys (or corresponding WASD keys) to move along the routes. After navigating through the routes, participants are asked to use the mouse to point to a particular building in relation to another previously learned building. This trial is given seven times for each building. Unity WebPlayer is required in order to load the virtual environment.

Small-Scale Spatial Tasks. In order to test small-scale spatial ability, a mental rotation and perspective taking task were implemented. The mental rotation task (MRT) is completed in SILCton, while the perspective-taking task is done by hand. In the MRT, there are two sections asking participants to identify the two blocks that are identical to the original block given, but rotated to some extent. Each section consists of ten questions, and participants have three minutes to complete each individual section. The perspective taking task, specifically the Spatial Orientation Test (Kozhevnikov & Hegarty, 2001) requires participants to look at a variety of objects on a piece of paper, and determine the angle by drawing a line where a chosen object is believed to be located when asked to imagine standing on another object's point, facing some other object (e.g. standing on a cat, facing a tree, and asked to identify where a stop sign is).

Working Memory. Working memory capacity was assessed through a dual N-Back task through the Psychology Experiment Building Language (PEBL) software (Mueller & Piper, 2014). In this task, participants are asked to identify when a match occurs, either for identical letters that come up or a square that flashes in the same location on a 3X3 grid. A match is identified after it is determined how many trials back a participant is required to remember. Asking a participant to identify a match based on a 1-back means that a letter or square position is a match when an identical letter or square position occurs 1 trial back. In a 2-back, a match occurs when a letter or square position is identical to one that occurs 2 trials back, and so on.

Surveys. Several different questionnaires were also used to assess self-reported spatial ability. The survey platform Qualtrics was used in order to incorporate the questionnaires into one setting.

SBSOD. The Santa Barbara Sense of Direction (SBSOD) scale (Hegarty et. al, 2002) is used as a way to assess general spatial ability through self-report, and consists of 15 questions that participants identify on a scale of 1 to 7 their agreement with a statement, with 1 being strongly disagree and 7 being strongly agree. This questionnaire has maintained consistency, reliability, and validity when measuring a participant's spatial ability through direct experience, and is a standardized questionnaire that is commonly referred to when measuring spatial ability.

Travel. Navigation and travel history were also assessed in order to get a better sense of how often participants have the opportunity to utilize GPS on a normal basis. Questions included asking participants how many new places they go to in a normal day, how often they go off-trail, how many different places were traveled to in both timeframes where participants traveled the most and the least, and the primary mode of travel utilized when going out.

GPS Reliance and Usage. Overall GPS use and reliance was also assessed, with questions asking how often participants use GPS for traffic estimates, a general sense of direction, and how much GPS is used for actual reliance (i.e. the actual need to use GPS to get to a specific location). These questions are used to measure if there is a difference in spatial ability among participants who use GPS for actual reliance, those who use it mainly for tasks other than actual reliance, and those who do not use GPS at all (refer to Appendix).

Extracurricular Activities. Participants were also asked two questions regarding extracurricular activities that may mediate spatial ability. The first one asks how often a participant plays first-person shooter games per week, and the second one asks the participant how many years they have participated in physical sports or dance.

Demographics. General demographics were asked in order to account for general mediating factors for spatial ability (e.g. sex differences, age as a restrictor for travel or GPS usage, etc.) and to be more thorough when accounting for and interpreting results.

Procedure

After filling out a consent form, participants completed the within- and between-objects pointing task that the SILCton (Weisberg et. al, 2014) provided. After completion of the SILCton task, the same program provided a mental rotation task that the participants completed. Once the participant finished with the mental rotation task, they then moved onto the perspective-taking task (Kozhevnikov & Hegarty, 2001). After, the dual N-Back task (Piper & Mueller, 2014) was taken to test the participant's working memory capacity. Once participants completed all these tasks, they filled out a survey containing the SBSOD, demographics, travel history, and GPS usage and reliance questions. Upon completion, the participant was debriefed and received credit in the University of Utah's participant pool.

Results

The primary hypothesis was that VSWM capacity (as indicated by spatial dual N-back performance) would be inversely related to levels of GPS usage and reliance. To test this, a linear regression was calculated to predict VSWM capacity based on GPS usage and reliance levels, for which there was significance ($F(1,36)=5.421$, $p=.026$, see Figure 1). Linear regressions were also calculated to predict large-scale spatial ability based on GPS usage and reliance levels, where significance was present for within-route pointing ($F(1,36)=6.816$, $p=.013$, see Figure 2), but not for between-route pointing ($F(1,36)=.024$, $p=.878$). In the data, a correlation existed between within-route pointing and VSWM capacity ($r(37)=-.350$, $p=.034$), but no correlation existed with between-route pointing and VSWM capacity ($r(37)=-.284$, $p=.089$). A linear regression was calculated to predict VSWM capacity based on within-route spatial ability and GPS usage/reliance levels, for which there was significance ($F(2,34)=3.578$, $p=.039$). Linear regressions were also calculated to predict different levels of small-scale spatial ability based on GPS usage/reliance. There was significance when predicting SBSOD scores based on GPS usage/reliance ($F(1,41)=6.965$, $p=.012$) as well as predicting scores on the perspective taking task based on GPS usage/reliance ($F(1,38)=7.695$, $p=.009$), but there was no significance when predicting MRT scores on these same metrics ($F(1,38)=3.532$, $p=.068$).

Discussion

Findings suggest that there does seem to be an inverse relationship between GPS usage/reliance levels and VSWM capacity, as well as GPS usage/reliance levels and most forms of spatial ability (except for the MRT, where GPS reliance may not affect general object rotation abilities). These results lead to suggest that GPS navigation may play a role in the development and maintenance of both spatial ability and VSWM, which has further implications as to the long-term effects GPS may have on future societies (e.g. mass loss of spatial awareness, extreme dependence on aids in navigation).This study helps to maintain conclusions of previous experiments done that would lead to the suggestion that GPS hurts spatial knowledge acquisition and VSWM capacities (e.g. Ishikawa, 2018; Steele, 2018; Gramann, Hoepner, & Karrer-Gauss, 2017; Bakdash, 2011; Leshed et. al, 2008; Ishikawa et. al, 2008; Munzer et. al, 2006). As for the experiment itself, there are implications that may affect the study's results. The questions related to GPS usage and reliance were broad in scope, and did not address how long participants had been using GPS prior to participating in the study. In future studies, looking at the length of time spent using GPS in years will hold greater significance as to determining the effect long-term usage of this technology has on VSWM and spatial ability. Participants were also primarily from the University of Utah, making demographics of participants non-representative (most were between the ages of 18-25, had no children, and vastly dominated as being of Caucasian descent). More extensive studies would need to be done to determine any potential effects outside of Utah, especially when accounting for the potential for more polarized levels of spatial ability in participants due to the grid system. Significance may be weak due to the low number of participants, and will need more extensive data collection to determine true significance.

Figures

Figure 1

Regression scatterplot for GPS reliance and VSWM capacity scores on dual N-back task

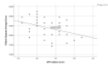
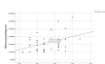


Figure 2

Regression scatterplot for GPS reliance and within-route pointing spatial ability



Appendix

GPS Questionnaire

1. How often do you use GPS when going out?
    a. Never
    b. Rarely – 1-24% of the time
    c. Sometimes – 25-49% of the time
    d. Often – 50-74% of the time
    e. Very often/Always – 75-100% of the time
2. How often do you rely on GPS to navigate in a new or unfamiliar territory (this does NOT include using it for the sole purpose of time and/or traffic estimates)?
    a. Never – 0%
    b. Rarely – 1-24%
    c. Sometimes – 25-49%
    d. Often – 50-74%
    e. Very often/Always – 75-100%
3. How often do you rely on GPS to navigate in an area you have a lot of experience with, such as a hometown, work area, or school you attend (this does NOT include using it for the sole purpose of time and/or traffic estimates)?
    a. Never – 0%
    b. Rarely – 1-24%
    c. Sometimes – 25-49%
    d. Often – 50-74%
    e. Very often/Always – 75-100%
4. How often do you use GPS for the sole purpose of time and/or traffic estimates (i.e. you know where the place is and could find it without needing a navigational aid)?
    a. Never – 0%
    b. Rarely – 1-24%
    c. Sometimes – 25-49%
    d. Often – 50-74%
    e. Very often/Always – 75-100%
5. How often do you utilize GPS for a minimal sense of navigation (i.e. to know the general direction or a couple of steps for a trip, but could otherwise find the destination on your own – this does NOT include using it for the sole purpose of time and/or traffic estimates)?
    a. Never – 0%
    b. Rarely – 1-24%
    c. Sometimes – 25-49%
    d. Often – 50-74%
    e. Very often/Always – 75-100%

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