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Spatial knowledge impairment after GPS guided navigation: Eye-tracking study in a virtual town

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ABSTRACT

There is a vibrant debate about consequences of mobile devices on our cognitive capabilities. Use of technology guided navigation has been linked with poor spatial knowledge and wayfinding in both virtual and real world experiments. Our goal was to investigate how the attention people pay to the GPS aid influences their navigation performance. We developed navigation tasks in a virtual city environment and during the experiment, we measured participants' eye movements. We also tested their cognitive traits and interviewed them about their navigation confidence and experience. Our results show that the more time participants spend with the GPS-like map, the less accurate spatial knowledge they manifest and the longer paths they travel without GPS guidance. This poor performance cannot be explained by individual differences in cognitive skills. We also show that the amount of time spent with the GPS is related to participant's subjective evaluation of their own navigation skills, with less confident navigators using GPS more intensively. We therefore suggest that despite an extensive use of navigation aids may have a detrimental effect on person's spatial learning, its general use is modulated by a perception of one's own navigation abilities.

1. Introduction

We have all been there. Feeling that after driving all the way across a city with a help of a GPS device, we remember nothing of the road and we feel that we won't be able to return without it. Recently, one of the authors heard few ambulance drivers from Prague discussing the difference between older and younger drivers. They agreed that many of the new drivers, who use GPS on a daily basis, do not know their way around the city even after five years of service, whereas their older superiors scarcely even look at the device. This anecdotal evidence points to the detrimental effect of GPS use over the long run (McKinlay, 2016), but the truth seems to be more complicated.

Efficient navigation in both small and large-scale environments requires formation of a mental representation (Shapiro, 2015; Taylor et al., 2008) that may be combined from several components, as was suggested by the route, landmark and survey theory (RLS) by Siegel and White (1975). According to this theory, landmarks serve as external reference points, routes connect these landmarks and survey knowledge binds everything together in a relational space representation. It was hypothesised that the survey knowledge grows with time, as routes are discovered between different landmarks and different relations are put into perspective (O'Keefe and Nadel, 1978; Siegel and White, 1975). This theory was later challenged by other studies demonstrating that route and survey knowledge can be actually acquired simultaneously (Aginsky et al., 1997; Hirtle and Heidorn, 1993). Some authors argue (Münzer et al., 2012; Shelton and McNamara, 2004; Willis et al., 2009; Zhang et al., 2014) that the quality of the representation may be affected by the modality or cues used during the encoding process (e.g. acquisition from a map versus directly from the environment), while other studies found no major differences (Huang et al., 2012). In particular, there are some indications that more abstract 2D representations (Münzer et al., 2006) can actually promote learning better than 3D simulations (Dillemuth, 2005). Moreover, while map-supported navigation positively stimulates forming of both route and survey knowledge, guided navigation forms only route knowledge (Münzer et al., 2006). While the use of maps, in general, could be beneficial in supporting survey knowledge and therefore the accuracy of the formed mental representation, extensive use of GPS based navigation may have a detrimental impact. Possible effects of GPS-based navigation systems should be therefore studied in more detail.

Mobile devices are currently taking over our everyday tasks as their adoption rate increases. Navigation systems surely bring a lot of relief to many users (Kim and Dey, 2009), but voices suggesting their negative impact on spatial abilities of everyday GPS users are growing (McKinlay, 2016). Such concerns are not without a cause. Indeed, spatial representations learned through a mobile interface have differ-

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ent and arguably worse properties than layouts acquired by actively walking around or from maps (Münzer et al., 2006; Willis et al., 2009). Moreover, recent fMRI study (Javadi et al., 2017) demonstrated different hippocampal activity in situations where participants were required to make navigation decisions in contrast to those where instruction was provided. It was argued that the GPS supported navigation requires less occupation with the task, which allows us to focus on other stimuli and become less mindful of the surrounding environment (Parush et al., 2007). Such disengagement of a navigator from an environment has been shown as a relevant source of spatial knowledge impairment (Leshed et al., 2008).

Some researchers have tried various techniques to increase the engagement with the environment in computer simulations but to a limited success (Parush et al., 2007). It was demonstrated that changing navigation instructions to personally relevant ("Turn left in front of the cinema, where they screen your favourite movie Star wars") or salient descriptions of landmarks can yield better results than plain directional statements ("Turn left in front of that building" Gramann et al. (2017). Studies also demonstrated that navigation with a map, requiring shared map-environment attention, leads to better survey knowledge than when participants are completely guided by technology (Aslan et al., 2006).

Overall, there is sufficient evidence pointing towards the fact that people using GPS devices or simply following directions tend to form worse representations of environments than those who engage with the world or who learn actively using GPS or other navigation aids (Ishikawa et al., 2008; Parush et al., 2007). However, there is a lack of information about how much time people actually spend using these aids. Also, not all studies control for cognitive correlates such as memory, which was shown to significantly influence navigation aptitude (Hegarty et al., 2006). It might easily happen that some people use GPS only sparsely, while others rely on the aid heavily during their navigation.

Using a virtual city environment (VE) presented in first-person view and an eye-tracking device, we aimed to address these gaps in knowledge in usage of GPS-based devices during acquisition of spatial information. We assessed spatial knowledge through return path length and time needed to finish each trial (Ishikawa et al., 2008), pointing tasks and blank maps (Münzer et al., 2012; Wang and Spelke, 2000). In order to simulate GPS based navigation system used e.g. during driving, the GPS-like map of the virtual city was displayed in the left corner of the monitor. Such combination of methods allowed us to precisely determine how much time people spend looking at the GPS cues, how much they relied on it during recollection of spatial relationships and possibly differentiate between various use strategies. In addition, we assessed participants' spatial and memory skills using various neurocognitive methods.

1.1. Aims

This study aims to answer several principal questions related to the impact of using GPS devices on speed and accuracy of human spatial navigation.

Firstly, we aim to determine individual differences in GPS use by measuring how long participants spend looking at the aid during their navigation in case it is directly required by the task itself or when its use is optional.

Secondly, we aim to identify the effect of GPS use on the accuracy of acquired spatial knowledge using various measures of navigation performance - path and time redundancy, pointing accuracy, a number of deliberation stops, and a blank map. We hypothesise that the more time people spend looking at the navigation aid during learning, the worse wayfinding skills they will demonstrate during the recall. We predict that their pointing accuracy will be worse and they will show slower navigation times and longer paths. We also hypothesise that their memory for location positions will be affected, but a memory for location names (non-spatial semantic information) will be unaffected.

And **thirdly**, we focus on the relationship between one's own subjective evaluation of navigation abilities, as well as objective assessment of navigation abilities with cognitive tests, and how much they use the navigation aids. Our assumption is that those who either feel less skilled or those who are objectively worse navigators would use the GPS more than those who trust in their navigation skills. Combined with the first aim, this may help us to understand where individual differences in navigation aid use originate from and how they relate to GPS' use in general.

As a necessary prerequisite for answering these questions, we also tested intraindividual stability in navigation performance. Participants therefore attended two sessions over the course of 3 months, each with a different virtual city simulation consisting of 21 there-and-back tasks (described in Section 2.6). Navigation in the virtual city was accompanied by eye-tracking measurements to identify the proportion of the time participants focused on the provided GPS-like map. Participant navigation skills were self-reported and assessed by a battery of psychometric tests.

2. Methods

2.1. Participants

Healthy participants were recruited through a local advertisement which included questionnaire addressed to persons interested in human cognitive enhancement technologies such as virtual reality and GPS navigation. This per protocol recruitment process affected the unbalanced gender distribution in the final sample of 42 participants, 36 males ($M_{age} = 27.3, SD = 6.5$) and 6 females ($M_{age} = 29.75, SD = 7.9$). Although we consider this sample suitable for our study, any gender related differences should be interpreted cautiously.

All participants had completed at least high school education, 17 subjects finished and 12 were attending university. Participants with ophthalmologist reported sight defects that could affect the eye tracking measurement were excluded from the study. All participants signed an informed consent approved by the Ethical Committee of NIMH-CZ. Participants were financially rewarded at the end of the second session.

2.2. Procedure

All participants attended two sessions over the course of 10–12 weeks. During each session, participants completed the virtual city task (described in Section 2.6) accompanied by eye-tracking. After a delay of approximately 90 min, each participant received a blank map and was asked to fill in locations and names of all remembered landmarks. To control for individual differences in cognitive performance, specifically in spatial abilities and delayed memory, participants were assessed using a short psychometric battery of tests and they were also interviewed about their gaming habits and subjective navigation experience. Both sessions had the same structure, but the virtual city environment was different to remove possible bias in location placement and to create more tasks overall.

2.3. Psychometric battery

Spatial abilities were assessed using the Money Road-Map Test (RMT, number of errors from total 32 left-right decisions and completion time) Money et al. (1965) and the Perspective Taking Spatial Orientation Test (PTSOT, number of correct trials completed in 5 min) Hegarty and Waller (2004). Repeatable Battery for the Assessment of Neuropsychological Status (RBANS) Randolph et al. (1998) was used to evaluate delayed memory performance (RBANS memory score calculated from List Recall, List Recognition, Story Memory, and Figure Recall).

2.4. Interview

We briefly interviewed each participant to determine their subjective navigation expertise on a scale from 1 to 5 (5 being the best). We also