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An exploratory real-world wayfinding experiment: A comparison of drivers' spatial learning with a paper map vs. turn-by-turn audiovisual route guidance

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ABSTRACT

Turn-by-turn (TBT) route guidance technology installed on mobile phones is very popular among car drivers for wayfinding purposes. Previous studies examined their effect on spatial knowledge predominantly on pedestrians or in virtual environments. Drivers' spatial knowledge was experimentally compared in two random groups: audiovisual route guidance using the TBT navigation feature of the Google Maps app installed on a mobile phone, and a paper map. Participants drove their own vehicles to a predesignated destination in an unfamiliar residential neighborhood. Spatial knowledge tests (orientation, landmark recognition and route recognition) were subsequently administered. The scores of map-assisted drivers were uncorrelated and, on average, higher in orientation (deviation in direction), landmark recognition and route recognition (error percentage). The landmark recognition scores of drivers assisted by TBT route guidance were significantly lower with a very large effect size. The route recognition scores of drivers assisted by route guidance showed strong correlations with orientation and with landmark recognition scores. Results can be attributed to the differences in cognitive effort required to complete the wayfinding task: unlike memorizing a global map survey, passively following TBT audiovisual instructions does not require drivers to actively encode, transform, and continuously monitor their egocentric position in space. Drivers also showed somewhat poorer performance relative to studies with pedestrians which can be explained by the greater mental effort, compared to wandering on foot, involved in wayfinding while safely driving a rapidly moving vehicle. The future implications of the increasing dependence on mobile navigation technologies are further discussed.

1. Introduction

Mobile phones equipped with navigation technologies using the Global Positioning System (GPS) have become very popular among car drivers. Navigation technologies can be defined broadly as any technological innovation that assists human navigation (McPherson, 2009), including also satellite navigation (aka sat-nav) technology. Technology assists users by indicating the direction to the destination from their current position and perspective, reducing consequently the effort in acquiring, processing and learning spatial knowledge.

1.1. Wayfinding and spatial knowledge acquisition

Wayfinding consists of a person's ability, both cognitive and behavioral, to purposefully reach destinations in space (Passini, 1984; Golledge, 1999). Spatial knowledge and learning are thus essential for successful wayfinding e.g. orientation in the environment and other mental spatial tasks such as navigating from point A to point B or directing another person to a specific place (see Wiener and Mallot (2003) for a taxonomy of human wayfinding tasks). However, numerous studies have found empirical evidence that technology-assisted wayfinding seems to decrease the acquisition of spatial knowledge compared to more traditional wayfinding methods e.g. using a paper map (e.g. Golledge et al., 1995; Aslan et al., 2006; Münzer et al., 2006, 2012, 2020; Parush et al., 2007, Ishikawa et al., 2008; Willis et al., 2009; Krukar et al., 2020).

In particular, what previously was an active cognitive task of information search, spatial processing, memorizing, and decision-making, is distilled to a passive task of following turn-by-turn (TBT) audiovisual route guidance instructions (i.e. being led through the environment without any motivated choice) which can hinder spatial learning (Held & Hein, 1963). Conversely, better wayfinding performance, in terms of duration and distance and with less navigational errors – detours and deviations, have been reported when directions

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or instructions are provided (Streeter et al., 1985; Lee & Cheng, 2008), implying the existence of a trade-off between wayfinding and spatial learning (Münzer et al., 2012). This issue is important as drivers must take spatial decisions and reorient themselves in the environment either due to technological malfunction (e.g. the satellite signal is not available or the battery has run out) or due to dynamic changes in the environment not reflected yet in the system's geospatial database (e.g. blocked roads due to an accident or a natural disaster).

Moreover, acquiring spatial knowledge is a necessary ability for generating and updating *cognitive maps* which are the mental representations of the physical environment concerning the spatial relations and attributes residing within a space-time context (Kitchin, 1994). Cognitive mapping is thus a fundamental process that allows people to perceive, acquire knowledge and operate, in space and to successfully process and encode environmental and geographical data (Downs & Stea, 1973). This process known as spatial knowledge acquisition which is an intentional and effortful cognitive process using the audiovisual senses that filter, abstract, integrate, and store spatial information in long-term memory in order to transfer knowledge to new situations (Wen et al., 2011; Aginsky et al., 1997; Salomon, 1984).

The classical theories of Hart and Moore (1973) and Siegel and White (1975), consider three distinct spatial knowledge elements: Landmark, Route and Survey knowledge. These three categories are not considered as discrete and independent forms progressed through in order; rather, spatial knowledge changes as a function of the direct experience in the environment (Golledge and Spector, 1978). Landmark knowledge relates to recognition of specific points-of-interest that have distinctive features but without the ability to link them to each other. Route knowledge links landmarks to create routes/paths between them, which generate mental representations that are conceived as a sequence of egocentric visual images of landmarks together with corresponding directions (Gillner & Mallot, 1998). Survey knowledge generates a cognitive map representing a network of landmarks with distances and directions between them that indicate a deeper understanding of the spatial relationships between locations. Sometimes route knowledge will transform into configurational knowledge incorporating Euclidean, as opposed to purely topological, relationships (Golledge et al., 1985; Hirtle & Hudson, 1991; see also Thorndyke, 1981; Thorndyke & Hayes-Roth, 1982, for reviews). Alternatively, Montello (1998) suggested that spatial learning is a quantitative process of accumulation and refinement that occurs quite quickly within a new environment and involves development of metric knowledge. Importantly route knowledge serves people to navigate to a destination, whereas survey knowledge to determine its exact geographic location (Meilinger et al., 2013).

1.2. Role of technology in wayfinding and impacts on spatial learning

While wayfinding (or direct navigation) abilities developed as human cognition evolved, throughout history people used various navigation aids to facilitate wayfinding, particularly paper maps. Thorndyke, & Hayes-Roth (1982) argued that maps supply a bird's eye view of the environment allowing for easier encoding of global spatial relations (i.e. survey knowledge) as a cognitive map. In contrast, when wayfinding people are able to connect diverse landmarks (i.e. route knowledge) to memorized traversed routes which enable to mentally simulate travel through the environment and but given this partial knowledge the computed spatial judgments are less accurate (estimating orientation, object location, or Euclidean distances).

In recent years, GPS-enabled mobile navigation technologies have taken over from direct navigation in real environments and somewhat replaced paper maps as well. Navigation technologies supply spatial information to users in various formats including: verbal navigational directions (e.g. TBT), static maps, interactive (mobile) maps, 3-D visualizations, animations, and virtual or augmented environments (see Montello et al., 2004, for a review). Numerous studies examined their influence on human spatial knowledge acquisition with the common empirical evidence pointing out to detrimental effects of technology-assisted wayfinding on spatial learning performance. Experiments were conducted either in the lab mainly using virtual environments or in the field. Important cognitive insights were gained from experiments involving virtual environments (e.g. Münzer et al., 2020; Löwen et al., 2019; Ruginski et al., 2019; Schwering et al., 2017; Javadi et al., 2017; Parush & Berman, 2004; Spiers and Maguire, 2006a, 2006b; Burgess et al., 2002), However, as noted by Coluccia and Louse (2004) and Munion et al. (2019), given their constraints in size, experienced velocity as well as their movement generating mechanism, whether virtual environments replicate sufficiently well real-world navigation remains yet questionable. Since the focus here is on drivers' spatial learning when wayfinding in the real world, the reminder of the review deals mainly with experimental field studies.

A relatively similar methodology was applied in all the reviewed studies. Participants were randomly divided in to a *treatment group* which conducted a technology-assisted wayfinding task equipped with some kind of nomadic (i.e. mobile) end-device (e.g. PDA, Tablet PC, mobile phone or a smartphone; and a *control group* which had to learn and memorize the route using paper maps sometimes within a certain time threshold (e.g. 2 min) with or without recall or with unlimited time (note: learning times are rarely reported). Under both conditions participants individually traversed the same routes and post-tests to measure spatial knowledge were administered subsequently These tests fall usually into the three aforementioned elements of landmark, route and survey knowledge e.g. pointing to the start point, placing landmarks in their correct location on a map, provide distance estimates or drawing sketch maps that were qualitatively and quantitatively evaluated (measures of survey knowledge); recalling physical elements en-route (landmark knowledge); recalling turning directions (route knowledge). In some studies participants repeated the tasks several times whereas in others only one exposure was measured. The frequent result found was that by memorizing and learning paper maps beforehand, followed by some direct navigation experience, participants obtained significantly higher scores compared to participants that followed route guidance instructions regardless of the technology medium.

Reviewed studies provided various plausible explanations to the observed differences in spatial learning performance between treatment and control groups. First, Krüger et al. (2004) and Münzer et al. (2006) consider that allocentric paper map perspective provides survey knowledge information that is actively encoded (Prince, 2004; Bonwell & Eison, 1991), transformed into an egocentric spatial perspective and finally memorized. In contrast, mobile navigation technologies better convey landmark and route knowledge to users, but generate insufficient survey knowledge because the necessary global spatial relations are not acquired and memorized well enough while on the move, whereas route memory (view and directions) is created incidentally. Additionally, they asserted that passive route guidance makes the mental effort involved in spatial transformation unnecessary resulting in disengagement towards the wayfinding process (see also Held & Hein, 1963; Streeter et al., 1985). Second, Ishikawa et al. (2008) proposed the group performance difference was due to smaller displays in mobile devices that allow to see only localized survey fragments at any given moment (see Golledge et al., 1995; Dillemuth, 2005 for discussions on display size and richness effects). Third, users split their attention between following the instructions of the navigation device and the outside environment (Willis et al., 2009) i.e. the focus of attention on the egocentric route guidance information interferes with the processing of global spatial information (Hejtmánek et al., 2018, Gardony et al., 2015). Fourth, Huang et al. (2012) and Von Stülpnagel & Steffens (2012) stressed the positive role of familiarity with the environment on spatial learning i.e. participants familiar to the study area had overall better performance than nonfamiliar ones. Fifth, Wang & Spelke (2000) and Ruginski et al. (2019), point to disorientation and mental rotation that occur when navigating with mobile devices while on the move as interfering with spatial learning.

1.3. Spatial learning and driving

Although the aforementioned studies provide valuable insights and elaborate behavioral explanations they were predominantly conducted on pedestrians or walking-like experiences in safe or in virtual environments (simulators). Very few studies were found that consider the effects of driving on spatial learning. Moreover, those were neither conducted in the field e.g. using driving simulators, (Burnett & Lee, 2005; Gramann et al., 2017), nor was spatial learning measured explicitly (Lee & Cheng, 2008; Knapper et al., 2015), nor specifically focused on car driving (e.g. bicycle, or passive front/back seat riding, Ishikawa & Montello, 2006; Von Stülpnagel & Steffens, 2012).

The main findings somewhat resemble pedestrian studies but essential knowledge gaps still remain. First, drivers in the treatment group received overall poorer spatial knowledge scores (landmark recognition, turn directions recall and sketch map details) compared to drivers in the control group (Burnett & Lee, 2005; Dickmann, 2012). Second, in the treatment condition drivers performed better in wayfinding tasks in terms of travel time, speed variation and car handling performances (Lee & Cheng, 2008; Knapper et al., 2015). Third, active front seat riders performed better than either backseat or passive front seat riders particularly in landmark and route knowledge (Ishikawa & Montello, 2006; Von Stülpnagel & Steffens, 2012). Fourth, survey knowledge (metric) was acquired very quickly while recurrent exposures often showed little improvement (Ishikawa & Montello, 2006). Fifth, the vestibular sensing of acceleration (i.e. inertial information) when riding in a car does not induce spatial learning compared to the additional proprioceptive information (i.e. kinesthesis and efference copy) while walking on foot (Waller et al., 2003, 2004). Sixth, using in-car navigation systems habitually over long periods resulted in poorer performance and less accurate route configurations (Ishikawa, 2019). These assertions, thus, point out that the impacts of mobile navigation technologies on car drivers' spatial learning remains a clear knowledge gap in the state-of-the-art.

1.4. Motivation and contribution

While negative impacts of mobile navigation technologies on spatial learning have been reported in car-like travel experiences, to date, these were never measured on drivers explicitly. Given the expected differences in the cognitive resources drivers, unlike pedestrians, can devote to spatial learning, while both safely controlling a rapidly moving vehicle and acquiring spatial information over a larger path area (Münzer et al., 2006; Dillemuth et al., 2007), unsurprisingly, investigating spatial learning differences between walking and driving, is considered a pressing research area in the state-of-the-art (Ishikawa and Montello, 2006; Raper et al., 2007). Moreover, nowadays car drivers are regarded as the main beneficiaries of mobile navigation technologies and the scope of their usage is increasing e.g. finding parking, route guidance and planning and querying travel time information (Pullola et al., 2007). In addition, the COVID19 pandemic and associated social distance restrictions have contributed to a dramatic reduction in public transport use with many travelers switching back to driving (de Vos, 2020), while the long term impacts of this relapse are unclear. Thus, clearly more research on the impacts of mobile navigation technologies on car drivers' spatial learning is unequivocally justified.

As far as possibly known no previous research examined the acquisition of spatial knowledge of car drivers in the field. To this aim, an exploratory small–scale field experiment was designed to answer the research question how drivers' spatial learning, while wayfinding in the real-world, is influenced by the use of a GPS-enabled mobile navigation technology (here: the Google Maps app) in comparison to a traditional paper map. The rest of the paper is organized in the following way: Section 2 presents the research methods; Section 3, presents the results. Section 4 discusses the study's findings, validity and its limitations and Section 5 concludes with future research directions.

2. Methods and materials

2.1. Hypotheses

The main hypothesis is that drivers conducting a wayfinding task assisted by a mobile phone equipped with GPS-enabled navigation technology will have lower spatial knowledge acquisition scores (as operationally defined below) compared to drivers, who conduct exactly the same task, assisted by first learning and memorizing a paper map. An exploratory small-scale field experiment was designed to test this hypothesis based on synthesizing the protocols applied in other spatial learning studies in order to ensure high data quality and reliability but fitted to the practical and ethical constraints of car driving.

2.2. Participants

44 (22 men and 22 women) non-students (n = 10) and students (n = 34) from Ben-Gurion University of the Negev volunteered to participate in this research. The sample was of comparable size to those employed in previous field studies (e.g. Thorndyke & Hayes-Roth, 1982; Ishikawa & Montello, 2006, Willis et al., 2009; Dillemuth, 2005; Lee & Cheng, 2008; Dickmann, 2012). Participants were recruited via an online announcement published on the University's ORSEE system (Greiner, 2015). Their ages ranged from 22 to 33 years old (mean = 27.03). All of them held a valid driver's license, and drove their own car at least once a week. Apart for three, all the other participants lived in the city of Beer Sheva, Israel. The median residency was 4 years (the average was 10 years). Participants were monetarily compensated for their participation receiving 60 ILS (about $18 USD). Their compensation was not dependent whatsoever on their performance.

2.3. Design

In order to guarantee a high degree of internal validity, a between-subjects design with randomized allocation to two equal-sized groups – treatment (N = 22) and control (N = 22) and counterbalanced for gender (11 women and 11 men were allocated into each group), was chosen. In the treatment condition drivers navigated by following audiovisual instructions provided by the TBT 'Google Maps' route guidance app installed on a mobile phone. In the control condition, drivers learned a paper map before performing direct navigation. Participants in both groups arrived with their own cars and drove the same route once from start to finish. Participants' own cars were used in order to limit the need to get acquainted with another vehicle, and avoid any issue of discomfort and further cognitive burden that risked adding unnecessary confounding effects (that could compromise validity), impose additional personal safety issues, as well as control for possible driving ability differences.

2.3.1. Pre-test

Before starting the experiment, background data was collected with a pre-test questionnaire that collected data on age, gender, residency location and duration, familiarity with sat-nav (or GPS) devices/apps (Y/N question) and their usage frequency (5 point likert scale). In order to prevent contamination effects, participants were also asked whether they had prior knowledge of the specific target area (knowledge about the area – Y/N question and the frequency of visiting there – 5 point likert scale). The well-known Santa Barbara Sense of Direction test (Hegarty et al., 2002) to measure prior navigation ability was not administered for both practical and substantial reasons (see Section 4.2 in the Discussion for further explanations).

2.3.2. Test phase

The test phase included driving the predesignated route. The route planning adopted a conservative approach in order to maintain maximal personal safety, avoid excessive stress for the participants, before or during the drive, which could influence the results on one hand, while providing sufficient stimuli for analysis, on the other hand. The route was planned in the "Ramot" neighborhood – a middle-class suburban residential area – located at the northeastern outskirts of the city of Beer-Sheva. These urban attributes lowered the chance that participants had been there before unless they actually lived there which would have disqualified them in advance. This location was chosen also due to the large number of roundabouts located at the junctions that have two additional important advantages: First, according to Israeli driving laws, the entrance to a roundabout demands yielding to incoming traffic but without any traffic lights operating. This fact guaranteed a relatively smooth drive, without crossing any signalized junctions which is both more dangerous and risked having mandatory stops with different lengths of time occurring en-route; second, each roundabout is decorated with a specific feature (e.g. a statue, a landscaped garden, a clock) which could be identified as a landmark. The total route length was 2.4 km (1.49 miles) consisting of six decision points (6 roundabouts) and seven road segments (see Fig. 1). Only the four roundabouts in decision points 3–6 were used in the analysis as these were located inside the neighborhood, whereas the first two were located on a busy thoroughfare that could well be familiar to many inhabitants of the city. It was purposefully decided that the route would be driven only in good weather, during daylight hours at the middle of the day when traffic volumes are low (off peak) and speeds resembled free flow conditions. This guaranteed good visibility, personal safety and minimized any possible variation in driving times. Note, the designated route was driven only once given that more replications could be difficult to manage safely without increasing the likelihood of unexpected events happening, as well as considering that sufficient spatial knowledge could well be acquired even with a single exposure (Ishikawa & Montello, 2006; Löwen et al., 2019).

2.3.3. Post-test

A post-test questionnaire was delivered after the drive to evaluate each participant's acquisition of spatial knowledge: landmark route and survey knowledge that included operationalizing measures based on previous studies, in order to ensure their reliability, as described below. The questionnaire included three questions that were answered in the following order (see Appendix 2):

(1) Pointing to the starting position – this test assessed orientation an important aspect in the formation of survey knowledge. Participants were asked to point with an arrow – on a cardboard compass wheel, which had rays drawn numbered from 0 (north) to 360 in increments of 10° – to the approximate direction of the starting position. The performance was measured as the absolute error measured in degrees between the true angle (211°) and the pointed one (Ishikawa et al., 2008, Willis et al, 2009; Von Stülpnagel, & Steffens, 2012; Huang et al., 2012). Absolute error is a good index of accuracy, in this case, as it reflects the probability that a particular participant's response falls within a particular range around the correct target (Spray, 1986).

(2) Landmark recognition – this test assessed the acquisition of landmark knowledge by measuring the ability to correctly identify the pictures of the roundabouts located along the driven route (e.g. see Fig. 2. Participants were presented with four randomly selected sets of three photographs of roundabouts printed on an A4 paper. For each set, they were asked to choose the one that was truly located along the navigated route and to write its ID letter on the form. The order of presenting the true roundabouts on the page was randomized and uncorrelated with the sequential order during the drive. The performance was measured by counting the number of correctly chosen photographs and computing the percentage of error (Huang et al., 2012; Burnett & Lee, 2005)[1].

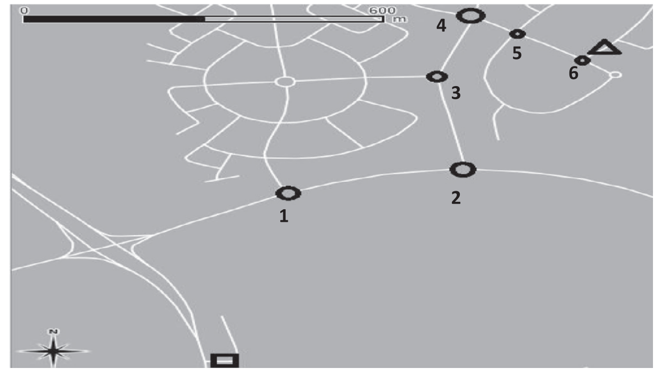

Fig. 1. Example of the paper map. The circles represent the roundabouts (decision points), the square represents the starting point and the triangle represents the finish point. Numbers represent decision points along the route.

(3) Route recognition – this test assessed the acquisition of route knowledge by measuring the participant's ability to correctly recall the turn directions taken at the roundabouts that were passed during the drive. Naturally, this test was performed only after the landmark recognition test to avoid contamination of the landmark recognition. Participants were shown four randomly ordered photographs, each printed on an A4 paper, of the true four roundabouts (decision points 3–6) they had actually passed through (some were already shown in the landmark recognition test). They had to indicate to what direction they turned (i.e. left, right or straight) at each of the roundabouts shown and write down this direction next to the roundabout's letter. The order of presenting the roundabouts to the participants was randomized and uncorrelated with their sequential order during the drive. The performance was measured by counting the number of correct turning directions in the participant's responses and computing the percentage of error (Münzer et al., 2006; Huang et al., 2012; Burnett & Lee, 2005).

2.4. Procedure

Each registered participant was randomly assigned into one of the two groups. He or she was instructed by email to arrive with his/her own car on a specific day and time to a predesignated meeting point (the start position) where the experimenter was already waiting. The meeting point included a safe parking spot for the car and a shelter. The experimenter sat in the backseat of the car and introduced the study to the participant as an experiment regarding navigation technology and driving behavior in order to prevent any understanding of the true purpose of the experiment which is to measure their spatial knowledge. While sitting in the car the participant received written and oral explanations about the expected task ahead (see Appendix 1), signed the consent form and filled in the pre-test questionnaire.

[1] Some studies (e.g. Von Stülpnagel & Steffens, 2012) measure the relative hit ratio instead which indicates participants' ability to discriminate encountered from non-encountered landmarks (hits minus false alarms; see Snodgrass and Corwin, 1988). Presentation of their results here was deemed forlorn given that similar results were obtained in comparison to the error rate.

Fig. 2. Examples of photographs of the roundabouts in the Ramot neighborhood. Roundabouts along the navigated route (Right) and “Dummy” roundabouts included in the post-test questionnaire (Left).

2.4.1. Treatment condition

The treatment group used an LG-G3 GPS-enabled smartphone running the most recent Google Maps app, provided by the experimenter, with a screen size of 5.5 in. installed to the right of the driver on the lower-middle section of the dashboard (Fig. 3). This location for the phone’s installation is both commonplace and, to ensure safety, keeps the driver's view unblocked. The navigation feature on the Google Maps app provided the participants with audiovisual TBT route guidance information, in Hebrew, based on a 2D map shown on the display and vocal turning instructions before and near the decision points. The experimenter preset the destination address on the Google Maps app before starting the drive. Participants could not see the destination address before or while driving.

2.4.2. Control condition

The participants in the control group received an A4 paper map, (see Fig. 1), covering only the area of relevance to the drive. The origin, decision points (the roundabouts they needed to drive through, but not their numbering), and the destination were clearly marked on the map without any further geographical information. Participants were instructed to learn the route to the destination and once confident, returned the map to the experimenter. Although the map contained scale information, the experimenter did not instruct the participant to learn metric distances. No formal time limit was set on the route learning (Münzer et al., 2006; Ishikawa et al., 2008; Burnett & Lee, 2005). Unlimited learning time was chosen so as to avoid timed recall episodes while sitting in the driver seat; to engender a real wayfinding experience; to reduce unnecessary stress or duress that could interfere with the wayfinding performance and risk contributing to dangerous or unlawful driving or unnecessary deliberation stops en-route. In practice, participants returned the map to the experimenter within about two minutes. This is issue is readdressed in the Discussion later on.

2.4.3. General procedures

All of the participants (in both groups) drove their own private car. All sessions were carried out during daylight hours at the late morning or at noon when there were low traffic volumes on the roads and always in good weather guaranteeing clear visibility conditions. Only one participant was driving at any given time. The task had no predesignated time limit and there was no implicit or explicit pressure to rush. The experimenter sat in the back seat to enforce the guidelines but without interacting with the driver unless absolutely necessary (Ishikawa & Montello, 2006; Lee & Cheng, 2008; Knapper et al., 2015). The experimenter could provide assistance to the driver only in case of an emergency, something that was explained in advance. The drive took approximately 5 min to complete.

Fig. 3. A participant in the route guidance (treatment) group while driving.

On reaching the destination and having parked the car, and the ignition key switched off, the participant was asked to answer and fill in the post-test questionnaire form with pencil and paper. The field experiment started in November 2017 and was completed by February 2018. All participants successfully completed the navigation tasks and there were no disqualifications or dropouts before or during the experiment. Neither were there any route deviations nor deliberation stops in either of the groups.

3. Results

First the results of the pre-test are presented followed by the analysis of the post-test surveys. Relative qualitative comparisons to related works are mentioned where relevant (absolute comparisons are naturally statistically invalid; see Knapper et al. (2015) for a discussion of relative vs. absolute validity).

3.1. Pre-test

Between group differences were verified for all the variables. In the map group the mean age was 27 and 26 in the route guidance group (t[1] = 1.3, p = 0.20). Mean residency duration in the city of Beer Sheva was 12.4 years in the map group and 9.25 years in the route guidance group; no significant differences were found (t[1] = 0.86, p = 0.39). All 44 of the participants stated they were familiar with GPS technology or navigation apps like Waze or Google Maps (Y/N question). In terms of usage frequency, 18 participants stated they used it in the last week; 22 in the last month; and 4 in the last year. This is not surprising given that the penetration of navigation technology and supporting apps in Israel is quite high especially for tech-savy young adults. No significant between group differences were found ($\chi 2[2] = 2.07$, p = .355). All participants apart for two knew about the existence of the 'Ramot' neighborhood (Y/N question). 15 participants never visited the neighborhood, while the remaining 29 stated they rarely visited there in the last year. No significant between-group differences were found ($\chi 2[1] = 0.91$, p = .340). No participant was therefore disqualified for holding prior knowledge. The fact that no significant between-group prior differences were found reduces the risk of alternative explanations (i.e. validity threats) for the measured cause and effect relationships (see Section 4.2 in the Discussion later on).

3.2. Post-test

The data was coded into SPSS where the response variables (pointing error; landmark recognition error; and route recognition error) were computed as described previously. Before starting the analysis the dataset was checked for outliers with a boxplot and none were found. Table 1 presents the main descriptive statistics for the entire sample and for each group. As evident in the skewness and kurtosis values all three response variables are not normally distributed and the Kolmogorov-Smirnov (KS) test came out significant in both groups. Based on these results the analyses were run using nonparametric tests (Mann-Whitney independent group test, and Spearman's rho correlation). In addition, where relevant, posterior effect sizes (Cohen's d) were estimated using a two sided power analysis assuming Asymptotic Relative Efficiency run with G-Power 3.1.9.7 (Faul et al., 2007).

In the *pointing task*, participants were asked to give an approximate direction to the starting point. The performance (see Fig. 4) was evaluated based on the absolute error in degrees from the true angle (211°). The mean error of the control (map) drivers (28.45, CI95: 18.9–37.98) was much smaller than of the treatment (route guidance) drivers (59.86, CI95: 33.62–86.10) and in addition based on the CI95 their provided estimates was more accurate and less dispersed relative to the latter. However, no significant between group difference was found (U = 182, p = 0.16). A log transformation showed the same outcome (t[42] = 1.474, p = 0.15).

In comparison to related works, Willis et al. (2009) found no significant differences between the mean pointing errors of pedestrians (~16°). Ishikawa et al. (2008) found a small relative mean ratio between pedestrians navigating with a mobile map (34°) paper map (24°) or direct navigation (19°). Von Stülpnagel and Steffens (2012) found no mean differences between active and passive navigation (~45°). Huang et al. (2012) also show very little difference between pedestrians familiar and unfamiliar to the environment (means of 25°, 29° respectively). It seems, therefore, that spatial disorientation while driving is somewhat larger than while walking but differences between treatment and control remain inconclusive.

In the *landmark recognition* task, participants needed to recognize (in four randomized sets) one of three pictures of roundabouts which were along the navigation route. The performance was evaluated based on the percentage of error. In terms of the mean percentage of error (Fig. 5), control drivers performed significantly better with a mean score of 25.0% (CI95: 17.4–32.7) compared to 55.7% (CI95: 45.5–65.9) for the treatment drivers (U = 77.5, p < 0.001) i.e. the relative performance difference is more than twofold. In addition, in a post-hoc power analysis a very large effect size was found (Cohen's d = 1.51). These results confirm that the difference between the two groups is both statistically significant and substantially large. That is, map-assisted drivers were likely more aware than those assisted by route guidance of their surrounding environment.

Regarding related works, Burnett and Lee (2005) show similar trends (in a driving simulator) with a mean of 40% recognition errors for map-assisted drivers compared to 76% for route guidance users. Huang et al. (2012) had no map condition; however route guidance was compared between pedestrians familiar and unfamiliar to the study area. Considering familiar users had already memorized the layout (somewhat like map users) the relative differences were somewhat larger but of smaller magnitudes compared to drivers (13% and 34% respectively). It appears, therefore, that drivers make relatively more errors compared to pedestrians. Naturally a more rigorous design is needed to compare the two modes of travel.

In the *route recognition* test, participants had to indicate, to which direction they turned at each of the four passed roundabouts (left, right or straight). The score was based on the percentage of error in identified directions. As shown in Fig. 6, control drivers performed better with a mean score of 27.2% (CI95: 17.7–36.9), compared to 40.9% (CI95: 30.9–50.9) for treatment drivers (U = 169.0, p = 0.07). A post-hoc power analysis with the same assumptions as before showed a medium effect size (Cohen's d = 0.6). The results suggest the route recognition gap between the two groups was smaller than for landmark recognition, whereby map assisted drivers performed much better (the relative performance difference is about 1.3) compared to those assisted by route-guidance.

In comparison to related works, Münzer et al. (2006) who studied pedestrians strolling in a zoo, had larger between group mean differences with a mean of 7% errors for map users compared to 20–25% for route guidance users, showing a threefold relative difference (depending on condition). Huang et al. (2012) showed pedestrians unfamiliar to the environment had a mean error rate twice more than unfamiliar ones (18%, 42% respectively). It seems, compared to pedestrians, drivers tend to make overall more route knowledge errors while the performance gap between drivers following route guidance and learning a map is relatively smaller than for pedestrians. More studies empirically comparing between the two modes of travel is necessary to explore these findings further.

Additional between-group effects: Gender as a mediating factor in a two-way ANOVA for gender and group with bootstrapping to avoid normality assumptions was not found to be significant for any of the response variables: for pointing (F[1,42] = 0.42, p = .42); for landmark recognition (F[1,42] = 0.19, p = .66; for route recognition (F[1,42] = 0.11, p = .74). These results are also in line with results of related works especially field studies that found no significant gender effects (Münzer et al., 2006; Meilinger et al., 2013). We note that some studies of virtual environments did find significant gender differences with men performing somewhat better than women and with less dependence on navigation technology (e.g.: Ruginski et al., 2019; Münzer and Stahl, 2011). The frequency of GPS use also did not show significant interactions with the response variables: for pointing (F[1,42] = 1.5, p = .22); for landmark recognition (F[1.42] = 1.0, p = .32); for route recognition (F[1,42] = 0.07, p = .78).

3.3. Correlation analysis

Correlations (Spearman's rho) between the response variables by group (Table 2), reveal an interesting picture. In the map group most of the correlations were low and none were significant. This suggests that good performance in one of the tasks had very little effect on good

Table 1
Descriptive statistics and KS normality test for response variables by group.

	Pointing error (degrees)		Landmark recognition (% error)		Route recognition (% error)	
	Map	Route Guidance	Map	Route Guidance	Map	Route Guidance
Mean (S.E)	28.45 (4.58)	59.86 (12.62)	25.0 (3.67)	55.68 (4.91)	27.27 (4.62)	40.90 (4.80)
Median	21.00	31.00	25.0	50.0	25	50
Std. Deviation	21.49	59.19	17.25	23.05	21.69	22.55
Minimum	1	1	0	25	0	0
Maximum	71	210	50	100	50	75
Range	70	209	50	75	50	75
Interquartile Range	33.25	99.75	12.50	31.25	50	25
Skewness	0.94	1.16	0	0.305	−0.187	−0.021
Kurtosis	−0.37	0.47	−0.685	−0.567	−1.69	−0.646
KS	0.233 (p = .003)	0.264 (p < .001)	0.273 (p < .001)	0.234 (p = .003)	0.262 (p < .001)	0.214 (p = .01)

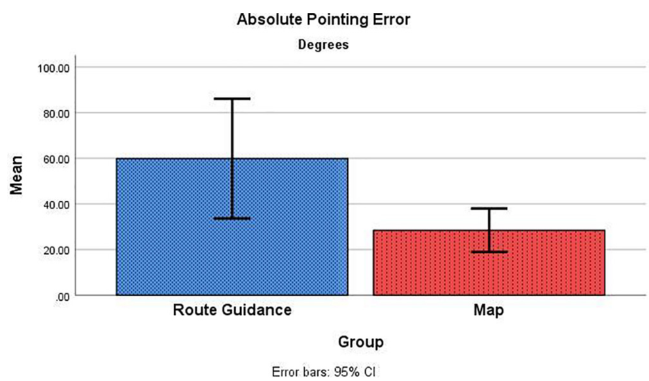

Fig. 4. Mean values and CI 95% for pointing error (degrees) by group.

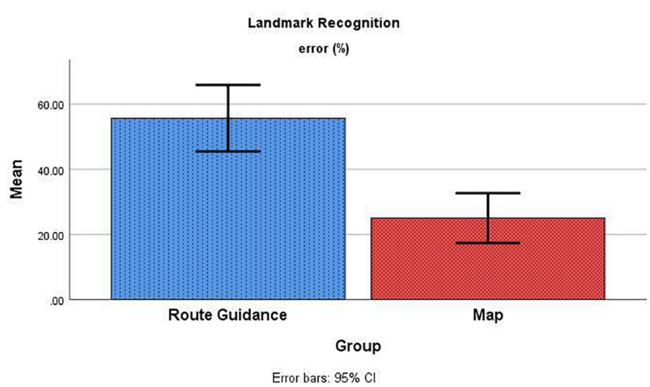

Fig. 5. Mean values and CI 95% for errors in landmark recognition (%) by group.

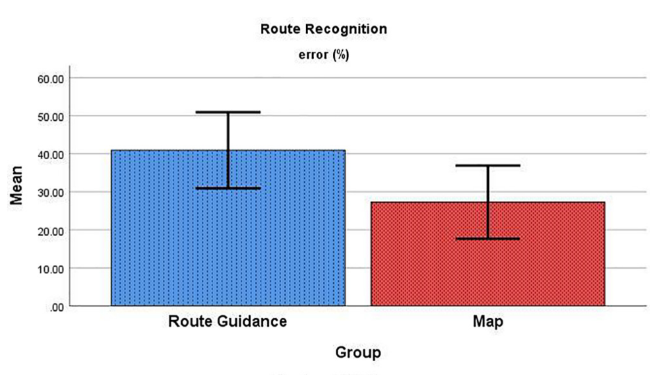

Fig. 6. Mean values and CI 95% for errors in route recognition (%) by group.

performance in the other tasks and vice versa. A very different result appears in the route guidance group, whereby strong correlations between pointing error and route recognition and between route and landmark recognition were obtained. That is, poor performance (more errors) in route recognition resulted in poor performance in pointing (degrees of deviation) as well as in landmark recognition. However, pointing error and landmark recognition remained uncorrelated.

To interpret this outcome an exploratory factor analysis (EFA) was performed for each group with the three response variables (see de Winter et al., 2009 for a discussion of EFA with small samples). Extraction was performed with principle axis factoring and rotation using the Equimax procedure in SPSS. Parallel analysis (using the SPSS syntax by O'connor, 2000) showed the estimates were not the result of a random process. Table 3 shows the rotated factor matrix.

The results confirm the correlation analysis. Map-assisted drivers do not show strong patterns in terms of factor loadings and the estimates are not orthogonal. In contrast, with route guidance two factors with high loading estimates are clearly visible. Factor 1 explained 27.0% and Factor 2 52.5% of the variance (in total 79.5%). Factor 1 is highly correlated between orientation and route recognition while Factor 2 is highly correlated with landmark and route recognition. It seems route recognition i.e. the memory of turn taking at the roundabouts provided the basis for identifying landmarks and estimating orientation. The results could well indicate different learning patterns in the two groups and justifies further inquiries. Map-assisted drivers may have relied on their memory of the global survey layout to provide estimates and answers whereas drivers assisted with route guidance provided estimates, to the other two tasks, based on fragmented and partial egocentric knowledge recalled from the TBT instructions, given that no other information was available.

4. Discussion

In this experiment the spatial learning of car drivers was empirically compared when conducting a wayfinding task either by directly navigating after memorizing a paper map or by following TBT audio-visual route guidance instructions. It was hypothesized that drivers who navigated by passively following route guidance instructions would show poorer spatial knowledge acquisition compared to drivers that first memorized a paper map before direct navigation. The pattern of results as shown in the three spatial knowledge tests somewhat supports this hypothesis. The implications of the findings in relation to car drivers in light of previous studies are briefly discussed followed by limitations (and validity threats) of the current study.

4.1. Interpretations

Related works can offer several interpretations and explanations why map-assisted drivers on average outperformed those assisted by route guidance (and generally GPS) users in spatial learning tasks.

Table 2
Bivariate correlations (Spearman's rho) between response variables (significance in parentheses) by group.

	Map			Route Guidance		
	Pointing error	Landmark recognition	Route recognition	Pointing error	Landmark recognition	Route recognition
Pointing error	1	0.123 (0.585)	0.055 (0.81)	1	0.116 (0.608)	0.444 (0.038)
Landmark recognition		1	0.147 (0.513)		1	0.372 (0.089)
Route recognition			1			1

Table 3
Rotated factor matrix (EFA) by group.

	Map			Route Guidance		
	Pointing error	Landmark recognition	Route recognition	Pointing error	Landmark recognition	Route recognition
Factor 1	0.511	0.63	0.164	0.687		0.578
Factor2	−0.296	0.124	0.444		0.676	0.548

First, drivers' attention was divided between the navigation device and its instructions and the outside environment (Hejtmánek et al., 2018, Gardony et al., 2015, Willis et al., 2009). It is unlikely that the drivers in the experiment could constantly follow the route guidance screen given that they were also busy driving and had to monitor the road and control motoric vehicular functions (steering, acceleration and breaking). Therefore, it is more likely they mostly followed the vocal information they heard rather than watch the display and this is what they probably attempted to recall later in the tasks. Conversely, drivers in the paper map group memorized the entire route from the start to end locations. This likely assisted them in acquiring better global survey knowledge as asserted by Thorndyke and Hayes-Roth (1982).

Second, the cognitive map created when using navigation devices is more fragmented and inaccurate compared to one generated by analogue maps (Dickmann 2012; Willis et al., 2009; Ishikawa et al., 2008). In the route guidance group the drivers could only observe piecemeal segments of the drive area surrounding their egocentric position. In contrast, in the map group the drivers were exposed to a global perspective and required to memorize the entire route passing through the landmarks recalled later, as well as the turns taken at each passed roundabout.

Third, passively following instructions replaces the need for drivers to actively encode the environment into spatial working memory (Huang et al., 2012; Münzer et al., 2006; Parush et al., 2007). Drivers assisted by route guidance were, on average, much worse in recalling landmarks of the surrounding environment they past en-route since the spatial information received was unnecessary for the primary goal of wayfinding, vehicle control and continuous orientation and direction monitoring (Schneider & Taylor, 1999). Nevertheless, they were somewhat better in recalling the turns taken in the route recognition task given that this was the only information important they needed to process to fulfil the wayfinding task. In contrast, map-assisted drivers were enforced to encode and memorize their route and their relative direction and turns to the destination in order to form a cognitive map describing the way from the origin to the destination and while driving they continuously needed to monitor their position and direction in relation to this cognitive map and transform this knowledge back and forth to their egocentric perspective (Raginski et al., 2019). This “active” wayfinding process assisted the spatial information to be better memorized resulting in better recognition of landmarks and better orientation expressed in the pointing task compared to the route guidance group.

Fourth, comparing the performance of drivers and pedestrians it is important to note that drivers must focus on controlling the vehicle, maintain velocity and avoid obstacles. This requires them to remain alert and constantly keep their eyes on the road. These constraints limit their field of view as well as their attention span compared to a wandering pedestrian or even a cyclist. Furthermore the increased velocity of traveling in a vehicle compared to walking or cycling means that drivers will have less time devoted to processing landmarks as these are passed and recede from their field of vision very quickly. Undoubtedly, more research is needed to corroborate these interpretations.

4.2. Limitations and validity issues

As in any experimental study, especially an exploratory and a small-scale one, limitations exist that can threaten the validity of the results. First refutable alternative explanations are noted followed by aspects considered validity threats and their implications.

4.2.1. Strengths to validity

In respect of internal validity, two main refutable alternative explanations are noteworthy. First, the small size of the maps shown on the smartphone display (and correspondingly the scale of the map) considered as an alternative explanation by Ishikawa et al. (2008) can be refuted. The display size used in the experiment measured 5.5 in. thus sufficiently large. Moreover, Gartner and Hiller (2009) conducted an empirical test to study the influence of display size on the acquisition of pedestrians' spatial knowledge and found it had no influence on performance. Second, lack of familiarity with the GPS device, also considered by Ishikawa et al. (2008), can be refuted given that our participants were largely familiar and used the technology quite often. All other between-group prior differences, as measured in the pre-test questionnaire, were not significant suggesting other threats to the validity of the results are likely low. In addition, other factors such as the route section (based solely on roundabouts), period of the day (off peak), driving the participant's own vehicle (i.e. driving ability), driving only once – ensured differences attributed to external environmental factors are also of rather low threat. Lastly, the very high post-hoc statistical power of the landmark recognition scores suggest that there is a substantial behavioral difference between map-assisted and technology-assisted wayfinding while driving which was further corroborated in the correlation analysis. As for external validity it is important to note the fact this was a real-world rather than a laboratory-based study strengthens its external validity (i.e. the ability to generalize the findings outside of the study's context) as the performance was indeed measured in an everyday situation albeit under necessary safety precautions and ethical constraints.

4.2.2. Threats to validity

Nevertheless, several limitations to this study are noteworthy. First, the *a priori* between-subject differences in sense of direction, navigation which can be measured with appropriate scales (e.g. SBSOD – Hegarty et al., 2002 and see also in Ruginski et al., 2019), were not administered. The reasons were first practical as it would have added another layer of administration that had to be done in the car before the drive; and second substantial – since other studies neither found good or consistent correlations between the test's scores and the actual performance (Ishikawa et al., 2008; Munion et al., 2019; Weisberg et al., 2014), nor that they predict the performance very well (Ploran et al., 2015; Rovira et al., 2016). Possibly this should be considered as a requirment in a future study. Second, survey knowledge needed to be better captured using measures such as landmark placement, landmark ordering and sketch maps, in addition to measuring orientation which comprises only a certain aspect of survey knowledge. Third, the designated route was driven only once, firstly for practical reasons i.e. that this was initially a small-scale exploratory study; and secondly because sufficient spatial knowledge could well be acquired even with a single exposure (Ishikawa & Montello, 2006; Löwen et al., 2019). However, in future studies more diverse measurements (e.g. pointing to different landmarks), varied routes (e.g. going back and forth repeatedly; longer routes), different driving times (peak and off peak), different locations (e.g. residential-suburban or downtown), are important to get a broader understanding of variations in wayfinding performance of drivers with different environmental exposures and technologies. For example, it is possible that under more stressful driving conditions spatial learning could well be hampered further. Fourth, timing of the map learning phase as a control measure is an important aspect to inquire in future work (but rarely reported in previous works). As noted, enforcement of the learning and memorization of the map, possibly, provided somewhat of a starting advantage which may have motivated drivers in the control group to be more vigilant than in everyday life situations, resulting in better than average performance. Fifth, the performance and between-group differences of drivers, cyclists and pedestrians were based here on a qualitative relative comparison to several somewhat similar studies. To gain more valid insights on this difference a different study should be designed where all considered modes of travel use the same route and are measured consistently under the same environmental conditions.

5. Conclusions

To conclude, there is ample empirical evidence that the use of GPS-enabled TBT route guidance, commonly used by drivers in everyday wayfinding tasks, hampers spatial learning and the acquisition of spatial knowledge when compared to the use of traditional paper maps. However, to date research has been predominantly done with pedestrians walking in relatively safe environments or virtual ones (e.g. a driving simulator) rather than car drivers who make the most abundant everyday use of mobile navigation devices.

The findings suggest, in a similar line to pedestrian wayfinding studies, that drivers who actively memorized a paper map before wayfinding perform somewhat better in terms of spatial learning scores (mainly in landmark recognition) than drivers passively following TBT audiovisual route guidance instructions. In addition, the spatial knowledge integration in drivers' working memory is likely different under the two conditions. That is, map-assisted drivers who first encoded the global survey layout in their cognitive map and later actively transformed it to their egocentric perspective while navigating, treated each knowledge component separately in recalling what they learned en-route. In contrast, route guidance followers mainly based their spatial judgments on the recalled egocentric route knowledge (i.e. turn directions) that was the only necessary information required to process in order to complete the wayfinding task and consequently their cognitive maps was likely more fragmented. There are also some qualitative indications that drivers' spatial learning is relatively poorer than pedestrians or cyclists in landmark and orientation tasks. The overall performance difference could well be attributed to the additional cognitive load including: motoric vehicle control, limited ability to observe the end device's display, higher travel velocity, narrower field-of-view and limited proprioceptive information, while driving.

In the future more empirical field studies, as well as lab studies involving simulators or even immersive virtual reality (VR) are recommended in order to compare drivers' acquisition of spatial knowledge with different navigation technologies. These studies should also consider different spatial environments and also traffic conditions such as congestion or bad weather and how they interact with spatial learning performance. Another direction would be to compare the spatial learning between drivers to another riding passenger in the car. Such a study could well be important to understand how riding in driverless automated vehicles might influence spatial knowledge acquisition in the future. It is also important to have better control over the route learning phase of the experiment both in terms of map exposure time, as well as the level of geographical information details. Finally our results could have implications for interface design that accentuates spatial learning i.e. support drivers to acquire more allocentric spatial knowledge while following TBT instructions by informing them of key information about their relevant surroundings in particular regarding expected landmarks that also enrich orientation information (e.g. Nothegger et al., 2004; Raubal and Winter, 2002; Burnett, 2000; Michon and Denis, 2001; Lovelace et al., 1999). While these ideas were recently tested in virtual wayfinding tasks (Schwering et al., 2017; Löwen et al., 2019; Krukar et al., 2020), real-world environments can be unsurprisingly quite different. Moreover, more research with drivers and especially comparing drivers and pedestrians with more widespread measurements than what was accomplished in this small-scale experiment, are unequivocally of added value. Lastly, given that there are already many studies that investigated the effect of mobile navigation technologies on spatial learning, it is highly recommend running a meta-analysis to generate broader behavioral and cognitive insights.

CRediT authorship contribution statement

Eran Ben-Elia: Conceptualization, Data curation, Formal analysis, Investigation, Funding acquisition, Methodology, Project administration, Resources, Supervision, Validation, Visualization, Software, Writing - original draft, Writing - review & editing.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.trip.2020.100280.

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