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Spatial Cognition & Computation
An Interdisciplinary Journal

ISSN: (Print) (Online) Journal homepage: www.tandfonline.com/journals/hscc20

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SPATIAL COGNITION & COMPUTATION
2022, VOL. 22, NOS. 1–2, 161–183
https://doi.org/10.1080/13875868.2021.1969401

Online mobile map effect: how smartphone map use impairs spatial memory

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ABSTRACT
This article examined people's spatial memory and navigation performance when they learned an environmental route using a smartphone map and a paper map. Our results showed that the use of a smartphone map impaired spatial learning and knowledge acquisition. Specifically, participants learned a route less accurately when they used a smartphone map than when using a paper map, revealed by a worse route retracing performance. Although navigation accuracy decreased for the second, unaided walk after the first walk aided with a smartphone map, participants' self-evaluation in terms of state anxiety and confidence ratings did not show a statistically significant difference. This suggests that smartphone map users did not perceive the memory impairment caused by the smartphone map use.

KEYWORDS
Navigation; route learning; sense of direction; spatial anxiety; Google Effect

1. Introduction

People consult navigation information including maps, verbal directions, and satellite navigation in an unfamiliar, or even familiar, environment. Among such major navigation tools are digital maps on a smartphone, which people use most frequently nowadays. Recent data show that mobile map applications have high percentages of market reach (90% worldwide; Liu, 2018; Statista, 2019), and a survey in Japan showed that 62% of people use maps on a smartphone, while 28% paper maps, during navigation (Zenrin, 2018). Smartphone maps guide the user to their destinations through instructions of where they are and which way to turn. In other words, smartphone maps' advanced geolocation functions might replace the cognitive processing in the identification of a current position and planning of a route that is required in navigation with paper maps.

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These navigation functions are convenient and expected to relieve the traveler of the cognitive burden of wayfinding, from a viewpoint of technology and engineering (Montuwy, Cahour & Dommes, 2019). The use of (or reliance on) navigation tools, however, has been shown to impair the user's spatial learning and memory (Gardony, Brunyé, Mahoney & Taylor, 2013; Ishikawa, Fujiwara, Imai & Okabe, 2008). Bakdash, Linkenauger and Proffitt (2008) discussed that active navigation and decision making, not merely the control of locomotion, are important for the acquisition of configurational spatial knowledge in the environment. When using a navigation tool, people control their locomotion (e.g., move the body and limbs to make a turn or avoid an obstacle), but lack decision making and route planning if they simply follow the directions given by the tool automatically. Von Stülpnagel and Steffens (2013) similarly observed deterioration of route memory with the lack of elaboration of spatial information in route planning. Thus, the replacement of the user's cognitive processing by a navigation tool and the distraction of the user's attention from the surrounding environment could "erode" human sense of place and orientation (McKinlay, 2016).

A negative impact of the lack of decision making may be especially applicable to users with low spatial aptitudes, because people with a poor sense of direction tend to be dependent on others for navigational route planning (Kato & Takeuchi, 2003) and, importantly, have difficulty remembering and understanding traversed routes (Hegarty et al., 2006). Note that people with poor ability in general face the dual burden of poor performance and ignorance of it. Kruger and Dunning (1999) showed that unskilled people tended to overestimate their abilities more heavily than skilled people, not only reaching erroneous conclusions on various tasks but also being unaware of their errors. In the context of spatial navigation, this kind of dual burden can keep people with a poor sense of direction from noticing their wayfinding errors at critical decision points.

In addition, beyond the use of navigation tools specifically, the effect of digital devices on the user's cognition in general has been reported. In an examination of the relationship between internet use and the user's memory, Wegner and Ward (2013) found that people had difficulty remembering learned information when they believed that the information would be saved and available later on a computer, and that they self-assessed their memory performance to be better than actually was with the use of an internet search (what is called the Google effect). The researchers ascribed the discrepancy between performance and self-assessment to the blurred boundary between knowledge in people's minds and information on the internet. If that is the case, navigation assistance on a digital device, which provides people with access to information online, would similarly result in a discrepancy between the user's wayfinding performance and their self-assessment of it.

With these issues of the widespread use of mobile tools and its possible negative consequences on human cognition in mind, this article examines the effect of smartphone maps on the user's wayfinding performance and self-assessment of it. Specifically, we see if the Google effect holds (a decrease in memory performance and overconfidence in one's performance due to internet use) holds for spatial learning and memory with online mobile maps. To that end, we will examine three hypotheses about spatial performance by people with different levels of sense of direction.

Our first hypothesis concerns the deterioration of spatial memory and the distraction of attention from the surroundings owing to the use of a mobile navigation tool (Ishikawa, 2018; Ruginski, Creem-Regehr, Stefanucci & Cashdan, 2019). In our experiment, participants first walk a route with either a smartphone map or a paper map, and then retrace the route by themselves without the assistance of any tool. If the use of a mobile tool interferes with spatial learning, performance on retracing would be worse when the route is learned with a smartphone map than when it is learned with a paper map.

A second hypothesis concerns the greater degree of reliance on a mobile tool (lack of decision making) by people with a poorer sense of direction (Bakdash et al., 2008; Kato & Takeuchi, 2003; Wegner & Ward, 2013). If the deterioration of retracing performance by smartphone users is observed as posited in the first hypothesis, the size of deterioration of performance would be greater for participants with a poorer sense of direction.

A third hypothesis concerns the discrepancy for people with lower ability between their actual performance and self-assessment of it (Wegner & Ward, 2013). When the deterioration of retracing performance by smartphone users is observed as posited in the first hypothesis, self-assessment ratings in terms of state anxiety and confidence would not be affected. That is, although retracing performance becomes lower, state anxiety and confidence remain low and high, respectively, for people with a poor sense of direction.

To examine these hypotheses, we conducted a field experiment and assessed participants' route learning and retracing performances and recognition memory of traversed environments, with their spatial aptitudes, anxiety levels, and past experience of using navigation tools taken into account.

2. Method

2.1. Participants

A group of 20 young adults (15 male and 5 female) participated the experiment in return for monetary compensation. Nineteen participants were undergraduate or graduate students recruited by an ad posted on a university campus,

Figure 1. Smartphone map (left) and paper map (right). The smartphone map was shown to participants on a 5.5-inch screen with a scale of about 1:8,000. The paper map was printed on A4-size paper with a scale of about 1:2,000. In this figure, the smartphone map shows Route A and the paper map Route B. Note that the red arrows and labels indicating the direction of travel and start/goal locations are for explanatory purposes only, and were not shown to participants.

and one participant was a working adult recruited by a research assistant. Their ages ranged from 20 to 28 years, with a mean of 22.7. None of the participants had prior experience of visiting the environment that was used as a setting for the experiment.

2.2. *Environment*

We set two routes in a residential area in Kyoto City as experimental routes for this study; participants traveled the routes using a smartphone map or a paper map (Figure 1). The experiment was conducted in a within-subject design. Participants traveled one route with a smartphone map (or a paper map) and then retraced it without any assistance; they traveled the other route with a paper map (or a smartphone map) and retraced it without assistance. The routes were comparable in terms of length (950 m and 1,000 m) and structural complexity regarding the number of turns (five and seven, respectively), street width (relatively narrow streets with more than half the segments one way), and scenes along the routes (surrounded by private houses). The area is free of distant views that could be used as navigation clues or global landmarks. Details of the routes used in the experiment may be available at https://www.google.com/maps/d/u/0/edit?mid=1H_EiRYVmxWlDCJ7zNq_AcTaNIqCEn82c&usp=sharing.

2.3. Assessments of psychological attributes

As important correlates of spatial learning and memory (or, more specifically, wayfinding and spatial orientation), participants' psychological attributes of spatial abilities (Hegarty & Waller, 2004), sense of direction (Hegarty et al.,2006), spatial anxiety (He & Hegarty, 2020), experience of tool use (Ishikawa, 2018; Ruginski et al., 2019), and wayfinding strategies (Lawton, 1994) were measured.

2.3.1. Spatial abilities

Participants took the Mental Rotations Test (Ekstrom, French & Harman, 1976) and the Perspective Taking Test (Hegarty & Waller, 2004). Mental rotation assesses the ability to rotate images mentally with 10 items, each of which asks whether eight alternative images are the same as, or different from, a criterion image after rotation. Participants received one point for a correctly identified item and lost one point for a wrongly identified item. They were given three minutes to finish the test.

Perspective taking assesses the ability to imagine how a scene would look like from different viewpoints. Participants were shown an arrangement of seven objects, and asked to imagine standing on one object facing another and point to a third object (12 items in total). Their responses were scored in terms of absolute angular errors in pointing. Participants were given five minutes to finish the test.

2.3.2. Sense of direction

Participants' sense of direction was assessed with the Santa Barbara Sense-of-Direction Scale (Hegarty, Richardson, Montello, Lovelace & Subbiah, 2002). On the scale, participants answer their navigational tendencies and experiences on a Likert-type 7-point scale (e.g., "I am very good at giving directions" or "I very easily get lost in a new city"). A mean of their responses to 15 items are taken, a larger score indicating a better sense of direction.

2.3.3. State and trait anxiety

Participants took the State–Trait Anxiety Inventory (Shimizu & Imae, 1981; Spielberger, Gorsuch & Lushene, 1970), which assesses two types of anxiety, state anxiety and trait anxiety, on a 4-point scale. The level of state anxiety varies temporally depending on the situation (e.g., calm); trait anxiety is more stable and reflects one's personality trait (e.g., enjoyable). Thus, in this study, state anxiety is considered to be a dependent variable in the analysis of self-assessment of navigation performance and measured before a navigation task; while the personality-measure trait anxiety is considered to be an independent variable in the analysis of navigation performance and self-assessment.

Table 1. Length of using pedestrian navigation systems, paper maps, and in-car navigation systems (numbers of participants and percentages).

	Pedestrian navigation system	Paper map	In-car navigation system
I have never used it	2 (10%)	2 (13%)	10 (50%)
Less than 6 months	0	5 (31%)	0
6 months to less than 1 year	2 (10%)	1 (6%)	1 (5%)
1 year to less than 3 years	3 (15%)	0	3 (15%)
3 years to less than 5 years	7 (35%)	0	3 (15%)
5 years to less than 10 years	6 (30%)	3 (19%)	2 (10%)
10 years to less than 15 years	0	0	0
15 years to less than 20 years	0	5 (31%)	1 (5%)
20 years or longer	0	0	0
Total	20	16	20

Data from four participants were missing for the use of paper maps due to experimental failure.

Table 2. Frequency of using pedestrian navigation systems, paper maps, and in-car navigation systems (numbers of participants and percentages).

	Pedestrian navigation system	Paper map	In-car navigation system
2–3 times a month or less	9 (39%)	14 (88%)	19 (90%)
1–2 times a week	8 (44%)	1 (6%)	1 (10%)
3–4 times a week	2 (11%)	0	0
5–6 times a week	1 (6%)	0	0
7 times a week (every day)	0	1 (6%)	0
Total	20	16	20

Data from four participants were missing for the use of paper maps due to experimental failure.

2.3.4. Spatial anxiety

Participants also took the Spatial Anxiety Questionnaire (Lawton, 1994), which assesses the level of anxiety, on a 5-point scale with eight items, that one has in a specific navigation situation (e.g., leaving a store that you have been to for the first time or deciding which way to turn to get to a destination). In this study, spatial anxiety is considered, similarly to trait anxiety above, to be an independent variable in the analysis of navigation performance and self-assessment.

2.3.5. Experience of using navigation tools

Participants answered their experience of using three different kinds of navigation tools in their daily lives: in-car navigation systems, pedestrian navigation systems, and paper maps (Ishikawa, 2018). They indicated the length of time (never, < 6 months, 6 months to 1 year, 1–3 years, 3–5 years, 5–10 years, 10–15 years, 15–20 years, or 20 years or longer), frequency (2–3 times a month, 1–2 times a week, 3–4 times a week, 5–6 times a week, or every day), and purposes (e.g., when traveling in an unfamiliar place, when traveling in a familiar place, or when traveling a short distance for a daily trip) of using these tools (see Tables 1 and 2).

2.3.6. Wayfinding strategies

Participants took the Wayfinding Strategy Scale (Lawton, 1994), which assesses on a 7-point scale the extent to which one relies on orientation strategies and route strategies. Orientation strategies concern the tendency that a person monitors his or her position with respect to environmental reference points (e.g., "I kept track of the direction [north, south, east or west] in which I was going"). Route strategies concern the tendency that a person focuses on sequential, turn-by-turn instructions in navigation (e.g., "Before starting, I asked for directions telling me whether to turn right or left at particular streets or landmarks").

2.4. Navigation tasks and performance

The navigation tasks on an experimental route were conducted in two parts: (a) the first trial of learning and walking a route with the aid of either a smartphone map or a paper map and (b) the second trial of retracing the route without any navigation tools. Participants were not informed beforehand that they would retrace the route in the second trial without a tool.

2.4.1. Navigation tools: smartphone and paper maps

In the first trial of navigation on a route, participants used either a smartphone map or a paper map. The smartphone map (the Google Maps application on Pixel 3 with a 5.5-inch display) showed the user's current position and a route to a destination in a north-up orientation, updated according to their movement in the environment, on a scale of about 1:8.000 (see Figure 1, left). Participants were allowed to zoom in and out on a map on the device screen and rotate the map (or the smartphone) if they wished; they were not allowed to use its automatic navigation functions (e.g., a heads-up display, turn-by-turn instructions, or live views). The paper map, printed on A4-size paper, showed a starting point, a destination, and a route to the destination on a scale of about 1:2,000 (Figure 1, right). Participants were allowed to rotate the map, if they wished.

2.4.2. Navigation accuracy and confidence ratings

The accuracy of performance on navigation was examined in terms of the measure of cosine similarity, which gives the degree of correspondence between the participant's route and a correct route (Ishikawa & Takahashi, 2013).[1] Specifically, it was computed by the length of the correct route directed by a navigation tool, divided by the square route of the product of the lengths of the participant's route and the correct route. Cosine similarity values can

[1]We also recorded time length, but unfortunately found its analysis was not as straightforward as we had expected, particularly because of differences among participants in the time need to wait at traffic lights or for vehicles to pass by, which was not controllable.

range from 0 to 1, a larger value indicting higher accuracy. As mentioned above, in the first trial (the aided condition), participants used a navigation tool (either a smartphone map or a paper map), but in the second trial (the unaided condition), they did not.

Just before starting the second trial (route retracing in the unaided condition), participants were asked about the degree of confidence in retracing the route without a tool, by choosing a number (percentage) from 0 to 100.

2.4.3. Scene recognition and landmark identification

Participants' scene recognition memory was examined after the first (aided) walk of a route. Participants viewed 10 pictures, and judged if they had seen the scene along the route on a 4-point scale (1 = *I definitely did not see it*; 4 = *I definitely saw it*). Five of the ten pictures depicted scenes along the route that they traveled, and the other five were scenes not along the route. Scene recognition performance was scored as the sum of the number of correctly identified scenes with greater confidence (i.e., *I certainly saw [or did not see] it*) multiplied by 2 and the number of correctly identified scenes with less confidence (i.e., *I probably saw [or did not see] it*), divided by the total number of scenes.

Participants were also asked to mention as many landmarks as possible that they had identified and used while navigating along the route (e.g., traffic lights, convenience stores, or the number of blocks before an intersection).

2.5. Procedure

On a separate day before an experimental session of route navigation, participants filled in the questionnaires of sense of direction, trait anxiety, spatial anxiety, experience of using navigation tools, and wayfinding strategies online. On the day of the experimental session, participants first took the tests of spatial abilities (mental rotation and perspective taking) and then, before starting the route navigation, filled in the questionnaire of state anxiety.

In the route navigation, participants first traveled a route with a tool, either a smartphone map or a paper map (the first walk, aided), and conducted scene recognition and landmark identification tasks. Participants were then told that they would travel the route from the goal to the start by themselves without a tool. They filled in the questionnaires of state anxiety and the level of confidence in retracing the route without a tool, and then started to walk the route (the second walk, unaided). During the navigation, the experimenter followed participants without making conversation, to ensure their security. Participants' navigation behaviors were recorded by a wearable camera and a smartphone's screen recorder and GPS tracker.

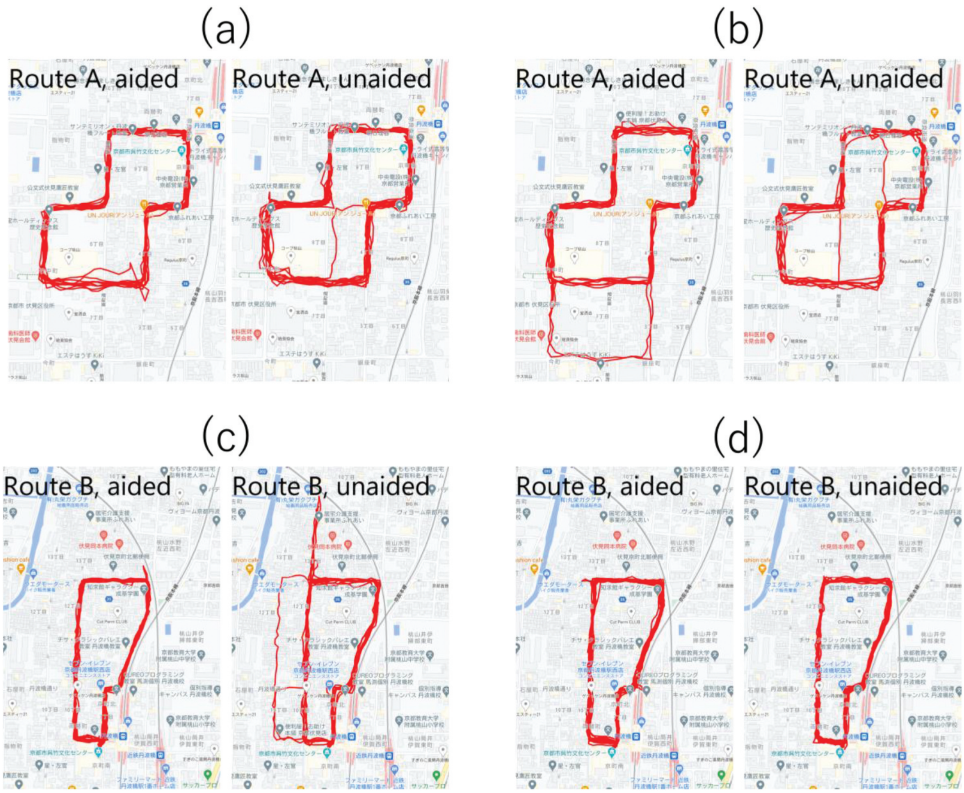

Figure 2. Maps showing the routes that participants took in the navigation tasks. Red lines depict the 20 participants' routes, and thicker lines indicate more participants. Many participants took a correct route as directed by the tools, but some deviations are seen. Note that participants who used a smartphone map (or a paper map) on Route A used a paper map (or a smartphone map) on Route B. Map data © 2021 Google.

After finishing these tasks for the first route, participants next conducted route navigation for the second route in the same procedure as above, this time using a tool different from the one they used for the first route (i.e., half the participants used a smartphone map for the first route and a paper map for the second route; the other half used a paper map for the first route and a smartphone map for the second route). The allocation of the two routes and tools to the aided and unaided conditions were counterbalanced across participants. It took 90 minutes, on average, for participants to complete the experimental session.

The research was approved by the Kwansei Gakuin University Institutional Review Board for Behavioral Research with Human Participants, and informed consent was obtained from the participants.

3. Results

3.1. Descriptive statistics

Descriptive statistics for the measured variables are shown in Tables 1–3. In particular, Tables 1 and 2 show data on our participants' experience of using three kinds of navigation tools, in terms of time length and frequency. The data point to a common use of pedestrian navigation systems (which include smartphone maps) among the participants.

3.2. Participants' routes

The routes that participants took in the aided and unaided navigation, when they used a smartphone map and a paper map, are shown in Figure 2. In the maps, the routes for the 20 participants are superimposed, so thicker lines indicate more participants. Many participants traveled as directed by the smartphone or the paper map, but some deviations from the directed routes are seen, especially in the unaided navigation after the use of a smartphone map (Figure 2a,c, right panels).

For Route A, all participants traveled the directed route correctly with a smartphone map in the aided condition, and one participant deviated from it in the unaided condition (Figure 2a). When using a paper map on Route A, two participants deviated from the directed route in the aided condition, one of whom also deviated in the unaided condition (Figure 2b).

For Route B, all participants traveled the directed route correctly with a smartphone map in the aided condition, and three participants deviated from it in the unaided condition (Figure 2c). With a paper map on Route B, all participants traveled the directed route in the aided and unaided conditions (Figure 2d).

One participant who deviated from the correct route in the aided paper-map condition on Route A (Figure 2b, left) also deviated in the unaided smartphone-map condition on Route B (Figure 2c, right).

3.3. Navigation tools and navigation performance

We first conducted an analysis of variance (ANOVA) to examine the effects of the use of navigation tools (a smartphone map and a paper map) on participants' navigation performances (navigation accuracy, scene recognition, and the number of landmarks identified) and self-assessments of performance (state anxiety and confidence ratings). Among these observed variables, navigation accuracy and state anxiety were measured twice on each route, in the first and second trials; so, we analyzed these variables in a two-way ANOVA, with map type (a smartphone map or a paper map) and navigation condition (aided or unaided) as within-subject variables. On the other hand, scene

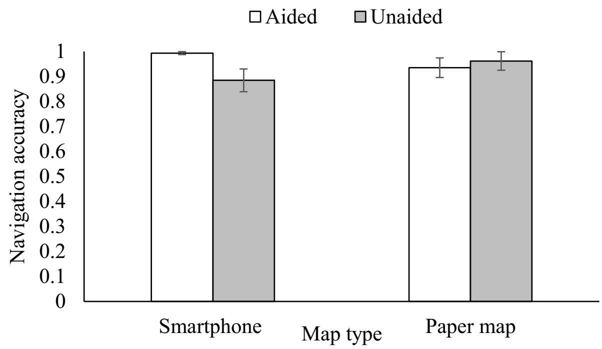

Figure 3. Navigation accuracy broken down by map type and navigation condition. With the smartphone map, navigation accuracy was lower in the unaided condition than in the aided condition.

recognition, the number of landmarks identified, and confidence were measured once on each route (scene recognition and the number of landmarks were performance measures for aided navigation, and confidence was a self-assessment measure for unaided navigation); so, we analyzed these variables in a one-way ANOVA, with map type (a smartphone map or a paper map) as a within-subject variable. An alpha level of .05 was used in all analyses below.

For navigation accuracy, the main effects of map type and navigation condition were nonsignificant, Fs(1, 19) = 0.12 and 3.54, respectively, ps = .728 and .075, η_p^2s = .01 and .16; but the interaction between map type and navigation condition was significant, $F(1, 19) = 4.54$, p= .047, $\eta_p^2 = .19$. An analysis of simple main effects with the modified sequentially rejective multiple-test procedure (Shaffer, 1986) revealed that the simple main effect of navigation condition was significant for the smartphone map (higher accuracy in the aided condition), but not for the paper map, Fs(1, 19) = 5.43 and 0.92, respectively, ps = .031 and .350, η_p^2s = .22 and .05 (Figure 3).That is, when traveling a route with a smartphone map, participants did not learn the route accurately and had difficulty retracing it without a tool.[2]

For the number of landmarks identified, the main effect of map type was significant, $F(1, 18) = 4.50$, p= .048, $\eta_p^2 = .20$. Participants mentioned more landmarks when traveling with a paper map (M = 4.00, SD = 1.63) than with a smartphone map (M = 3.00, SD = 1.76).

[2]To examine a possible difference in retracing performance on the two routes (because participants knew that they would retrace a route without assistance on the second route, but not on the first route), we conducted a paired t test for the navigation accuracy in the unaided condition for the two routes, and found that the difference was nonsignificant, Ms = .93 and 94, respectively, $t(19) = 0.43$, p = .670. Similarly, an unpaired t test for the number of zooming in and out in the aided condition for the two routes observed a nonsignificant difference, Ms = 0.60 and 1.70, respectively, $t(18) = 0.93$, p = .362.

For state anxiety, the main effect of map type was nonsignificant but that of navigation condition was significant, *F*s(1, 14) = 0.37 and 7.95, respectively, *p*s = .553 and .014, η_p^2s = .03 and .36. Participants had a lower degree of state anxiety in the aided condition than in the unaided condition (*M*s = 1.66 and 1.86, respectively, *SD*s = 0.36 and 0.52). The interaction between map type and navigation condition was nonsignificant, $F(1, 14) = 0.05$, $p = .831$, $\eta_p^2 = .00$.

For scene recognition and confidence, no significant effects were observed, *F*s(1, 18) = 1.36 and 0.00, respectively, *p*s = .259 and .979, η_p^2s = .07 and .00.

3.4. Multilevel modeling of navigation performance and self-assessment

Next, we conducted a multiple regression analysis to examine the effects of participants' psychological attributes on each of the navigation-performance and self-assessment measures. Specifically, the measured variables of navigation performance (navigation accuracy, scene recognition, and the number of landmarks identified) and self-assessment (state anxiety and confidence), respectively, were regressed on spatial abilities, sense of direction, anxiety (spatial anxiety and trait anxiety), experience of tool use, and wayfinding strategies. In the regression models, map type (a smartphone map or a paper map) and navigation condition (aided or unaided) were entered as repeated measures (coded as 1 and – 1 for each of them, respectively), and all numerical predictor variables were centered so as to minimize correlations for multiplicative terms.

To avoid the problem of overfitting owing to the treatment of repeated measures as data from independent participants (known as pseudoreplication in ecology and biostatistics; Lazic, 2010), we adopted a multilevel modeling approach. For the models of navigation accuracy and state anxiety, we used a random intercept and slope model, positing different intercepts and slopes of map type and navigation condition for each participant. For the models of scene recognition, the number of landmarks identified, and confidence, random slope models did not converge, and so we adopted a random intercept model. Using these multilevel models, we tested the fixed effects of psychological attributes, map type, and navigation condition. Table 4 shows the coefficients of determination for each model[3] and Table 5 shows the correlations between explanatory variables.

[3]Overall model fit was statistically tested with respect to a marginal *R*-squared value (R^2_m). Interactions of independent variables were considered only for the regression of navigation accuracy on sense of direction (for which the interactions among sense of direction, map type, and navigation condition were of interest to the examination of our second hypothesis). We ensured in each regression analysis that models with and without interactions led to the same conclusion about the significance of independent variables.

3.4.1. Navigation performance

3.4.1.1. Navigation accuracy. The regression model of navigation accuracy on sense of direction, map type, navigation condition, and their interactions showed a significant main effect of sense of direction, β = .37, $t(20.24) = 2.64$, $p = .016$, showing that participants with a better sense of direction retraced the learned route with higher accuracy (Table 6). The interaction of map type and navigation condition was also significant, β = .21, $t(60) = 2.98$, $p = .004$.

Simple slope tests revealed that the effect of map type was nonsignificant in the aided condition, but significant in the unaided condition, βs = .18 and – .24, respectively, *t*s(50.40) = 1.64 and 2.17, *p*s = .107 and .035. Also, while the effect of navigation condition was nonsignificant for the paper map, β = – .09, $t(51.30) = .76$, $p = .452$, it was significant for the smartphone map, β = .34, $t(51.30) = 3.02$, $p = .004$. These results show that when learning a route with a smartphone map, participants retraced the route less accurately in the unaided condition, consistent with the finding in the analysis of variance above. That is, participants did not learn the traveled route accurately when using a smartphone map, and had difficulty retracing the route if the tool was removed (see Figure 3).

3.4.2. Number of landmarks identified

The regression model of the number of landmarks identified on sense of direction showed significant main effect of map type, β = – .29, $t(20.07) = 2.20$, $p = .039$, showing that participants identified more landmarks when they used a paper map, consistent with the finding in the analysis of variance above (Table 7).

3.4.3. Self-assessments

3.4.3.1. State anxiety. The regression model of state anxiety on sense of direction showed a significant main effect of sense of direction, β = – .44, $t(17.88) = 3.55$, $p = .002$, showing that participants with a better sense of direction had a lower degree of state anxiety in navigation.

The regression model of state anxiety on spatial and trait anxiety showed significant main effects of spatial anxiety, β = .53, $t(19.83) = 5.31$, $p = .000$, trait anxiety, β = – .31, $t(21.36) = 3.01$, $p = .007$, and navigation condition, β = – .22, $t(23.02) = 2.88$, $p = .008$. These results show that participants with higher spatial anxiety and lower trait anxiety and in the unaided condition had a higher degree of state anxiety.

The regression models of state anxiety on spatial skills, experience of using navigation tools (both frequency and length), and wayfinding strategies showed a significant main effect of navigation condition, βs = – .22, – .30, –

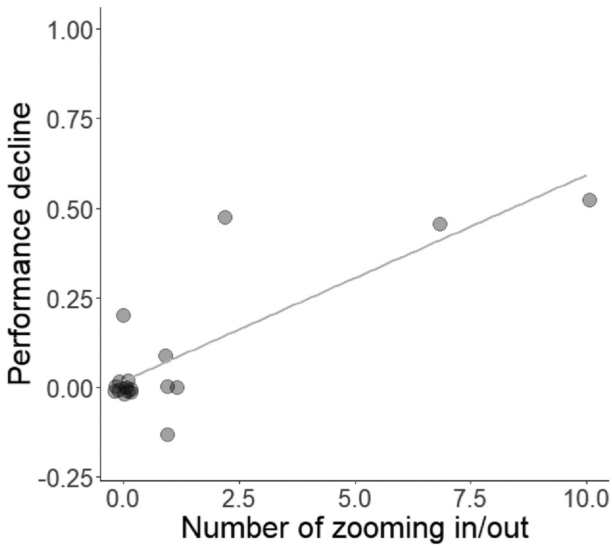

Figure 4. Relationship between the frequency of zooming in and out on a smartphone map and the decrease in navigation performance. In the graph, overlapping data points are moved slightly to increase their visibility and a gray line indicates a fitted regression line. Participants who interacted with the smartphone map more frequently showed a greater decline in navigation accuracy in the unaided condition.

.30, and – .30, respectively, $t(23.06) = 2.87$, $t(20.45) = 3.59$, $t(19.78) = 3.56$, and $t(20.27) = 3.62$, *ps* = .009, .002, .002, and .002, showing that participants in the unaided condition had a higher degree of state anxiety (Table 8).

Table 3. Descriptive statistics for measured variables.

Task	*M*	Min	Max	*SD*	Skewness	Kurtosis
Mental rotation (score of 0–80)	61.3	31	80	15.1	−0.54	−0.47
Perspective taking (absolute error of 0°–90°)	12.8	6.5	28.8	5.7	1.93	3.74
Sense of direction (1 poor; 7 good)	4.3	2.0	6.3	1.0	−0.53	0.11
State anxiety, aided (1 weak; 4 strong)	1.7	1.1	2.4	0.4	0.23	−0.85
State anxiety, unaided	1.9	1.1	3.0	0.5	0.59	−0.37
Trait anxiety (1 weak; 4 strong)	2.2	1.6	3.3	0.4	1.04	2.30
Spatial anxiety (1 low; 5 high)	2.6	2.0	3.6	0.4	0.99	2.08
Survey strategy (1 low; 7 high)	5.1	3.0	6.3	0.9	−0.58	0.57
Route strategy (1 low; 7 high)	4.1	1.0	6.3	1.3	−0.68	1.33
Navigation accuracy, aided	0.96	0.39	1.00	0.13	0.96	16.12
Navigation accuracy, unaided	0.93	0.26	1.00	0.17	0.93	6.96
Confidence (0 weak; 100 strong)	69.1	10.0	100.0	22.4	−0.92	0.83
Scene recognition (0 poor; 2 good)	0.8	0.4	1.6	0.3	0.94	1.36
Number of landmarks identified	3.5	0.0	8.0	1.7	0.25	−0.03

Numbers in parenthesis show a possible score range for each variable.

Table 4. Coefficients of determination for each multilevel model.

Objective variable	Explanatory variable	R^2_m	R^2_c
Navigation accuracy			
	Sense of direction (with interaction)	.25	.59
	Sense of direction	.08	.46
	Anxiety	.11	.45
	Spatial skills	.07	.44
	Navigation tools use frequency	.05	.53
	Navigation tools use length	.03	.52
	Strategy	.02	.51
Scene recognition			
	Sense of direction (with interaction)	.06	.06
	Anxiety	.06	.06
	Spatial skills	.05	.05
	Navigation tools use frequency	.06	.06
	Navigation tools use length	.10	.10
	Strategy	.17	.17
Number of landmarks identified			
	Sense of direction (with interaction)	.13	.33
	Anxiety	.01	.16
	Spatial skills	.04	.16
	Navigation tools use frequency	.02	.16
	Navigation tools use length	.29	.29
	Strategy	.14	.17
State anxiety			
	Sense of direction (with interaction)	.29	.76
	Anxiety	.32	.73
	Spatial skills	.13	.75
	Navigation tools use frequency	.13	.74
	Navigation tools use length	.12	.75
	Strategy	.11	.74
Confidence			
	Sense of direction (with interaction)	.16	.36
	Anxiety	.10	.35
	Spatial skills	.10	.32
	Navigation tools use frequency	.12	.13
	Navigation tools use length	.01	.18
	Strategy	.12	.12

Gray cells indicate significant main effect or interaction of map type or trial number.

3.4.3.2. Confidence. The regression model of confidence on sense of direction showed a significant main effect of sense of direction, $\beta = .40$, $t(20.07) = 2.43$, $p = .025$, showing that participants with a better sense of direction felt more confident in navigation (Table 9).

3.5. Participants' smartphone map use and navigation performance decline

Given the poor performance on route retracing when a route was first learned with a smartphone map (in contrast to a paper map), we examined in detail how participants used the smartphone map. Specifically, we looked at the manner in which participants interacted with the smartphone map in terms of zooming in and out on the map. Participants' behavior of rotating a map on the smartphone screen digitally was also recorded, but only two participants did it, and some participants physically rotated a smartphone itself as they rotated a paper map; so, its analysis was not found to be informative and not pursued further.

Table 5. Correlations between explanatory variables.

	Mental rotation	Perspective taking	Sense of direction	Spatial anxiety	Trait Anxiety	Pedestrian navigation use length	Paper map use length	Pedestrian navigation use frequency	Paper map use frequency	Survey strategy	Route Strategy
Mental rotation	1.00	−.27	.35	−.61**	−.60**	.03	.35	−.22	−.11	−.12	.01
Perspective taking		1.00	−.34	.29	−.06	.10	.00	.01	.00	−.20	.00
Sense of direction			1.00	−.80	−.08	.05	.22	−.14	.04	.38	.34
Spatial anxiety				1.00	.42	.19	−.20	.29	−.07	.02	−.10
Trait Anxiety					1.00	.23	−.20	.12	.07	.57**	.29
Pedestrian navigation use length						1.00	.21	.27	−.52*	.12	.01
Paper map use length							1.00	−.15	.34	.00	.41
Pedestrian navigation use frequency								1.00	−.29	.18	−.32
Paper map use frequency									1.00	.27	.51*
Survey strategy										1.00	.60**
Route Strategy											1.00

Note. $*p < .05$. $**p < .01$.

Table 6. Summary of multiple regression analysis (sense of direction) for navigation accuracy.

Explanatory variable	*β*	*SE*	*df*	*t*	*p*
Main effect					
Sense of direction	.37	.14	20.24	2.64	.016
Map type	−.03	.08	31.72	0.37	.714
Navigation condition	.13	.08	35.35	1.61	.116
Interaction					
Sense of direction × Map type	−.12	.08	31.72	1.45	.158
Sense of direction × Navigation condition	−.15	.08	35.35	1.87	.071
Map type × Navigation condition	.21	.07	60	2.98	.004
Sense of direction × Map type × Navigation condition	−.10	.07	60	1.41	.164

Navigation condition coded as 1 = aided; − 1 = unaided.
Map type coded as 1 = smartphone map; − 1 = paper map.

Table 7. Summary of multiple regression analysis for the number of landmarks identified.

Explanatory variable	*β*	*SE*	*df*	*t*	*p*
Main effect					
Sense of direction	.19	.17	20.81	1.13	.272
Map type	−.29	.13	20.07	2.20	.039
Interaction					
Sense of direction × Map type	.05	.14	20.53	0.37	.713

Map type coded as 1 = smartphone map; − 1 = paper map.

To see how reliance on a smartphone map negatively affects route learning, we correlated the frequency of zooming in and out and the size of decrease in navigation accuracy (Figure 4). The former was measured based on the recordings of participants' screen touch behavior, and the latter was computed by subtracting the navigation accuracy (cosine similarity value) in the unaided condition from that in the aided condition (a larger value indicting a greater decline in accuracy). The two measures were found to be correlated significantly ($r = .81$, $p < .001$, $n = 19$), showing that participants who interacted with the smartphone map more frequently learned the route less accurately (i.e., poorer retracing performance).[4]

4. Discussion

This article examined the effect of the use of a smartphone map, compared with a paper map, on the user's navigation performance and self-assessment of it, and particularly a possible difference between their actual and perceived performances. We looked at participants' navigation and memory performances and their state anxiety and confidence ratings, when they used a smartphone map or a paper map, with their various psychological attribute variables taken into consideration.

[4]Data from one participant were missing due to a malfunction of a recorder. The correlation was still significant with a logarithmic transformation of the frequency, $r = .81$, $p < .001$. The correlation was also significant when the data point for one participant whose performance-decline value was negative was removed (better performance in the unaided condition), $r = .83$, $p < .001$.

Table 8. Summary of multiple regression analysis for state anxiety.

Explanatory variable	*β*	*SE*	*df*	*t*	*p*
Sense of direction					
Main effect					
Sense of direction	−.44	.12	17.88	3.55	.002
Map type	.00	.12	19.49	0.02	.985
Navigation condition	−.23	.07	22.98	3.11	.005
Interaction					
Sense of direction × Map type	−.05	.11	18.08	0.42	.681
Sense of direction × Navigation condition	.04	.07	21.47	0.58	.570
Map type × Navigation condition	.03	.06	38.37	0.45	.655
Sense of direction × Map type × Navigation condition	.11	.06	36.64	2.02	.051
Anxiety					
Spatial anxiety	.53	.10	19.83	5.31	.000
Trait anxiety	−.31	.10	21.36	3.01	.007
Map type	.01	.12	18.82	0.10	.924
Navigation condition	−.22	.08	23.02	2.88	.008
Spatial skills					
Mental rotation	−.26	.14	21.33	1.87	.076
Perspective taking	.04	.14	21.99	0.30	.765
Map type	.01	.12	19.29	0.09	.932
Navigation condition	−.22	.08	23.06	2.87	.009
Navigation tools use frequency					
Pedestrian navigation	.16	.22	17.46	0.72	.482
Paper map	.26	.19	15.87	1.35	.196
Map type	−.05	.13	15.09	0.37	.720
Navigation condition	−.30	.08	20.45	3.59	.002
Navigation tools use length					
Pedestrian navigation	−.21	.16	15.70	1.28	.219
Paper map	.07	.18	16.66	0.40	.697
Map type	−.05	.13	15.30	0.36	.728
Navigation condition	−.30	.08	19.78	3.56	.002
Strategy					
Survey strategy	−.21	.23	19.05	0.92	.369
Route strategy	.07	.23	18.77	0.32	.751
Map type	−.03	.13	15.17	0.25	.810
Navigation condition	−.30	.08	20.27	3.62	.002

Navigation condition coded as 1 = aided; − 1 = unaided.
Map type coded as 1 = smartphone map; − 1 = paper map.

Table 9. Summary of multiple regression analysis for confidence.

Explanatory variable	*β*	*SE*	*df*	*t*	*p*
Sense of direction	.40	.16	20.07	2.43	.025
Map type	−.03	.13	19.34	0.23	.823
Sense of direction × Map type	.05	.13	19.81	0.38	.706

Map type coded as 1 = smartphone map; − 1 = paper map.

Overall, navigation performance correlated with sense of direction. Participants with a better sense of direction retraced the learned route more accuracy, when they used either a smartphone map or a paper map. Also, state anxiety that participants had during navigation was affected by sense of direction and spatial anxiety about navigation. Participants with a better sense of direction and lower spatial anxiety had less state anxiety. The level of state anxiety was lower when participants traveled a route with a tool than when they did without a tool. The level of confidence was also affected by sense of direction, with higher confidence ratings for participants with a better sense of direction.

The results of the ANOVA on navigation accuracy (Figure 3) support our first hypothesis about the degradation of route learning with the use of a smartphone map. Participants learned a traveled route less accurately when they used a smartphone map than when they used a paper map, revealed by a worse route retracing performance. It was also observed that the frequency with which participants zoomed in and out on a smartphone map was related to a decline in retracing performance (Figure 4). Note that such a decrease in performance with a smartphone map was not observed for the scene recognition task. Memory of individual scenes is not necessarily sequenced in the correct order associated with navigational actions, as required in the route retracing task. These results point to the selective impairment of spatial memory by the use of a smartphone map.

The results from the multiple regression analysis on navigation accuracy were not in line with our second hypothesis. Namely, the lack of a statistically significant interaction of sense of direction and map type does not support the hypothesis that the performance on route retracing with a smartphone map would decline to a larger extent for people with a poorer sense of direction. It may be due to a ceiling effect in the route retracing task: In the present experiment, participants showed perfect accuracy in route retracing on 80% of all trials (see the navigation accuracy for the unaided condition in Table 3). This kind of ceiling effect is often observed in navigation tasks with a smartphone map, because of a generally high success rate in reaching goal locations with such assistance (e.g., Ricker, Schuurman & Kessler, 2015). Examination with a more difficult navigation task or other measures such as the number of stops (Ishikawa et al., 2008), think-aloud protocols (Kato & Takeuchi, 2003), and eye-tracking data (Brügger, Richter & Fabrikant, 2019; Brunyé & Taylor, 2009; Piccardi et al., 2016) would be desirable in a future study.

The results from the ANOVA on state anxiety and confidence ratings support our third hypothesis: Nonsignificance of the effect of map type points to the lack of a statistically detectable decrease in the subjective ratings of performance with the use of a smartphone map. Although navigation accuracy deteriorated in the unaided condition when they learned a route with a smartphone map (as shown in Hypothesis 1 above), participants' self-evaluations in terms of state anxiety and confidence did not show a statistically significant difference with or without a tool. This suggests that users of a smartphone map were not aware of the memory impairment caused by its use. We note that this observation is based on null results and, therefore, accumulated evidence from replication studies is needed in future research.

The degraded performance on route learning with a smartphone map observed in this study aligns with the findings reported in past studies of deterioration of spatial orientation and wayfinding after the use of mobile navigation tools. Researches discussed possible reasons for the deterioration, including divided attention, the novelty of navigation tools, the small size of a mobile device, the distraction of attention from the environment, and the lack of decision making (e.g., Bakdash et al., 2008; Gardony et al., 2013; Ishikawa et al., 2008; von Stülpnagel & Steffens, 2013). The smartphone map used in the present experiment was not equipped with navigation functions such as speech, street-view, or vibration guidance, and so it does not require special attention for the user and not particularly different from the paper map. Satellite navigation is popularly used now, more frequently than paper maps (see the data in Tables 1 and 2, and Zenrin, 2018), and hence it does not pose the problem of novelty. On the other hand, navigation information shown on the smartphone map was limited, provided in a piecemeal fashion in association with the user's movement in space. Moreover, the smartphone map showed the user's current position and allowed the user to go to a destination without monitoring their locations and routes actively. So, for the present experiment, the small size of a smartphone device and the lack of decision making on the part of the user can be identified as major reasons for the impaired route learning.

The lack of active route planning and decision making may relate to the smartphone map users' poor self-assessment of performance: They are neither attentive to the task of wayfinding nor sensitive to the deterioration of spatial learning and memory due to smartphone map use. This, in part, contrasts with the relationship of spatial anxiety with navigation performance or strategy use observed in past studies (Kato & Takeuchi, 2003; Lawton & Kallai, 2002). A possible explanation of that is given by the Google effect (Wegner & Ward, 2013) applied in the context of mobile-assisted navigation (which may be called an online mobile map effect). As internet users misinterpret information available online as their own knowledge and overestimate their memory performance, smartphone map users assume that they conduct the wayfinding task and process navigation information by themselves, when, in fact, the information is provided by the smartphone map.

Since this online mobile map effect is unconsciously produced, users may not realize how much they rely on the smartphone. The blurring of the boundary between knowledge in people's minds and information on the internet in perception and memory (Wegner & Ward, 2013) can thus be extended to spatial cognition. Some researchers discussed its negative influence on people's metacognitive control, which is essential for efficient spatial learning (Dai, Thomas & Taylor, 2018). In the long run, such unconscious reliance on mobile navigation would have a long-term negative consequence on the human skill of spatial orientation and sense of place (Ishikawa, 2018;

McKinlay, 2016). More use of a smartphone map leads to greater impairment of spatial memory without being noticed, which, in turn, leads to further reliance on a smartphone map (He & Hegarty, 2020; Ruginski et al., 2019). The distraction of attention by the use of a smartphone map was also evidenced by the fewer landmarks identified by smartphone map users than paper map users.

The finding that participants with lower spatial anxiety and higher trait anxiety, respectively, had a lower degree of state anxiety is noteworthy (see Table 8). Participants with higher trait anxiety may have attended to the spatial learning and navigation tasks more actively to compensate for their higher degrees of anxiety as a personality trait, resulting in lower state anxiety during navigation. On the other hand, trait anxiety was not significantly related with confidence ratings in the multiple regression analysis, and past research reported a positive correlation between trait and state anxiety (Shimizu & Imae, 1981). Furthermore, it may also be possible that people with high trait anxiety avoid cognitively demanding spatial tasks (e.g., Alvarez-Vargas, Abad & Pruden, 2020). This issue needs further investigation.

In summary, when people travel a route using a smartphone map, they retrace the route less accurately without any assistance than when they used a paper map, and they do not notice the impairment of spatial learning and navigation. Despite the decrease in navigation performance, their self-assessment of performance in terms of state anxiety and confidence remains the same with or without the assistance of a smartphone map. Satellite navigation tools are convenient and helpful in navigation, especially for people with visual impairments; therefore, we do not simply argue against the use of those tools. The possibility that smartphone map users unconsciously lose their ability to learn and navigate in the environment, however, needs careful attention. Considering the importance of user personalities and human factors in the design of navigation systems (Brügger et al., 2019; Taylor, Brunyé, & Taylor, 2008), our results offer important implications for the development of geospatial tools that are to both provide convenience and support human cognition.

Acknowledgments

This research was support by funding from the Japan Digital Road Map Association. We thank Hideyuki Maekawa for his help in data collection.

Funding

This work was supported by the Japan Digital Road Map Association [0106].

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