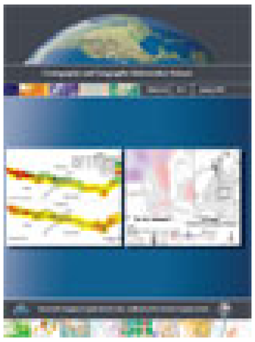

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ARTICLE

The effects of visual realism, spatial abilities, and competition on performance in map-based route learning in men

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ABSTRACT

We report on how visual realism might influence map-based route learning performance in a controlled laboratory experiment with 104 male participants in a competitive context. Using animations of a dot moving through routes of interest, we find that participants recall the routes more accurately with abstract road maps than with more realistic satellite maps. We also find that, irrespective of visual realism, participants with higher spatial abilities (high-spatial participants) are more accurate in memorizing map-based routes than participants with lower spatial abilities (low-spatial participants). On the other hand, added visual realism limits high-spatial participants in their route recall speed, while it seems not to influence the recall speed of low-spatial participants. Competition affects participants' overall confidence positively, but does not affect their route recall performance neither in terms of accuracy nor speed. With this study, we provide further empirical evidence demonstrating that it is important to choose the appropriate map type considering task characteristics and spatial abilities. While satellite maps might be perceived as more fun to use, or visually more attractive than road maps, they also require more cognitive resources for many map-based tasks, which is true even for high-spatial users.

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Visual realism; cartographic abstraction; spatial abilities; route learning; memory; empirical user study

Introduction and related work

Memorizing routes is important to our survival (Farrell et al., 2003; Golledge, Dougherty, & Bell, 1995). In this fundamental task, maps – as external memory and spatial reference devices – have always played a central role (Thrower, 2008). The word "map," however, does not refer to a single representation. For example, online map providers include cartographic maps, information-rich satellite images, terrain models, oblique 3D views, photo-realistic 3D city models, and street-level photography (Çöltekin, Lokka, & Boer, 2015).

Previous studies suggest that map users tend to believe that these visually more realistic maps will support their decision-making. However, abstract maps have been shown to be more, or equally, effective for many map-based tasks (Smallman & St John, 2005a, 2005b; Srinivas & Hirtle, 2010; Wilkening & Fabrikant, 2011a). Aside from the degree of visual realism, how effective participants are with a certain map type might also depend on participants' abilities (e.g. visual and spatial abilities, experience with map use), and the context in which the map is used (e.g. competition, time pressure) (Smallman & St John, 2005a, 2005b; Srinivas & Hirtle, 2010; Wilkening & Fabrikant, 2011a).

Yet, it is still unclear what role precisely visual realism plays in route memorization and recognition tasks associated with map-based route learning, which are very demanding on visuospatial working memory. We contribute toward filling this gap with findings from a controlled lab experiment. Specifically, we measure map-based route learning performance of male participants as well as their confidence in their performance as they memorize a complex route displayed as an animated moving dot on abstract cartographic maps vs. realistic satellite images with a super-imposed road layer. In the following sections, we first summarize previous empirical work that motivated our study, and then present our hypotheses, methods, results, and a discussion of our findings.

Visual realism

Abstraction and realism feature prominently in map making and cartographic research (Çöltekin, Bleisch, Andrienko, & Dykes, 2017). Rapid developments in technology have accelerated the creation and use of increasingly realistic displays, along with the seemingly common belief that more realism is better for geo-spatial tasks. For example, Zanola, Fabrikant, and Çöltekin (2009) showed

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that people trust realistic displays more than their less realistic alternatives. Such beliefs are often explained based on the reasoning that *verisimilitude* (i.e. representing objects as realistically as possible) allows for more intuitive recognition of the represented features (Dykes, Moore, & Fairbairn, 1999; Keuth, 1976; Popper, 1976). However, Smallman and colleagues report a dissociation between map-type preference and map-use performance, especially with respect to the amount of realism shown in a display, which they coin *naïve realism* (Smallman & Cook, 2011; Smallman & St John, 2005a, 2005b). Specifically, Smallman and Cook (2011) compared participants' effectiveness in a forecasting task with two kinds of weather maps, one of which had added realism. Participants preferred the more realistic display, despite their poorer performance with it (Smallman & Cook, 2011). In a similar study, Hegarty, Smallman, Stull, and Canham (2009) demonstrated that, in tasks that involved reading information from weather maps, participants preferred high-dimensional, animated displays, and believed that these displays were better for the given tasks, whereas their actual performance was better with the more abstract, static 2D map displays. The authors call this mismatch *naïve cartography*.

Related subsequent empirical findings examining naïve realism and naïve cartography show mixed results in terms of the seeming contradiction between preference and performance with realism in map displays (Brügger, Fabrikant, & Çöltekin, 2016; Scerbo & Dawson, 2007; Wilkening, 2010; Wilkening & Fabrikant, 2011a). For example, Wilkening (2010) and Wilkening and Fabrikant (2011a) tested road maps and satellite maps for a road selection task, in which map type did not affect decision-making performance; nevertheless, participants preferred the satellite maps and felt more confident with them. In another study by the same authors, participants performed a slope detection task for a helicopter landing scenario and performed better with the more abstract display, suggesting that task-irrelevant information impairs performance (Wilkening & Fabrikant, 2011b). However, the response confidence was consistent with response accuracy in this study, indicating that participants were able to assess their own performance accurately.

Even though previous studies implicitly or explicitly caution against realistic looking, information-rich map displays, this does not mean one should categorically dismiss a given display type because different task types may require different display types (Çöltekin, Lokka, & Zahner, 2016). For example, in a task requiring terrain understanding, participants performed better in two of the three tasks with more realistic looking (3D) displays (St John, Smallman, Bank, & Cowen, 2001). Furthermore, in a study analyzing the effect of 2D versus 3D displays on spatial memory tasks, no significant differences were observed in performance, suggesting that in this case neither did the "more realistic" 3D version impair performance, nor did the more abstract 2D version improve it (Tavanti & Lind, 2001). In such cases, one might then argue for using 2D displays because of their simplicity or for 3D displays because of their attractiveness and potential engagement they offer.

Depending on the task, this argument might be extended for other forms of realistic and abstract displays as well, such as for satellite maps versus road maps. One can posit two opposing statements regarding satellite maps vs. road maps. On the one hand, more realistic satellite maps overall contain more information than abstract cartographic maps, therefore they might lead to more cognitive load in working memory (e.g. Mitchell & Miller, 1983), and thus impair performance. On the other hand, recognizing symbols on abstract cartographic maps requires additional cognitive effort or previous knowledge, as expressed with the term "map literacy" (Shryock, 1939). Furthermore, with more abstract cartographic maps it might be harder for the map reader to identify nameable elements, thus inhibiting the use of verbal memory in addition to visuospatial memory (Vogel, Woodman, & Luck, 2001).

Such mixed evidence and opposing arguments primarily suggest that, along with map design, different task types in map use might be important to consider. Therefore, in the next section, we focus on the map-use task we examine in this paper.

Map-based route learning and working memory capacity

In the context of this paper, we describe our experimental task as *map-based route learning*. Using this label, we distinguish the kind of route learning we examine (i.e. map-based) from real-world navigational route learning. This clarification is necessary because route learning literature most often deals with real-world navigation (e.g. Farrell et al., 2003), whereas we study route learning performance in a lab with a map alone, as it might happen prior to navigation.

This type of map-based route learning can be characterized as a memorization and recognition task (Thorndyke & Hayes-Roth, 1982), and as such, it is important to consider how information encoding and retrieval works in this context. During map-based route learning, Meilinger (2005) found that given the sequential, (quasi) one-dimensional nature of routes, people seem to memorize route information retrieved from a map predominantly as a sequence of verbal instructions to themselves (e.g. "left," "left," "right," "left"). That is, they translate parts of the visual information into verbal information, which would reduce the amount of information that needs to be remembered, but also its modality. This proposition relies on the *dual channel* (the visual and verbal materials are processed under separate systems) and *limited capacity* (each channel is limited in how much information it can process) assumptions (e.g. Mayer & Moreno, 2003). Furthermore, it has been suggested that using two channels helps successful recall through the so-called *active processing assumption*, that is, the cognitive system builds connections between the two channels (e.g. Mayer & Moreno, 2003).

Meilinger (2005) used a static map, while we used moving-dot animations to mark the routes in our study (Figure 1), because one of our goals was specifically to verify the effect of visual realism for tasks that are demanding on working memory (such as memorizing a route based on a moving-dot animation). Previous studies suggest that cognitively it is harder to break down an animated route down into discrete segments, and therefore this might be more demanding on the visuospatial part of working memory than a static route representation (Baddeley, 1986; Höffler & Leutner, 2007; Lee, Klippel, & Tappe, 2003). Höffler and Leutner (2007), based on a meta-analysis of learning from animated and static displays, state that animations provide only transient information, and thus impose additional cognitive load because of the temporal limits of working memory.

In summary, participants' working memory capacity is an important factor in studies such as ours, and it has been previously linked with spatial abilities (Miyake, Friedman, Rettinger, Shah, & Hegarty, 2001), especially with animated stimuli.

Spatial abilities

Individuals differ in their spatial abilities and in their understanding of visuospatial displays (Hegarty & Waller, 2005). Spatial abilities not only play an important role in route learning in the real world (e.g. Montello, Lovelace, Golledge, & Self, 1999), but also with map use (Wilkening & Fabrikant, 2011a). Spatial abilities can be measured with a variety of standardized tests, for example, the Mental Rotation Test (MRT) (Vandenberg & Kuse, 1978), and the scores from such tests often predict performance in understanding visualizations (Keehner, Hegarty, Cohen, Khooshabeh, & Montello, 2008; Velez, Silver, & Tremaine, 2005).

Because spatial abilities and working memory are linked (Miyake et al., 2001), one would expect that if a task is demanding on working memory, people with

Figure 1. An illustration of example trajectories on a road map (left) and on a satellite map (right). The starting positions are marked with a dot, and end positions are marked with an arrow (neither these, nor the dashed lines were visible to the participants during the experiment). Participants watched an animation (twice) where a single red dot moved on one of the trajectories in the route learning phase. After that, they watched another animation where an animated dot followed either of the two trajectories (as illustrated in the figure), and judged whether the trajectory was the same|different from the previously shown (initial) trajectory. Figure reprinted from Thoresen et al. (2016) with permission.

lower spatial abilities ("low-spatial") might struggle with solving spatial tasks more than those with higher spatial abilities ("high-spatial"). For example, Pazzaglia and De Beni (2006) showed that low-spatial map users have more difficulty in integrating spatial structures into their map reading strategies than do high-spatial map users. Similarly, Huk (2006) demonstrated that, when learning visualizations, cognitively demanding interactive 3D models may be more beneficial for high-spatial learners compared to low-spatial learners. In another context, Höffler and Leutner (2011) studied how spatial abilities interacted with learning outcomes when learning from static and dynamic visualizations. In contrast to Pazzaglia and De Beni (2006) and Huk's (2006) findings, they observed that high-spatial participants benefitted more from static visualizations than did low-spatial participants; but when the two groups worked with animations in a multimedia learning context, the learning outcome did not depend on spatial ability.

Such contradicting evidence is an indication that the interaction between spatial abilities and performance with visualizations is a complex one, and that the context of use is important. Framing these opposing findings, two hypotheses have been suggested: Höffler and Leutner's (2011) findings support the *ability as a compensator* hypothesis, that is, low-spatial participants might profit from "visually explicit" material (such as realistic displays, animated instructions), because they would not have to invest the cognitive effort of figuring out the abstract symbols. Pazzaglia and De Beni (2006) and Huk's (2006) findings support the alternative *ability as an enhancer* hypothesis, which suggests that high-spatial participants have more cognitive resources, therefore, they benefit from complex visualizations (i.e. even if the visualization is demanding, some resources are there to spare). Evidence for the *ability as an enhancer* hypothesis was also found in studies related to learning with animations and realistic displays (e.g. Brucker, Scheiter, & Gerjets, 2014; Hegarty & Kriz, 2008).

In addition to performance, an interesting aspect to consider in understanding how spatial abilities interact with the way humans perceive and process visual information is their *preference* regarding visual realism in displays. Smallman and Cook (2011) observed that both high- and low-spatial participants preferred more realistic displays *before* solving an experimental task with realistic displays. However, *after* the experiment, high-spatial participants recalibrated their preference while low-spatial participants did not, suggesting that low-spatial participants were not able to evaluate their own performance accurately (Smallman & Cook, 2011). Confirming this difference, Hegarty et al. (2009) reported that high-spatial participants adjusted their preference from a more realistic 3D display to a more abstract 2D display (with which all participants were more effective), low-spatial participants did not change their preference. In contrast, Wilkening and Fabrikant (2011a, 2011b) demonstrated that participants' preferences and response confidence aligned with their performance. Similarly, Brügger et al. (2016) demonstrated that both low- and high-spatial participants' preferences aligned with their performance when the preference question was asked at the task level. Seemingly, at least in some cases, people are able to assess their own performance accurately, according to the display type they use.

As previous work clearly demonstrates that spatial abilities play an important role in map-based task performance in relation to visual realism, we take spatial abilities into consideration in our work. Next, we turn to the map-use context (in our case, competition), which can also affect performance with map-use tasks.

Competition

Aside from visual realism (a factor relating to map design) and spatial abilities (a factor relating to map users), various other factors might affect performance in map-based route learning, such as the context in which the map is used. In our study, we examined a competitive condition against a control condition. In the competitive condition, participants were told they were competing against each other (and the most successful one would be rewarded), while in the non-competitive condition participants were told nothing.

We chose competition as a map-use context because competition lends itself well to validating whether the hypothesized differences in performance would persist when the context changes in a considerable, yet realistic, manner. Competition is known to induce both positive and negative effects on learning and decision-making performance, as well as influence confidence in decisions (e.g. Bandura & Cervone, 1983; Butt, Weinberg, & Horn, 2003; Cooke, Kavussanu, McIntyre, & Ring, 2011; Kilduff, Elfenbein, & Staw, 2010; Murayama & Elliot, 2012).

In a previous publication, we demonstrated that anxiety induced by competition has a negative influence on map-based route learning (Thoresen et al., 2016). Similarly, Wilkening and Fabrikant (2013) found that time pressure can have negative effects on map-based decision-making. It is also known that a lot of stress can impair memory (Salehi, Cordero, & Sandi, 2010). However, pressure can also have positive effects on performance with a range of tasks. It is well-documented that decision-making performance increases under moderate pressure and decreases when the pressure goes beyond a tipping point, displaying an "inverted U-shaped curve" pattern (Yerkes & Dodson, 1908).

Relevant to our work, Wilkening and Fabrikant (2011a, 2011b) demonstrated that map-based decision-making is influenced similarly (i.e. showing an inverted U-shaped curve pattern) when decision time is limited. Srinivas and Hirtle (2010) also showed that participants in a time-pressure condition with the promise of a reward were faster in a virtual reality wayfinding task than a control group without any time limitations or promise of reward. Seemingly, competition can lead to increased engagement and arousal. Competitive map use is also imaginable in real-world situations, for example, if map users are engaged in playful activities, such as orienteering competitions or geocaching.

In summary, effects of competition on human performance and confidence are well-documented in a variety of contexts. Nevertheless, the role visual realism plays in a map-based route learning task in a competition context is still unclear.

Hypotheses

First of all, we hypothesize that the high density of visual information in satellite maps, as opposed to the more abstract information in cartographically designed road maps, will impair map-based route learning performance, due to the additional processing load in working memory (e.g. Miyake et al., 2001; Smallman & St John, 2005a, 2005b). We also predict that high-spatial participants will perform better in the route learning tasks than low-spatial participants (e.g. Pazzaglia & De Beni, 2006; Wilkening & Fabrikant, 2011a). Furthermore, high-spatial participants will outperform low-spatial participants particularly with the satellite maps because these are more demanding on working memory. We further hypothesize that competition will serve as an incentive to increase effort, and that participants in the competition group will thus have more accurate responses with shorter response times than participants in the control group where there is no competition (e.g. Bandura & Cervone, 1983; Cooke et al., 2011; Kilduff et al., 2010). Finally, we expect that participants in the competition group will be more confident than participants in the control group (Wilkening & Fabrikant, 2011b).

Methods

Using a mixed factorial design, we studied the effects of map type, spatial abilities and competition in a map-based route learning task. Map type was designed as a within-subject variable, while spatial ability and competition were treated as between-subject variables. We measured response accuracy (i.e. effectiveness), response time (i.e. efficiency), and confidence as dependent variables. *Accuracy* in this experiment refers to the ability of the participants to identify whether an animated route was the same as (or different from) the route they had learned in a previously shown animation. *Response time* refers to the measured task completion time, and confidence refers to participants' self-reported confidence in the accuracy of their answers. We measured participants' spatial abilities using a French version of the MRT (Albaret & Aubert, 1996; Vandenberg & Kuse, 1978).

For a parallel study, we additionally measured participants' state and trait anxiety levels, using Spielberger et al.'s (1970) State-Trait Anxiety Inventory (STAI), and obtained saliva samples to monitor participants' cortisol levels throughout the experiment as a measure of competition-induced arousal (which interacts with anxiety levels of participants; reported in Thoresen et al., 2016, and not discussed further in this paper).

Participants

We recruited 120 male students from the Swiss Federal Institute of Technology in Lausanne (EPFL) and University of Lausanne to participate in our study. Due to technical complications, some participants could not complete the experiment and their data were therefore excluded from the analyses. The statistical analyses reported in the results section are thus based on the data obtained from 104 participants (mean age 20.8 years, SD = 2.6).

We recruited only male participants to control for potential confounding variables based on gender differences (Lawton & Kallai, 2002). For example, sex hormones that fluctuate across the menstrual cycle are known to influence visuospatial abilities (e.g. Hausmann, Slabbekoorn, Van Goozen, Cohen-Kettenis, & Güntürkün, 2000). Also, there is evidence that men display overconfidence in their performance in visuospatial tasks, irrespective of their actual performance (Biland & Çöltekin, 2017; Nardi, Newcombe, & Shipley, 2013), and that females tend to exhibit lower confidence than males in pre-competitive conditions (Jones, Swain, & Hardy, 1993).

Participants were grouped according to the competition factor (two levels: competition and control), and spatial ability (two levels: low- and high-spatial) based on their performance in the MRT using a median split (excluding the median). The control group included 54 participants (mean age 21.0 years, *SD* = 2.7) with an average 2.5 years of university education (*SD* = 1.7). The competition group had 50 participants (mean age 20.1 years, *SD* = 2.5) of whom two held a university degree, and 48 had an average of 2.4 years university education (*SD* = 1.9).

Ethical clearance was obtained from the EPFL's Brain Mind Institute Ethics Committee for Human Behavioral Research. All participants were compensated with a monetary gift of CHF 25.–, and one participant in each session (four participants worked on the experimental tasks at the same time in a session) could win an additional sum between CHF 5.– and CHF 30.–. In the competition condition, "winning" meant being the best performer in the group. In the control group, it was based on a raffle. In either group, the winner threw a die. Based on the die roll, additional money was awarded in incremental steps (i.e. CHF 5/10/15/20/25/30 for each of the six possibilities from 1 to 6 on a die).

Materials

All participants worked with 48 displays in total (24 road maps and 24 satellite maps; see Figure 1 for examples). We gathered all visual stimuli using Google Static Maps API (https://developers.google.com/maps/documentation/staticmaps/) and removed all map labels to prevent the explicit use of verbal memory in the recall of the routes. The stimuli were selected from urban areas as to include similar levels of visual complexity. Route density was also kept similar. While some variability in our stimuli was unavoidable, we believe variation in the map content is controlled sufficiently as we average obtained results.

The to-be-memorized routes were represented by a red dot moving over selected trajectories for all 48 stimuli; this procedure was performed using Adobe Flash CS4. We ensured that the selected routes were of identical length, each with identical number of turns (12). Animations were then converted into Windows Media Video (.wmv) format using Adobe After Effect CS6. We used *Qualtrics* (http://qualtrics.com/) to create an online questionnaire to collect demographic information of our participants, and Eprime (www.eprime.com) to conduct the lab experiment. The stimuli were displayed on 17-inch LCD computer screens with identical color depth and resolution (1920 × 1080) in controlled lab conditions.

Figure 1 shows two example routes that participants may see during the study. Note that Figure 1 is for illustration purposes only and is not to scale. In the experiment, all stimuli were shown as 640 × 640 pixels, the size and scale were kept constant, and the route was not marked (but shown using an animated dot). The routes were counterbalanced against an alignment effect (Klippel, Freksa, & Winter, 2006), that is, the routes were varied in their orientation with respect to the map display (some run predominantly from top to bottom, some from right to left, etc.).

Procedure

We invited participants to take part in a two-stage map reading study and informed them that the study involved "map learning and individual differences". Three days before the lab session, participants completed the online questionnaire with demographics questions, the MRT, and the STAI trait subscale (STAI-T). We then conducted the experiment in controlled settings in a lab at the EPFL, each session hosting four participants in parallel. Before the main experiment, we briefed the participants regarding the experiment procedure.

The main experiment was conducted in three blocks, and ahead of each block, we gave them four practice trials to introduce them to the experimental setup and tasks. Each block included 24 randomized animations, where a red dot followed a route on either a road map or a satellite map. We used the breaks between these blocks for collecting saliva samples and administering the state anxiety (STAI-S) questionnaires for the parallel study (Thoresen et al., 2016). Furthermore, in the first break, participants in the competition group were told they were competing against each other and that the winner would get an extra monetary reward.

There was a learning phase at the beginning of each trial in which participants watched a 17-s-long animation twice including either of the two map types in a randomized order. At the end of the animation, the red dot was frozen for 2 s at the spot where the movement trajectory ended. This was followed by the response phase, in which participants watched a second animation which lasted 13 s (again twice) and the red dot remained frozen for 4 s at the spot where the movement trajectory ended. After the second break, to further challenge working memory, we increased the speed by roughly 40% for both the learning animation (from 17 s to 12 s) and the response animation (from 13 s to 8.4 s).

Participants then answered the question "Is this the same route as before?" Half the time it was the same route; and half the time it was not (see red and blue routes in Figure 1 for an example). Participants responded with either "same" or "different", using the keyboard at any time during the response phase, but with a time limit of 4 s after the end of the animation.

At the end of each trial, participants answered the question “How sure are you of your answer?” to indicate their confidence in their responses on a six-point rating scale (going from “not confident at all” to “very confident”).

When the tasks were completed, one participant (the best performer in the competition group and the winner of the raffle in the control group) rolled a die and received the additional reward. At the end of the experiment, we debriefed the participants, thanked and paid them for their efforts.

Results

We analyzed the data using SPSS (IBM SPSS Statistics, version 21), with $\alpha = .05$ as significance threshold for all tests. We report associated p-values and partial η^2 (η_p^2) as an estimation of effect size. Note that the rules of thumb for interpreting η_p^2 are as follows: small effect: .01, medium effect: .06, and large effect: .14 (Ellis, 2010).

Response accuracy was calculated as the rate of correct answers over the total number of trials. If participants did not answer a question, the answer was counted as incorrect. Response time was averaged only for correct responses, while average confidence ratings were calculated across all trials in which participants responded.

The effect of visual realism on response accuracy, response time, and confidence

Our analyses reveal that participants are overall more accurate in recalling the routes, and more confident in their ability to recall the routes, with the road maps than the satellite maps; while response times are very similar across map types (Figure 2).

A repeated-measures analysis of variance (ANOVA) revealed that map type has a significant main effect on response accuracy with a medium effect size [$F(1, 103) = 7.9$, $p = .006$, $\eta_p^2 = .072$; Figure 2(a)] and confidence with a large effect size [$F(1, 103) = 17.6$, $p < .001$, $\eta_p^2 = .146$; Figure 2(c)], but not on response time [$F(1, 103) = 2.8$, $p = .10$, $\eta_p^2 = .026$; Figure 2(b)]. Overall, participants are more accurate in assessing whether the two animations were the same with road maps ($M = 0.71$, $SD = 0.09$) than with satellite maps ($M = 0.67$, $SD = 0.11$). They also show more confidence in their responses with road maps ($M = 4.44$, $SD = 0.78$) compared to satellite maps ($M = 4.32$, $SD = 0.76$), but their response speed is not affected by the different visual realism levels across the tested maps. Next, we assess whether performance is also influenced by the context of use.

The effect of visual realism in a competitive map-use context

Irrespective of the level of realism, participants in the competition condition show overall higher confidence in their performance (Figure 3).

A 2 (competition) × 2 (map type) mixed-design ANOVA revealed that the competition group is more confident in their responses than the control group with a small effect size [$F(1, 102) = 4.9$, $p = .029$, $\eta_p^2 = .046$], even though their response accuracy [$F(1, 102) = 0.23$, $p = .614$, $\eta_p^2 = .002$] and response time $F(1, 102) = 1.96$, $p = .165$, $\eta_p^2 = .019$] do not differ compared to the control group. We also do not see any evidence of an interaction between competition and visual realism for any of the analyzed variables, i.e. accuracy [$F(1, 102) = 0.08$, $p = .774$, $\eta_p^2 = .001$], response time [$F(1, 102) = 0.04$, $p = .838$, $\eta_p^2 < .001$], or confidence [$F(1, 102) = 0.04$, $p = .843$, $\eta_p^2 = .001$]. Next, we turn to individual and group differences, specifically users' spatial ability.

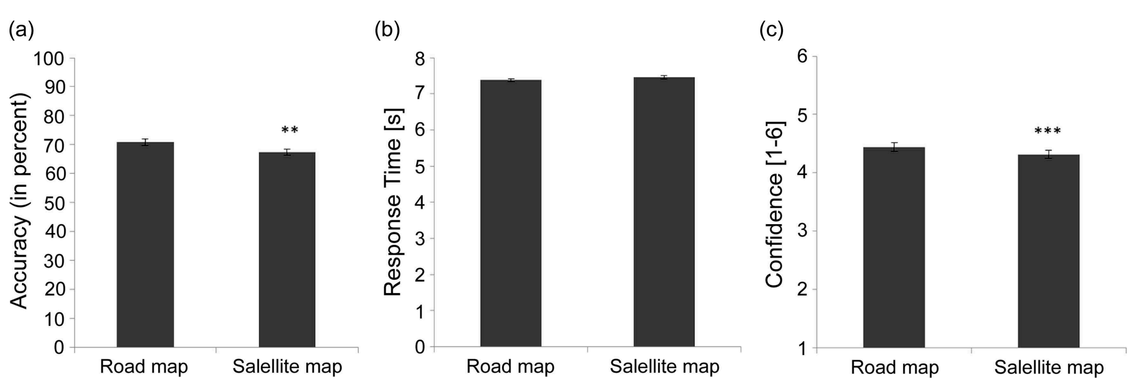

Figure 2. (a) Mean response accuracy with road maps and satellite maps. (b) Mean response time with road maps and satellite maps. (c) Mean confidence ratings with road maps and satellite maps. Error bars: ±SEM. **$p < .01$, ***$p < .001$.

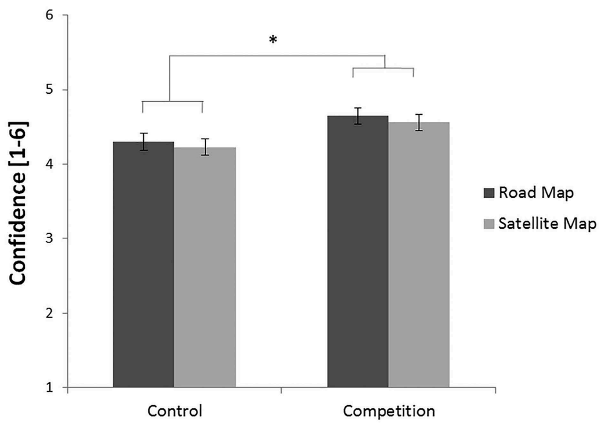

Figure 3. Mean confidence ratings for road maps and satellite maps for the control and competition groups. Error bars: ±SEM. *p < .05.

The effect of spatial ability on response accuracy, response time, and confidence

Figure 4 shows overall accuracy across spatial ability (a); and each group's overall accuracy across levels of realism (b). Overall, high-spatial participants are more accurate in recalling the routes than low-spatial participants (Figure 4(a)), and this pattern remains true when accuracy is compared across realism levels (Figure 4(b)).

A 2 (spatial ability) × 2 (map type) mixed-design ANOVA showed that, overall, high-spatial participants are able to memorize the routes more accurately than are low-spatial participants, with a medium effect size [$F(1, 96) = 8.6$, $p = .004$, $\eta_p^2 = .082$; Figure 4(a)]. However, we observe no interaction between spatial ability and map type for accuracy [$F(1, 96) = 0.14$, $p = .708$, $\eta_p^2 = .001$; Figure 4(b)].

Next, we report on response time analysis across spatial ability. Figure 5(a) shows that response times for the high- and low-spatial groups are similar on average. In Figure 5(b), however, we see that high-spatial participants are faster with the more abstract road maps, while for low-spatial participants, varying visual realism does not affect response time.

A 2 (spatial ability) × 2 (map type) mixed-design ANOVA confirms that, at the aggregate level, spatial ability does not affect response time [$F(1, 96) = 1.9$, $p = .167$, $\eta_p^2 = .020$; Figure 5(a)]. However, a repeated-measures with fixed factor (spatial ability) ANOVA suggests that spatial ability and visual realism interact in terms of response time, with a medium effect size [$F(1, 96) = 7.3$, $p = .008$, $\eta_p^2 = .071$; Figure 5(b)]. A pairwise comparison using a Bonferroni adjustment shows that high-spatial participants answered significantly faster with road maps than with satellite maps, with a medium effect size ($p = .003$, $\eta_p^2 = .094$), while low-spatial participants' response times were not affected by realism ($p = .715$, $\eta_p^2 = .002$).

Figure 6 illustrates that high-spatial participants are overall more confident in their responses than low-spatial participants (Figure 6(a)), and this is true for both map types (Figure 6(b)).

A 2 (spatial ability) × 2 (map type) mixed-design ANOVA confirms that the confidence difference between high- and low-spatial participants is statistically significant, with a medium effect [$F(1, 96) = 6.7$, $p = .011$, $\eta_p^2 = .065$; Figure 6(a)].We observe no interaction between spatial ability and map type in terms of confidence [$F(1, 96)<0.001$, $p = .945$, $\eta_p^2 < .001$; Figure 6(b)].

The combined effects of visual realism and spatial ability in a competitive map-use context

A 2 (competition) × 2 (spatial ability) × 2 (realism level) mixed-design ANOVA revealed that there are no significant interactions between the three analyzed

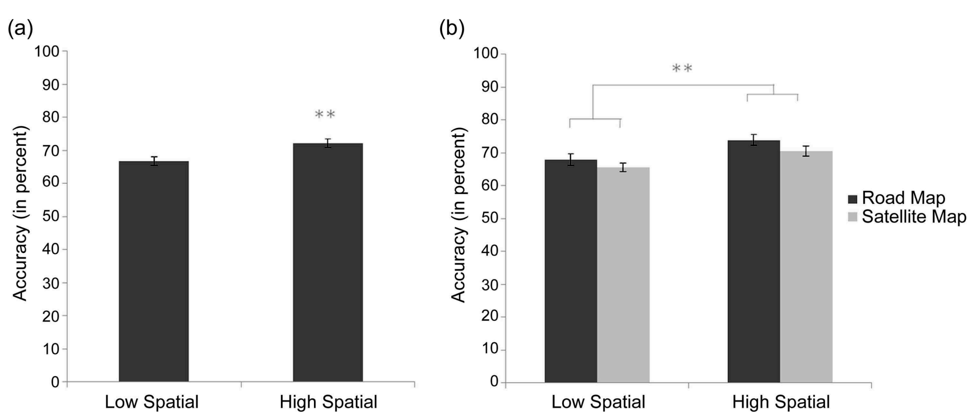

Figure 4. (a) Mean accuracy of low- and high-spatial participants. (b) Mean accuracy with road maps and satellite maps, grouped by spatial ability. Error bars: ±SEM. **p < .01.

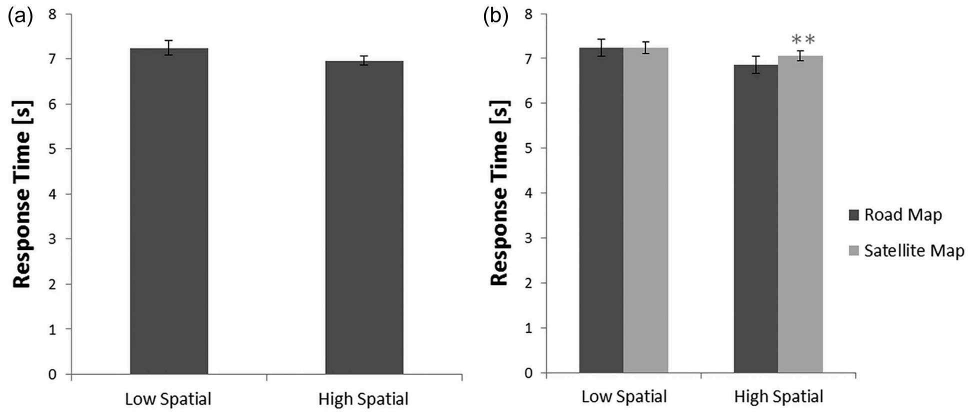

Figure 5. (a) Overall response time of low- and high-spatial participants. (b) Average response times for each map type for the two groups. Error bars: ±SEM. $^{**}p < .01$.

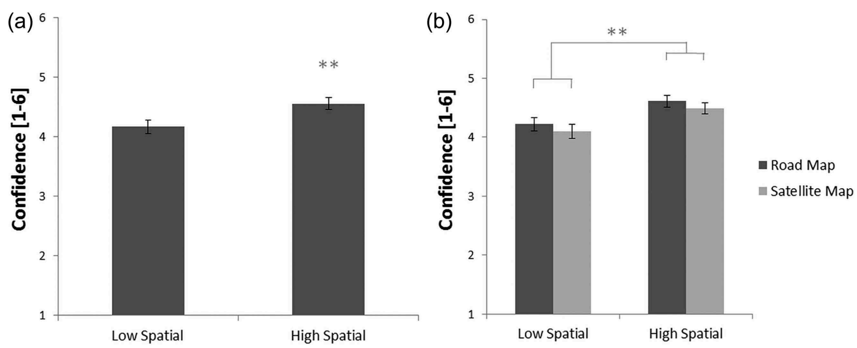

Figure 6. (a) Mean confidence ratings of low- and high-spatial participants. (b) Mean confidence ratings with road maps and satellite images, grouped by spatial ability. Error bars: ±SEM. $^{**}p < .05$.

factors combined for accuracy [$F(1, 94) = 1.9$, $p = .169$, $\eta_p^2 = .020$], nor between spatial ability and competition [$F(1, 94) = 0.93$, $p = .338$, $\eta_p^2 = .010$]. Similarly, response time analyses do not yield any interactions between the three factors [$F(1, 94) = 1.15$, $p = .286$, $\eta_p^2 = .012$], nor between competition and spatial ability [$F(1, 94) = 0.46$, $p = .501$, $\eta_p^2 = .005$].

Summary of results

Overall, participants perform the route learning tasks more accurately and feel more confident with the abstract road maps compared to the realistic satellite maps, while their overall response times do not differ across maps with different amounts of visual realism. As hypothesized, spatial ability is an important moderating factor on recall accuracy and confidence, i.e. high-spatial participants perform more accurately and feel more confident than do low-spatial participants, irrespective of the level of visual realism. Visual realism and spatial abilities interact, however. High-spatial participants are faster with road maps than with satellite maps, while response times do not differ across visual realism levels for low-spatial participants. As expected, competition leads to an overall increase in response confidence, although it does not have any effect on performance, and does not interact with spatial abilities.

Discussion

We empirically investigated whether different levels of visual realism affect map-based route learning of participants with varying spatial abilities in a competitive map-use context against a baseline condition (no competition). Below, we discuss the implications of the key findings.

Participants are more effective with road maps than with satellite maps in map-based route learning

Extending previous research (Smallman and St John, 2005a, 2005b; Hegarty et al., 2009; Wilkening & Fabrikant, 2011a) on to a new task that is specifically challenging on working memory, we empirically demonstrate that participants perform better with abstract road maps compared to visually dense, realistic satellite maps. As hypothesized, our participants are overall more effective with road maps than with satellite maps in the route memorization tasks we tested.

Wilkening (2010) and Wilkening and Fabrikant's (2011a, 2011b, 2013) work demonstrated that map-use performance depends not only on map design characteristics, but more often than not on the map-use task (as well as the map-use context, and user background and training). For example, Wilkening (2010) demonstrated that participants were more accurate in selecting the shortest route with a satellite map, while they were more accurate selecting the fastest route with a road map. Such studies suggest that task difficulty might require additional cognitive resources that might compete with added perceptual demands by a visually dense display (Wilkening & Fabrikant, 2013). In our study, participants were no longer able to access the animations after having watched them. They needed to remember what they had previously seen and compare the new animation to what they remembered. Because of this, it is possible that the additional (perceptually salient, but task irrelevant) information in the satellite maps might have added to the already high cognitive load, and thus reduced participants' overall accuracy in memorizing and comparing routes.

Besides the task difficulty, time limit might be important to consider. Participants were not at liberty to study the route for as long as they might have wished. If a participant took more than the four allotted seconds to respond, we denoted this trial as incorrect. It is possible that more realism would not have negatively affected accuracy if longer decision time had been available (Hegarty et al., 2009). Also, the trials did not allow participants to repeat the animations as many times as they might have liked. As the animations disappeared after the given time limit, it is not clear whether granting participants more time for their answer would have changed results significantly, without also making the animations available for further inspection. Wilkening (2010) found that changes in decision time on a (static) route selection task comparing road maps with satellite maps did not significantly influence decision makers' accuracy. One might argue that if a display requires more time for the same amount of accuracy, then, comparatively speaking, it is inefficient (Wilkening & Fabrikant, 2011a+b).

High-spatial participants benefit more from road maps than the low-spatial participants

Consistent with our predictions, and corroborating previous studies (e.g. Pazzaglia & De Beni, 2006; Wilkening & Fabrikant, 2011b), high-spatial participants were overall more accurate than low-spatial participants in recalling the routes, irrespective of the level of visual realism in the map stimuli (Figure 4(a,b)). This finding supports the *ability as an enhancer* hypothesis, similar to, for example, studies by Brucker et al. (2014) and Hegarty & Kriz (2008). With this finding, our experiment offers another critical piece of evidence suggesting that task characteristics and user background are important factors to consider in studies related to map use (and not only map design).

On the other hand, we see that high-spatial participants responded faster with the road maps than with the satellite maps, while low-spatial participants were not affected by the level of realism in terms of response time (Figure 5(b)). Note that we conducted this analysis only with correct responses, thus, the differences in recall speed in each group indicate an *added* improvement in the performance of high-spatial participants. Therefore, we see that design (visual realism negatively, or abstraction positively) especially affects the performance of our high-spatial participants (Figure 5(b)).

One can frame this finding as either "satellite maps impair efficiency for high-spatial participants" or as "abstract maps help them." Because satellite maps show the task-irrelevant details with similar levels of visual saliency as the task-relevant details, high-spatial participants might be distracted by these irrelevant details. Such distraction, in turn, might increase their cognitive load and impair their efficiency. Fabrikant, Hespanha, and Hegarty (2010), and Hegarty, Canham, and Fabrikant (2010) found similar results in thematic map-use studies involving weather maps. According to Hegarty (2004), well-designed maps can serve as *cognitive prosthetics* by removing task-irrelevant details. In our experiment, road maps might have acted as cognitive prosthetics for the high-spatial participants, sparing them from distractors, thus improving their efficiency. We believe that both arguments (that the satellite maps impair the efficiency and the road maps help) contribute to explaining why the high-spatial participants do better with road maps both in terms of accuracy and response time.

Low-spatial participants use similar amounts of time with both maps (Figure 5(b)), but "achieve more" with road maps than with satellite maps within this time frame (Figure 4(b)). This finding suggests that low-spatial participants too were distracted by the task-irrelevant details shown in satellite maps to some degree. Therefore, this observation also overall supports the idea that abstract maps serve as "cognitive prosthetics" against too much information (which impairs the working memory) (Hegarty, 2004).

On the other hand, the fact that we observe no response time differences between satellite and road maps within the low-spatial participants implies that they did not benefit from the "prosthetic" *as much as* the high-spatial participants did. This might be linked to a limitation in their *base capacity* (also proposed by Hegarty, 2004) to process visual information. Even if they solved the tasks accurately, the tasks were comparatively harder for low-spatial participants than for high-spatial participants. This may have challenged their base capacity to process visual information, thereby reducing the benefits offered by the prosthetic. This may be analogous to, say, differences in fitness levels of people in two groups (e.g. highly fit vs. less fit). For example, in a bike ride exercise, a lighter bike might help both the highly fit and less fit people to complete the ride. But the fitter group would also do it in a shorter time, simply because they are fitter.

Another consideration on the effects of spatial ability worth contemplating is the tool we used to measure the spatial abilities, that is, the standardized MRT. Spatial visualization ability is an important factor in solving the MRT accurately, and this is possibly why we see an effect of spatial ability in our experimental conditions. However, the MRT can also be solved using nonspatial strategies (e.g. verbal, analytical). Therefore, there is the possibility that the high-spatial participants in our experiment use a combination of spatial and non-spatial strategies. If they did, our findings might imply that this strategy was useful in memorizing (or encoding) the routes, and in recognizing them during the same/different task we presented in the response phase in our experiment. However, our data does not allow for assessing this possibility further.

Competition affects participants' confidence in their performance

We observed that competition does influence response confidence, but, contrary to our hypotheses, does not improve participants' performance in our study. These findings are in contrast with previous research suggesting improved task performance in competition (e.g. Bandura & Cervone, 1983; Cooke et al., 2011).

There might be various reasons for this, including, for example, context (most of the previous studies were not about map use) or task difficulty. In a difficult task, such as ours, an already heightened cognitive load might limit possible performance improvements (i.e. the task is simply too hard no matter how hard one tries). Supporting this argument, Srinivas and Hirtle (2010) have shown that performance could be improved under similar experiment conditions to ours, but only when the task was not too hard. On the other hand, overall accuracy observed in our study appears reasonably high for a cognitively demanding task. Thus, this explanation of cognitive load limiting performance improvements might not completely tell the story. A consideration for a future study might be to add continued feedback on performance during the test phase as this might increase participants' sense of competition, as information on self-performance is linked to an increase in effort (Stanne, Johnson, & Johnson, 1999).

Competition did increase confidence in our route learning study, generally supporting results of previous studies conducted in other domains (e.g. Bandura & Cervone, 1983; Butt et al., 2003; Parfitt & Pates, 1999). Increased confidence in the competitive group might be explained by the possibility that the participants simply were more focused when they competed and have mistaken this "focused attention" with better performance. Follow-up studies to further explore potential effects of other relevant factors (e.g. of display design, task difficulty, decision time limits, or continuous feedback on how well participants are doing) are necessary to better understand the interactions between user engagement and motivation in connection to competition on map-based route learning tasks.

Limitations

To properly interpret our findings, some limitations may be important to consider. First, we did not collect data on the expertise of the participants, which could be a factor influencing performance. However, we believe this is likely not an issue because sampling was random and the sample was relatively large ($N = 104$).

Second, it is important to note that the participants were all men, which, one might argue, may limit the generalizability of the findings. The same kind of critical reflection is necessary regarding whether our findings will transfer to maps of different scale or size to the ones used in the experiment. It is also important to note that even though we called the task "map-based route learning," what we truly measure is a subprocess essential in route learning (namely encoding, followed by recall/recognition of a route). This may not cover "route learning" in the most commonly understood sense of the term, that is, actually learning how to move from some origin to a destination. Nonetheless, we believe findings in this study provide relevant contributions to our understanding of cognitive processes involved in map-based route learning.

Conclusions and implications for further research

We report on a map-based route learning experiment where we aimed to assess the potential effects of a display's visual realism in a competitive map-use scenario. We discovered that our participants memorize animated routes more effectively using more abstract road maps compared to more realistic satellite maps. Irrespective of visual realism, participants with better spatial skills are more effective in their map-based route learning than participants with lower spatial skills. Finally, added visual realism slowed down high-spatial participants in correctly recalling the shown routes, but it did not have an effect on low-spatial participants' response times.

Future studies should be further expanded to mixed-gender populations, different age groups, and participants with varying educational backgrounds to confirm the findings for a more general audience. However, our findings provide critical empirical evidence that factors relating to map design – in this case the amount of visual realism – are important to consider *also* in memory-demanding tasks such as map-based route learning. Visually salient but task-irrelevant information in displays (here: satellite maps) might impose increased cognitive load, thus impairing effective memorization of routes. This is particularly relevant for high-spatial participants as high-spatial participants needed more time to process the information-rich satellite maps than the abstract road maps. However, a base capacity of spatial ability seems to be necessary to take full advantage of effective map design. For low-spatial participants, abstract maps did not facilitate the cognitively demanding route memorization task in terms of response time.

In a digital age of map personalization, we need to consider the pertinent question whether map designs should indeed be better matched to individual differences of the users. For example, in another paper, we demonstrated that map readers' anxiety levels and their spatial abilities interact when learning routes; that is, low-spatial *and* high-anxious participants' route memorization performance was worse than those with lower spatial abilities but low-anxiety levels (Thoresen et al., 2016). This again suggests that the relationships of map design, user characteristics, and task contexts are complex, and require further empirical studies. It is important to be aware of the individual differences in contexts that go beyond personalizing maps, for example, in educational contexts and in public participation projects where such individual differences would clearly exist and may significantly influence outcomes.

In the cartographic community, map-use context has only recently received the empirical attention it deserves, perhaps accelerated due to increased in situ, mobile map use. Our unique results in a competitive map-use context, namely that competition had an effect on participants' confidence, even if it did not result in better recall performance in any of the tested conditions, point to a potentially very interesting psychological effect, and leads to novel research questions. Why do participants feel more confident (irrespective of their spatial abilities) even though they are not performing better? This question and similar questions would be an interesting direction for future research.

Our findings further highlight the importance of using suitable displays that are fit for the task at hand and for the target audience. Cartographers and other visualization experts could benefit from studies such as ours to develop criteria for creating and recommending displays that are appropriate for the map-use context and a user's abilities. We also caution map users to be aware of the implications that map designs and map types might have on them and the task they wish to accomplish. Ideally, these displays should facilitate the understanding and learning of the spatial information they reflect, and be effective for a large and varied audience. Most importantly, awareness of the advantages or disadvantages of different map types should be increased amongst map users for them to make better decisions when choosing between the broad variety of currently available map displays.

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