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THE EFFECT OF GENDER AND SPATIAL ABILITIES ON MAP USE PREFERENCES AND PERFORMANCE IN ROAD SELECTION TASKS

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ABSTRACT

In this study, we investigate the effect of individual and group differences on the efficiency and effectiveness of map-based decision making under varying map use contexts. Specifically, we examine potential interrelationships between spatial ability (individual difference) and gender (group difference) for a map-based road selection task under varying time pressure scenarios. We first report on the results of an experiment involving human map display and map interaction tool preferences, based on people's background differences. This is followed by results from a second experiment where we assessed participants' response accuracy and confidence for the same map use context and tasks. We indeed find significant relationships between user background, map type, and inference making tasks. We also replicate the known phenomenon of male over-confidence in spatial decision-making, specifically for a road selection task under severe time pressure. Our results also demonstrate that commonly used classification and aggregation methods to study participant backgrounds can influence the outcomes of empirical map use studies and their respective interpretations.

INTRODUCTION

Previous empirical research in cartography has looked at how the design of maps might influence human spatio-temporal inference and decision making (Fabrikant and Goldsberry 2005, Rosenholtz et al. 2005, Reichenbacher and Swienty 2007). However, only few researchers in cartography and geovisualization have studied how individual spatial abilities or differences in background and training in groups of people might affect the effectiveness and efficiency of how people make spatio-temporal decisions with map displays (Lloyd and Bunch 2005, Lloyd and Bunch 2008, Cohen and Hegarty 2007). In fact, relatively little is known about the potential interaction effects of individual differences in spatial ability, gender, age, etc., with other commonly known map use factors, such as the map purpose and usage context, or the spatio-temporal inference task type.

In this paper, we first report on an empirical study on how individual differences in spatial abilities might influence map use preferences for a classic road selection task (task type) under varying time pressure scenarios (map use context). We studied which map display types (e.g., satellite images or road maps) and which map interaction tools (e.g., zooming, panning, tilting, and rotating) people might prefer for this context. In a follow up experiment, we systematically assessed people's map use performance, again on a road selection task, similar to the first experiment. We evaluated participants' response accuracy and confidence in their decisions for three time pressure scenarios. In both experiments, we were specifically interested in exploring whether and how people's mental rotation abilities (individual difference factor) and gender (group difference factor) might affect map type preferences and participants' performance under varying time pressure conditions. The potential interaction between all controlled factors is also considered.

RELATED WORK

The study of individual and group differences, also coined differential psychology, dates back to Charles Darwin in the 19th century. It is based on the assumption that each person is in certain respects either "like all other people" (i.e., the entire population), "like some other people" (i.e., member of a group of similar people), or "like no other person" (i.e., a unique individual) (Kluckhohn and Murray 1953). Studies of individual differences (i.e., uniqueness) distinguish humans by parameters that can be measured on individuals, such as IQ scores, language ability, or spatial ability. Studies of group differences on the other hand, emphasize the aspect of difference across homogeneous groups of (similar) individuals (i.e., age groups, gender, or expertise).

Gender differences in cognitive abilities have been studied by psychologists in various fields, ranging from epidemiology to the assessment of linguistic skills. For example, Weiss et al. (2003) have empirically confirmed the longstanding assumptions that males have advantages in visuo-spatial abilities and map reading, while females have advantages in verbal tasks. Previous empirical studies do not show conclusive differences in performance between males and females in GIS- and map-related tasks (Albert and Golledge 1999). However, in a memory-location task, Lloyd and Bunch found female accuracy advantages and slower reaction times for males (Lloyd and Bunch 2005). Various studies about the self-assessment of spatial intelligence (Furnham 2001, Furnham, Fong and Martin 1999) have demonstrated that males tend to overestimate their spatial abilities related to map-reading tasks, while females often underestimate them. This phenomenon has also been found for visual categorization with aerial photographs (Lloyd, Hodgson et al. 2002).

Several researchers have shown that the ability to mentally rotate an object is an ability for which gender differences are largest (Linn and Petersen 1985, Voyer and Saunders 2004). In these studies, where males outperform females, typically the Vandenberg Mental Rotation Test (MRT) (Vandenberg and Kuse 1978) has been employed to assess individuals' performance. The MRT is also one of the most commonly used measures for quantifying humans' spatial visualization ability (Hegarty 2010). A variety of arguments exist for explaining this male advantage, such as environmental and socio-cultural differences, traditional gender roles (e.g., spatial tasks are perceived as being masculine in western cultures), biological factors which emphasize differences in brain activity, but also spurious experiment-related variables, such as test time limits, task difficulty, or previous experience (see Parsons et al. (2004) for an extensive discussion). For instance, Prinzel and Freeman (1995) have uncovered that gender differences in spatial abilities increased with increasing task difficulty.

As there seems to be a relationship between gender and mental rotation abilities, one might also expect potential interactions of these two factors when assessing the effectiveness and efficiency of map-based decision making. One might expect that male visuo-spatial preferences and performance would be more similar to the preferences and performance of so-called "high-spatial" people (i.e., those participants who would typically score high on an MRT).

Two competing hypotheses relating to mental rotation abilities seem relevant for our study. Firstly, one might argue that because high-spatial participants are easily able to rotate objects such as maps in their heads, they would less be inclined to do it physically. This could also mean that high-spatial people would rotate a paper map less frequently during navigation in the real world, and thus might also not need to use a map rotation tool in a digital and interactive map use setting. In contrast, we could hypothesize that people with good internal visuo-spatial abilities are more likely to rotate complex external visualizations, especially those in 3D, as they are more likely to assess the benefit of rotation for complex visuo-spatial tasks, compared to low-spatial participants. In fact, Cohen and Hegarty (2007) have shown that subjects with good internal visualization abilities are more (and not less) likely to rotate 3D visualizations. This could mean that spatial abilities are indeed a necessary prerequisite for using an external visualization effectively and efficiently (Keehner et al. 2008).

EXPERIMENT I

In our first experiment, we assessed map display and interactivity tool usage preferences with a road selection task under two time pressure scenarios. In the time pressure condition ("TP" in the following) participants were told at the outset to rescue a severely injured friend as quickly as possible. In the no-time pressure condition ("NTP" in the following), subjects were told that they were planning an excursion without any time constraints.

Participants. Seventy participants (forty male and thirty female) were recruited from cartography and geography classes at the University of Zurich, and the Swiss Federal Institute of Technology (ETH) Zurich. In terms of participants' background, seventy-nine percent stated to have had one year or more training in cartography, and eighty-nine percent in GIS, respectively. Seventy-nine percent specified to use maps at least occasionally in their leisure time.

Materials. We tested six different map types and four interactivity tools that seemed suitable for road selection tasks: a terrain map with hill shading (Map A), a topographic map including contour lines (Map B), two types of road maps (Maps C & E), and two satellite images, one oblique (Map D) and one in orthographic perspective (Map F). The map stimuli shown in Figure 1 below had a size of 145 x 189 pixels, so that they could be displayed next to one another in a web browser on a 17-inch color display, without the need for scrolling. The tested map interaction tools included the standard tools that can typically be found in interactive maps: tilting, zooming, rotating and panning. The main portion of the experiment followed a within-subjects design, thus as all participants were exposed to all conditions.

Figure 1: *Test map stimuli*

Procedure: The experiments took place in a lab equipped with standard personal computers connected to the Internet. First, participants performed a paper-and-pencil version of the Vandenberg's Mental Rotation Test, which took about 15 minutes. The digital portion of the experiment was carried out with a standard web browser displayed in full-screen mode on a 17-inch color display set to 1280x768 pixel screen resolution. After completing the MRT, participants were asked to complete a background questionnaire. Next, participants were introduced to the two time pressure scenarios described earlier. The order of the two scenarios was systematically rotated, so that one half of the participants began with the emergency response task and the other half with the excursion planning task. For each of the scenarios, subjects were asked to rate the six map types and the four interactivity tools according to task suitability on a rating scale from "1 – the map/tool is not suitable" to "5– the map/tool is very suitable". Participant responses were collected digitally. We recorded and analyzed participants' preference ratings for map and tool type which will be discussed in the next section.

INDIVIDUAL DIFFERENCE EVALUATION

On average, participants scored 20.81 points (SD = 8.518) out of 40 possible points. The median score was 20.00 points. The male (N=40) average score was 23.35 (SD=8.20), while females (N=30) scored 17.43 (SD=7.84) points on average. The boxplot in Figure 2 shows the response distribution by gender in graphic form. An independent samples t-test confirms that MRT scores grouped by gender are indeed significantly different ($p<0.01$). In other words, our participants represent the expected gender differences in mental rotation abilities, as mentioned earlier.

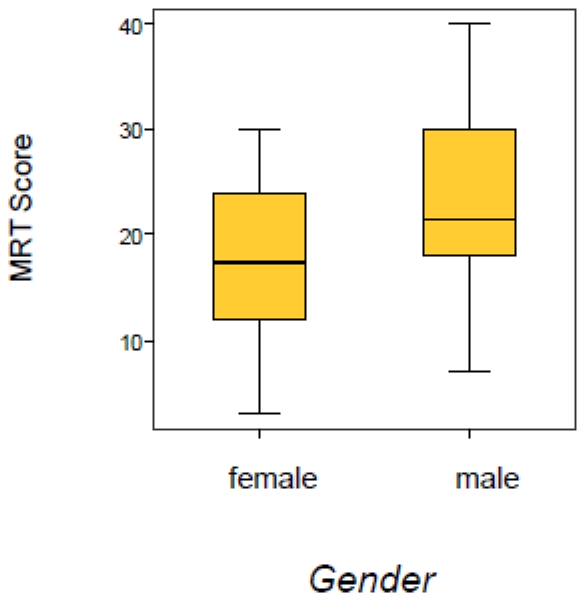

Figure 2: *Boxplot of the MRT distribution by gender*

Next, we were interested in exploring how mental rotation scores might influence participants' preferences for map display types and map interaction tools. For this purpose, we first assigned test participants to two groups by a median split on the MRT score, as has been done in similar studies that did not include map stimuli (Downing, Moore and Brown 2005). Thirty-three participants thus were assigned to the “low-spatial” group and thirty-seven to the “high-spatial” group, respectively.

RESULTS

Mental rotation abilities did not significantly influence participants’ map type preferences when using the median split. However, some effects of mental rotation abilities on interactivity tool preferences were evident: On average, except for the tilting tool, the high-spatial group showed a higher preference for three out of four interaction tools (i.e., zooming, rotating and panning) compared to the low-spatial group, regardless of the time pressure context (see Figure 3). As discussed earlier, one key research question is to shed light on the contradicting hypotheses whether people with higher mental rotation abilities show a lower or a higher preference to rotate a map.

The map rotation tool was preferred more by the high spatial group than the low-spatial group for both TP and NTP scenarios. The mean preference ratings under time pressure are 2.81 (SD=1.60) for high-spatial participants and 2.21 (SD=1.01) for low-spatial participants. Without time pressure, the average preference ratings are 2.76 for the high spatial (SD=1.42) group and 2.33 (SD=1.24) for the low-spatial group. While the differences show the expected tendencies, they are, however, not statistically significant.

Mental rotation abilities seem indeed to significantly affect the preferences for two other interaction tools: Participants with high spatial abilities have a significantly higher preference for panning (M=4.70, SD=0.52) under time pressure, compared to the low-spatial group (M=4.15, SD=1.12). Similarly, the high-spatial group has a significantly higher preference for zooming (M=4.97, SD=0.16) under time pressure than the low-spatial participants (M=4.76, SD=0.61).

Similarly to what Cohen and Hegarty (2007) have found in a 3D rotation and perspective taking task, our high-spatial participants not only seem to have an overall higher preference for using interactivity tools, but also specifically prefer being able to rotate a map for solving a road selection task, irrespective of the time pressure context.

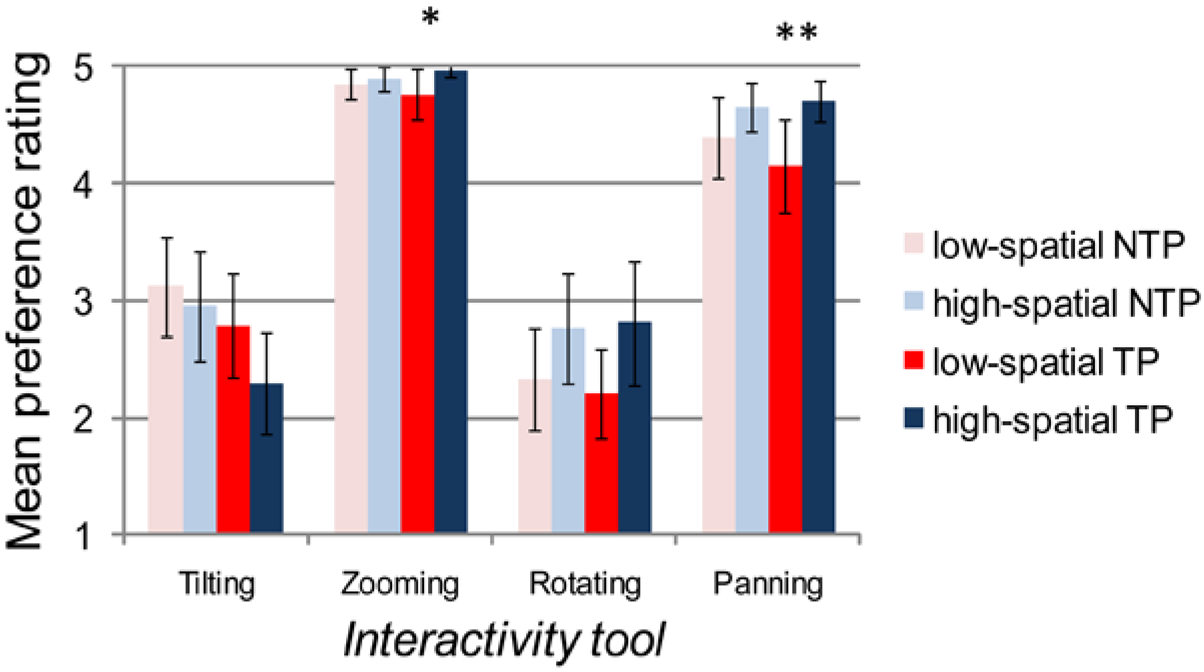

Figure 3: *Interactivity preferences dependent on time pressure and spatial abilities. Error Bars: ± 2SE, * $p<0.05$, ** $p<0.01$.*

Next, we wanted to explore the robustness of these findings considering the median-split aggregation procedure of individual MRT scores. Following Sholl and Liben's (1995) approach, we divided participants into three spatial ability groups using terciles of their MRT scores and assigned them to a low-spatial (N=24), medium-spatial (N=26), and high-spatial group (N=20). In the following, we present and discuss the results only for the newly created high-spatial and low-spatial groups, and do not further consider the medium-spatial group.

Comparing Figures 3 and 4, one can see that the overall response pattern is almost identical. In other words, regardless of the high-low spatial grouping procedure, we find the same preference patterns for the map interaction tools. However, while the lower preference for the zooming tool in low spatial participants was significantly different from the high-spatial group when using a median-split grouping, this significant difference disappears using the tercile approach. In contrast, the significantly lower preference for the panning tool in low spatial participants remains significant ($p<0.01$), regardless of the classification scheme.

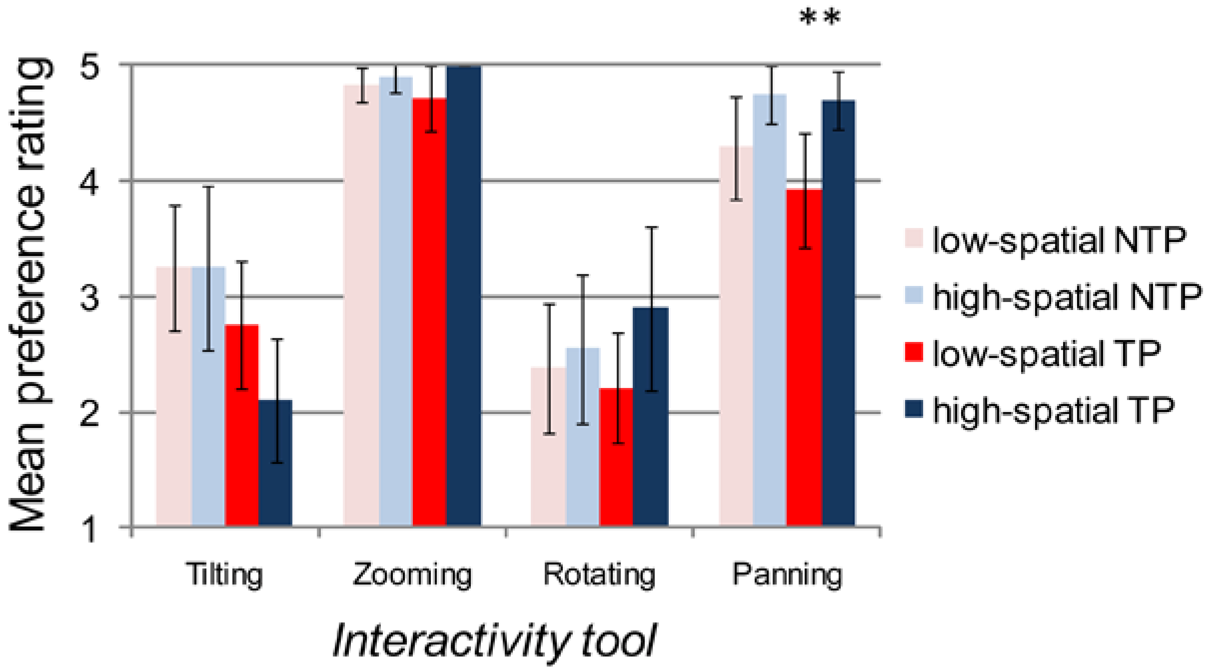

Figure 4: *Interactivity preferences when using three classes of spatial abilities. Preferences for the medium-spatial group are not displayed in this figure. Error Bars:* $\pm 2E$*, ** $p<0.01$.*

When analyzing the effect of these newly built groups on map display preferences, new significant effects emerge: For the excursion planning scenario (NTP), the low-spatial group has a significantly high preference for Map C (road map with hillshading). As for the emergency response (TP) scenario, the preference for Map E (the road map with distances) is significantly higher for the high-spatial group (see Figure 5). This is in contrast to the median split classification with two groups, where there were no significant differences in map display preferences.

These results show that possible interpretations about the effect of spatial abilities on map use preferences might also significantly depend on the classification methods used to study these individual differences. This further means that researchers have to take great care in validating found effects by cross-checking results with various established methods.

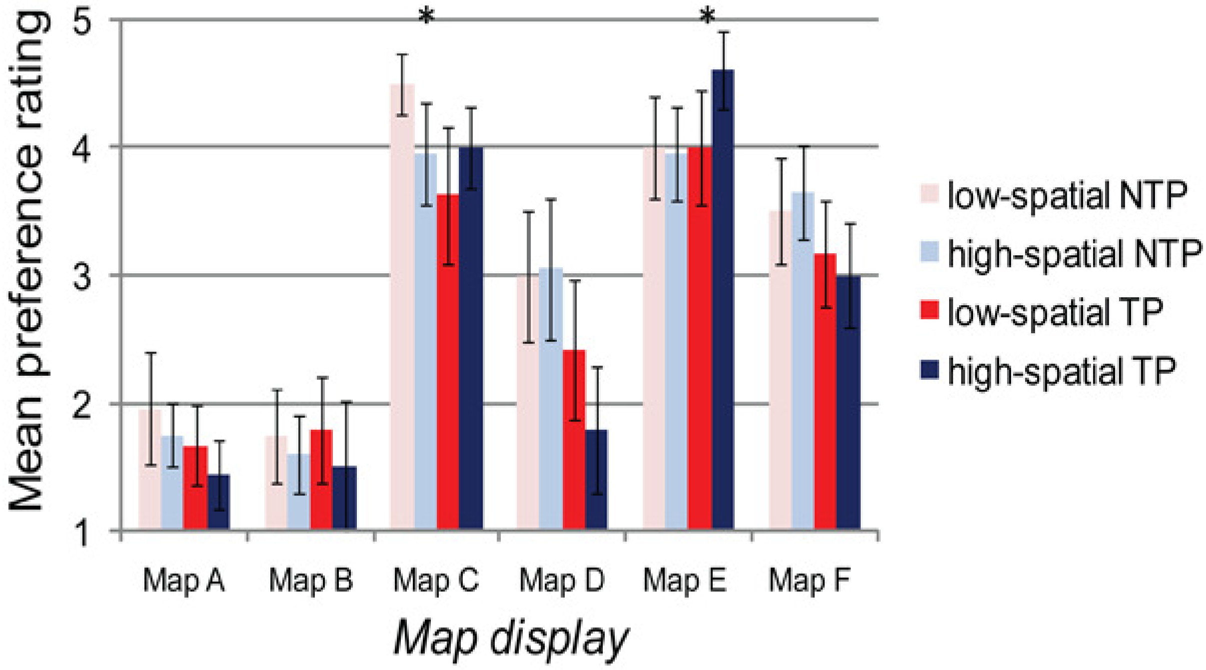

*Figure 5: Map preferences according to classification into three classes of spatial abilities. Error Bars: ± 2SE, * p<0.05.*

THE EFFECT OF GENDER ON SPATIAL ABILITY

As reviewed in the related work section earlier, gender and mental rotation scores are interdependent. One might therefore expect that on average more males will be found in the high spatial group, and thus have similar visuo-spatial preferences, while female preferences will be more like those of the low-spatial group.

A Chi-Square test of independence assessing the relationship between MRT response patterns (grouped by a median-split) and gender suggests a significant relationship ($\chi 2= 5.85$, $p<0.01$). This relationship remains significant when using the high-low spatial groups from the tercile classification (excluding the medium-spatial group). However, with the tercile classification the association is considerably weaker ($\chi 2=3.88$, $p<0.05$).

Even though there seems to be a significant dependence of gender and spatial abilities, our male participants do not have the same map use preferences as would be expected by high-spatial participants. Similarly, our female participants do not share the same map use preference as low-spatial participants, as we will see in the next section.

THE EFFECT OF GENDER ON MAP USE PREFERENCES

First and most importantly, we did not find any significant gender differences in map interaction tool preferences. While the overall map type preference patterns are strikingly similar in Figures 5 and 6, one can see that male/high-spatial and female/low-spatial patterns are not congruent. We found highly significant gender differences in map type preferences: Map E (the road map including road distances) was preferred significantly more by females (NTP: M=4.08, SD=0.91, TP: M=4.35, SD=0.74) than by males (NTP: M=3.60, SD=0.97, TP: M=3.69, SD=1.01) in both conditions. This is particularly interesting as high- (and not low-) spatial people preferred Map E significantly more than the other maps in the same condition (see Figure 4). Female preferences were also higher for the other road map, C, under both conditions, and this difference was significant for the NTP condition (see Figure 6).

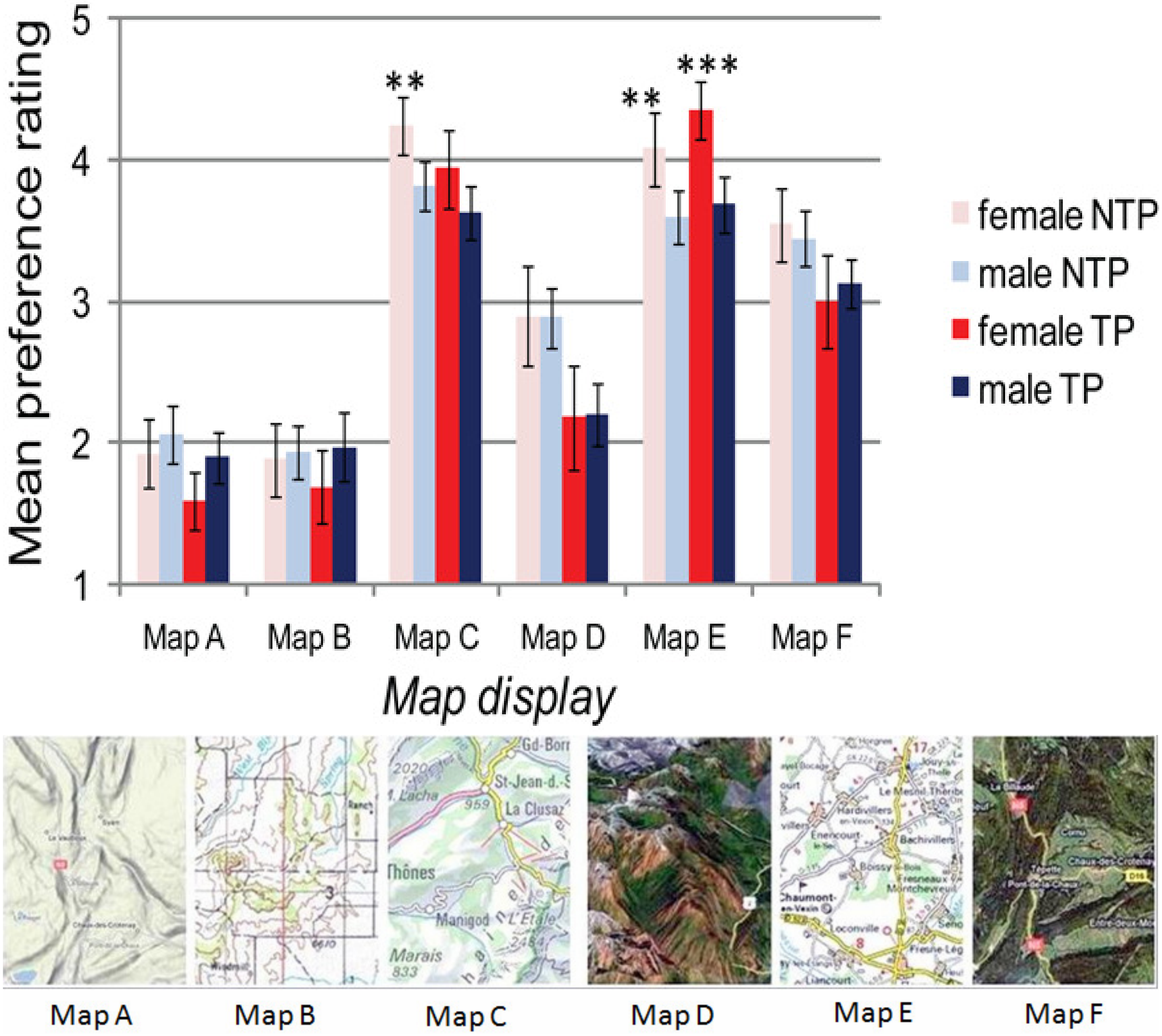

Figure 6: *Map display preferences dependent on time pressure and gender. Error Bars: ± 2E, ** p<0.01, *** p<0.001.*

EXPERIMENT II

The map use task for this second experiment was again road selection under varying time pressure conditions, but in flat, urban terrain. As orthographic satellite image maps and road maps obtained the highest preference rankings in Experiment I, we chose these two map types for this experiment. We also investigated how spatial ability and gender might influence participant performance. Time pressure was simulated by giving participants either 10, 20 or 30 seconds to solve the task. Each of these three time limits was randomly assigned to four road maps and four satellite images. Time pressure and map display type thus were within-subject variables. Participants were randomly assigned to either the "fastest route", or the "shortest route conditions, so that "task type" was a between-subject variable.

Participants. Seventy-six participants (44 male and 32 female) participated in this experiment. Their recruitment and background was similar to Experiment I. Ninety-seven percent stated to use maps at least occasionally professionally, and ninety-two percent at least occasionally in their leisure time.

Materials. Participants were exposed to twenty-four map stimuli, of which twelve were road maps and twelve were satellite images (see Figure 7 for two sample stimuli). Each map display had a size of 400x400 pixels, and contained three differently coloured routes.

Figure 7: *Test stimuli: road map (left) and rotated satellite image of the same area (right).*

Procedure. The experiment took place in a lab equipped with standard personal computers connected to the Internet and was carried out with a standard web browser displayed in full-screen mode on a 17-inch color displays set to 1280x768 pixel screen resolution. After filling in an online background questionnaire, participants continued with solving the road selection portion of the experiment. Participants were asked to either select the fastest or the shortest routes from three labeled roads displayed in the map within a given time limit. After selecting a route, participants were asked to rate their confidence on a scale from "1 – not confident at all" to "4 – very confident". Responses were collected digitally. We recorded participants' accuracy (percentage of correct answers regarding the shortest or the fastest route) and (self-reported) confidence. In the remainder of this section, we will discuss response accuracy and confidence with respect to gender.

RESULTS

On average, females (M=0.43, SD=0.18) were more accurate than males (M=0.41, SD=0.20) in their responses for all time limits and map types. These differences in accuracy were not significant, however. Replicating prior work, we found a significant gender effect on participants' confidence. Male confidence ratings (M=2.77, SD=0.38) are significantly ($p<0.05$) higher than those for females (M=2.58, SD=0.32) in all conditions, as shown in Figure 8. These differences are significant for the 10s and 20s time limits (10s: male M=2.69, SD=0.51, female M=2.47, SD=0.40, 20s: male M=2.86, SD=0.40, female M=2.61, SD=0.39), but not significant for the 30 seconds time limit. For female participants, confidence ratings generally increases with having more response time, while male confidence seems to decrease when having more than 20 seconds for decision-making.

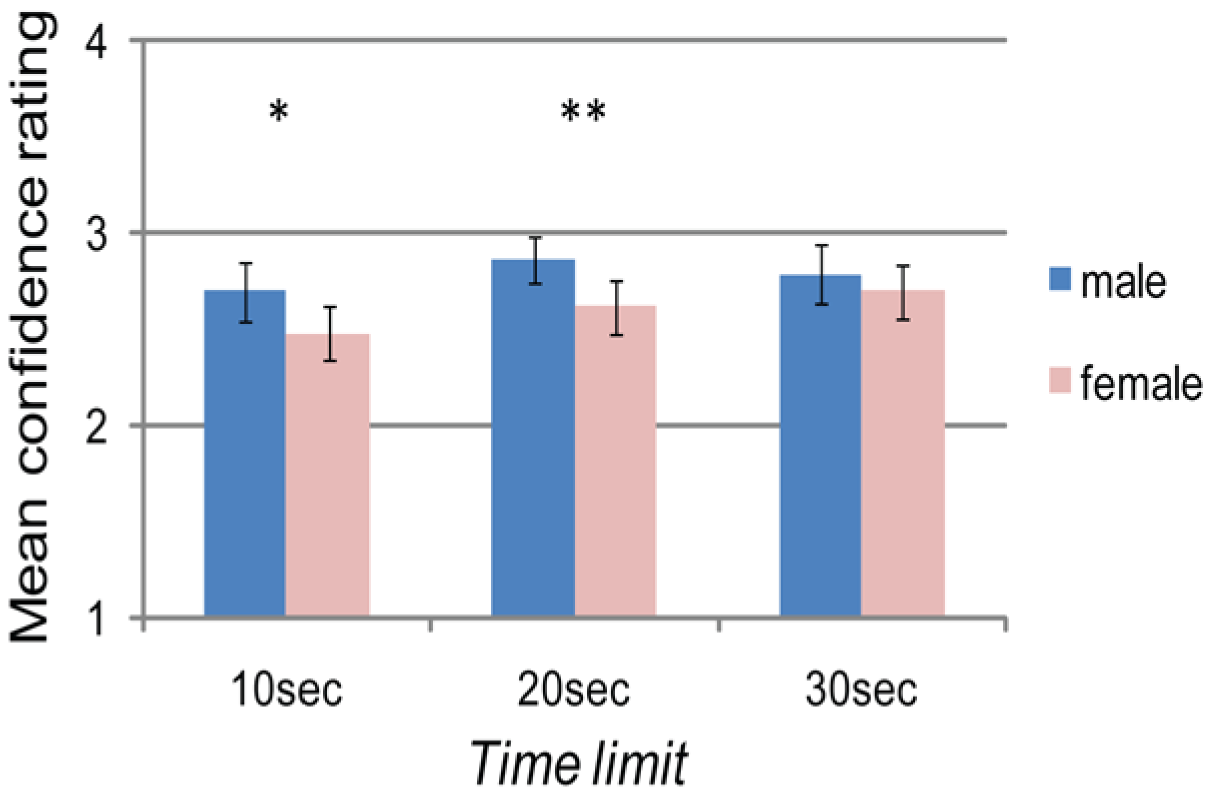

Figure 8: *Confidence ratings grouped by gender and time limits. Error Bars: ± 2SE, * p<0.05,** p<0.01.*

Male and female accuracy is not influenced by map type (satellite image or road map). However, for both map types, overall females' confidence is significantly lower compared to males ($p<0.05$). The results regarding response accuracy and confidence with different time limits and map types are described in more detail elsewhere (Wilkening 2010).

SUMMARY AND DISCUSSION

Inspired by previous work in psychology, we investigated how human factors (i.e., individual and group differences) might affect the effectiveness and efficiency of human decision making with maps under time pressure. In a first experiment about map type and map interaction tool preferences for an emergency response and an excursion planning scenario respectively, we replicate an interaction effect of gender and spatial abilities, confirming results from previous research. However, gender does not influence map type and interactivity tool preferences in the same way that spatial abilities do. As different classification methods lead to different significant preferences, these results also suggest that the methods employed to measure and group subjects based on spatial abilities can influence the robustness of empirical research results.

Somewhat counter-intuitively, our results show that high-spatial participants overall prefer to use more map interaction tools than low-spatial participants. Good mental rotators also prefer to use the map rotation tool more than low-spatial participants, but this difference is not significant. This is in accordance with findings by Cohen and Hegarty (2007), who have found that subjects with good internal visual abilities are more (and not less) likely to rotate external 3D visualizations.

In a second road selection experiment with road maps and satellite image maps we find that females are more accurate than males irrespective of the time limit, or the map type. Males, on the other hand, showed higher confidence in their performance than females, under all conditions. This male over-confidence effect known from previous spatial cognition research (Furnham 2001, Furnham et al. 1999, Lloyd, Hodgson and Stokes 2002) is especially striking for the short response time limits. In contrast, female confidence seems to generally increase with more response time available. With these studies we provide rare empirical evidence on how not just cartographic design affects human-spatial inference and decision making with maps, but also map use context (i.e., time pressure), task type, and human factors such as, spatial abilities and gender.

The relationships between decision-making under time pressure with maps is being further investigated in a follow-up experiment on a more complex slope detection task. In this experiment, specifically involving the third dimension, we investigate potential effects of spatial abilities and gender on inference-making performance using virtual globes. This will allow us to further examine whether spatial abilities influence patterns of interactive behavior with 3D displays, which have been investigated with Keehner et al. (2008), and in which respect increasing task difficulty influences gender differences, as found by Prinzel and Friedman (1995).

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