# Mapinou: A Game to Assess the Skill of Using Pan-Scalar Maps

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## Abstract

The widespread adoption of topographic maps on smartphones, typically implemented as pan-scalar digital cartographic interfaces, has altered the competencies required for their effective interpretation and use. The skills necessary to navigate and analyze these maps now differ substantially from those associated with reading and employing traditional paper-based topographic maps. To facilitate a more rigorous assessment of these emerging competencies, the paper introduces a serious game, termed Mapinou, which is designed to be executable on any modern smartphone device. The game alternates between tasks that require the use of a pan-scalar map and spatial skill tests to study potential relations between the spatial skills of users and their competencies in pan-scalar map use. Our goal when designing this game was to propose a predictor of pan-scalar map use skills, and the spatial skill tests embedded in the current version of the game are intended to test the robustness of this prediction. In this paper, we analyze the data collected from almost two hundred early players of the game. The results show a weak but significant relation between the success in the game and the success to the water-level task, which is known to be related to spatial skills.

**2012 ACM Subject Classification** Applied computing → Cartography

**Keywords and phrases** cartography, pan-scalar map, sense of direction, spatial skill, serious game

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**Supplementary Material** *Software*: `https://github.com/LostInZoom/mapinou/`
archived at `swh:1:dir:b485063356204f36b4a6208d2753ce9b615ccf6f`

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## 1 Introduction

Reading a topographic map used to be a niche activity that required the unfolding of a large piece of paper, and decoding a map with a high density of information. Not everyone was able to properly read a topographic map. Now that almost everyone has access to topographic maps of the world at any scale, thanks to their smartphone, and use them for daily navigation tasks, it is important to wonder if people have the skills to use these new topographic maps. Here, it should be noted that we consider Google Maps, Apple Plan, or even the default OpenStreetMap map as those new forms of topographic maps, even if they do not represent contour lines and relief as detailed as 1:25,000 scale maps from Swiss Topo would. Those maps are different from the paper, single-scaled topographic maps, as they are pan-scalar, i.e., zoomable, interactive, and multi-scale [14]. The main differences are twofold: the size of a display with a small screen for pan-scalar maps compared to the large piece of paper for printed maps; and the interactivity possible with the pan-scalar maps, through touch gestures. As a consequence, the skills required to read those maps might be different from the skills required to read topographic paper maps. For instance, the users of pan-scalar maps may be subject to cartographic disorientation [43] and to the desert fog effect (i.e., the disappearance of the known landmarks that were still visible in the previous view [20]), when they pan and zoom in the map [42]. From our observations, some users are more subject to the desert fog and to disorientation than others. More generally, some users are more crafty than others with the use of hand gestures to pan and zoom in a pan-scalar map [45], as the pinch gesture can be complex to achieve with precision [44, 31].

The skills and competencies required to read a topographic map have been studied by researchers. Those skills include specific competencies such as reading contour lines, or using a scale bar [41, 2], but also include cognitive processes that are not specific to map reading (e.g. mental rotation, distance estimation, symbol identification) [28, 46, 26]. Some of these general cognitive skills can be summarized as the visual-spatial ability, which can be defined as the ability to visualize and manipulate geometrical figures in space [46]. But do those competencies translate to the use of pan-scalar maps on smartphones? Using and understanding pan-scalar maps requires visual-spatial abilities, but as mentioned earlier, it also requires at least touch gesture skills and the mental ability to relate scales to one another. We are convinced that it is important to better understand the competencies required to use this new medium. As a first step, we want to be able to discriminate between the users who succeed in using these maps and those who fail, or at least those who face difficulties.

To answer such questions, we need to collect data from a very large and diverse sample of the population. Gamification constitutes a strategy for fostering participation in citizen science by incorporating game-like elements and mechanics into research activities [13, 27]. In recent years, gamification has been increasingly integrated into platforms and projects related to volunteered geographic information (VGI) [1, 39, 5]. Beyond the mere collection of geospatial data, serious geo-games [37] can be designed to serve a variety of additional purposes. They can function as educational tools for teaching geography and cultivating spatial competencies, and they can also be employed as experimental instruments in the empirical sciences [38]. Furthermore, some geo-games are developed primarily for recreational use, as evidenced by the widespread popularity of applications such as Geocaching [30] and GeoGuessr.

Our principal source of inspiration for the design of a serious game targeting map-use skills is Sea Hero Quest, a game co-developed by academic researchers and a video-game studio [40]. This mobile game was specifically created to investigate demographic factors influencing spatial skills and their decline, and it reached a large user base of 3.9 million players. The resulting dataset has made it possible to identify global determinants of spatial abilities, including the geographic region in which individuals were born and raised, as well as gender-related differences [8, 7, 6]. Although our ambitions are considerably more modest – particularly because our serious game has been developed without the collaboration of a professional video-game studio – we nevertheless aim to recruit several thousand players. This will enable us to gain a more comprehensive understanding of pan-scalar map-use skills.

In this paper, we introduce Mapinou, a serious, mobile-based geo-game that we have developed. The game entails intensive engagement with and exploration of a topographic, pan-scalar map. Within Mapinou, map-use tasks are interleaved with standardized spatial ability tests drawn from the literature, thereby enabling direct comparison between players' in-game performance and their outcomes on established spatial skill measures. Our primary objective with Mapinou is to use the game as a predictor of pan-scalar map reading and using skills. If there is light or strong correlations between the game and these 4 spatial skill tests, the game could be used as a predictor, as pan-scalar map reading and using skills are partly related to spatial skills. A futher objective is to better understand of the global determinants of these pan-scalar map using skills (e.g., age, gender, prior cartographic experience). In this article, we report the initial empirical findings derived from data collected with the first cohort of players.

## 2 Materials and Methods

### 2.1 Experimental Design

In this study, we are interested in measuring the skills of users in their use of pan-scalar maps, so we opted for a between-subjects design. Each user of Mapinou plays the same game, with the same levels in the same order, and also performs the same spatial skill tests.

The game consists in 16 levels of increasing difficulty. Each level requires solving two distinct tasks. The game is not designed to be completed in a single continuous session. Each level, with a duration ranging from one to five minutes, can be undertaken in a separate session, as the player's progress is persistently stored.

A map is a multi-purpose communication tool, and it can be used for achieving a wide variety of tasks [9, 4, 22]. The interactivity of the pan-scalar maps adds new usages of the map compared to printed maps [35]. If we focus on the most frequent tasks map users achieve with pan-scalar maps, we can cite *global search*, i.e., searching the whole map area for specific targets or locations, *distance estimation*, *route planning*, and *route following* [21, 33]. The task that we designed for each level of the game combines these four generic tasks, and is composed of two subtasks.

The first task consists in *finding a target*: the rabbit the user plays in the game gives textual instructions about search areas. For instance, the rabbit says "I must be in the south of Paris" (Figure 1(a)). Then, if the user zooms in on the south of Paris, another instruction is triggered. Instructions are chained until the user has zoomed enough to visualise and point the target (usually a small town) in the map. When the user is lost, the rabbit gives messages to find the right track (usually by zooming out). The score in this task increments as seconds pass. The goal is to find the target as quickly as possible. There is no penalty for pointing at the wrong target; this only triggers a message "I am not there". This task is mainly a *global search* task.

The second task mixes *route planning*, *distance estimation*, and *route following*, as the user is asked to find a route to reach a rabbit friend located further on the map (Figure 1(b)). The user has to point a location on the map and then the rabbit runs to that location using the roads and the paths from the map. Similar to the first task, the score increments as seconds pass. Pointing to a location to go to is only possible at large scales, which forces the user to memorize the route or to zoom in and out to adjust the route as the rabbit moves. To make the task harder, and force the user to read the map and zoom in and out frequently, we added obstacles to avoid, in the form of enemies: snakes, eagles, and hunters. Those enemies have a radius of influence, and if the rabbit runs into those areas, the score increments with a penalty (Figure 1(c)). To add another layer of reasoning, we introduced vegetables that appear when the rabbit comes close. Eating vegetables gives a bonus to the score, so the user is really incentivized to regularly update the route.

Alternating with the pan-scalar map-use tasks described above, Mapinou presents four established assessments of spatial ability. Figure 2 illustrates how these four tests are embedded within the game environment. First, participants complete a digital implementation

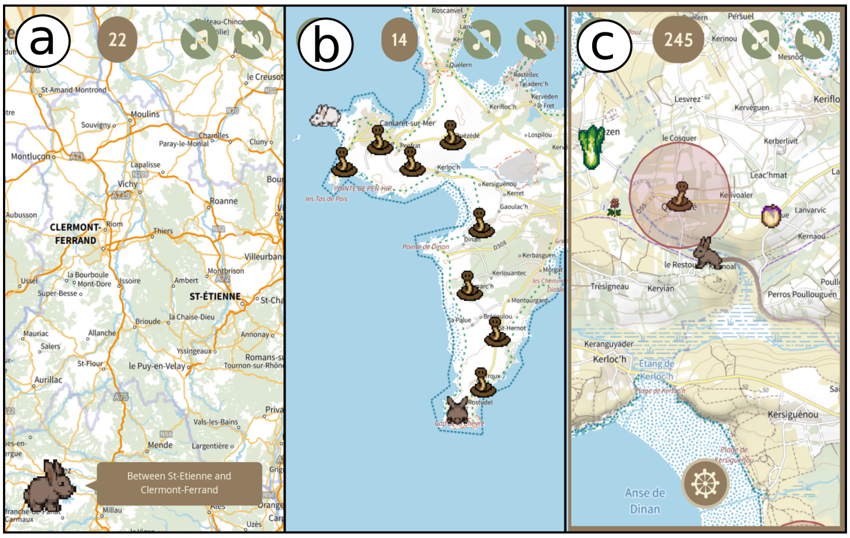


**Figure 1** Two tasks to perform during a Mapinou game: (a) find the rabbit using the textual indications; (b) the route planning task; (c) enemies and rewards appear during the second task. All three captions are extracted from the first games available in Mapinou.

of the water-level task. Originally introduced by Piaget [32], this task depicts a cross-sectional view of a bottle filled halfway with water. In the test, a rotated version of the same bottle is shown, and the participant must draw the line corresponding to the interface between water and air. The correct response is the horizontal line that divides the interior of the bottle into two regions of equal area. This task has been extensively employed in prior research on spatial ability, as it has been shown to correlate strongly with other spatial cognition measures [24, 49, 25]. In our application, the line is drawn by tapping twice on the touchscreen to specify the start and end points of the line segment. Because of the inherent imprecision of touch input, we do not require a perfectly horizontal line for a response to be considered correct. Each participant is presented with five bottles, each rotated at a different angle.

We then used the Santa Barbara Sense of Direction Scale [17] that is composed of 15 questions about the self-declared sense of direction of participants. For each assertion (e.g., “I am very good at giving directions”), the participant decides on a Likert scale with 7 values if they strongly agree or strongly disagree with the assertion. This scale was used to study the global determinants of spatial ability [50], to better understand spatial ability [18, 16], or just as a proxy measure of spatial ability to characterise the sample of participants in user studies.

The third spatial ability test is the Perspective Taking Spatial Orientation Test (PTSOT) [23, 18]. In this test, several distinctive symbols are drawn on a paper or displayed on a screen, and the participant is given several questions. For each question, the participant should imagine they are standing at the location of one these symbols (which will be named at the center of the circle), and they are facing at a second of these symbols, named at the top of the circle; they are asked to draw an arrow from the center object showing the direction to a third symbol from this facing orientation. This test requires perspective-taking and mental rotations as cognitive processes. In the application, we used a recent revised version of the PTSOT [11], and we changed the symbols for the sprites used in the game (a rabbit, a snake, an eagle, a pigeon, a zucchini, a hunter). The user has to point to the location of the target symbol on the circle for the line to be drawn.

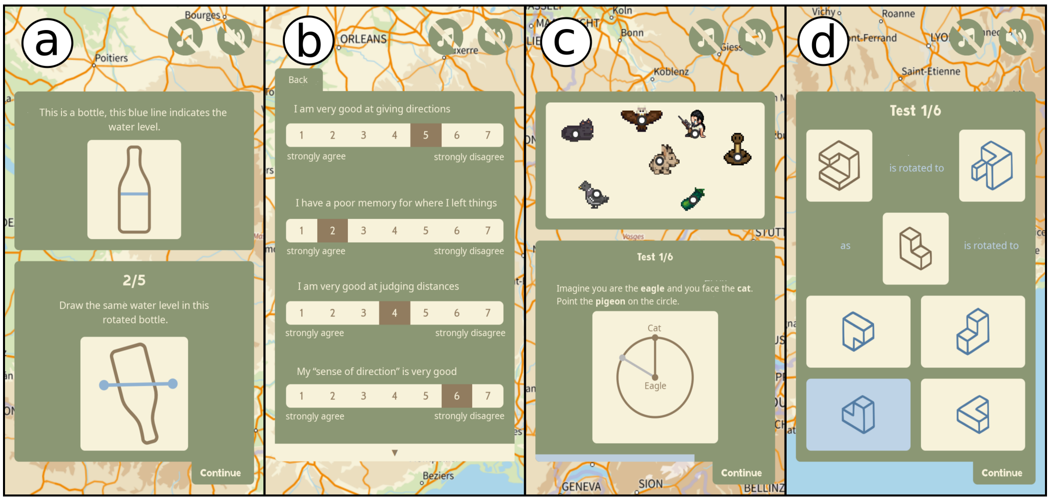


Figure 2 Screen capture of the four spatial skill tests included in the game: (a) the water-level task; (b) the Santa Barbara Sense of Direction Scale; (c) the Spatial Orientation Test (PTSOT); (d) Purdue spatial visualization test for rotations.

**Table 1** Number of Mapinou users according to the level they reached in the game.

| **level reached** | level #1 | level #4 | level #8 | level #12 | level #16 |
|---|---|---|---|---|---|
| **nb of users** | 196 | 112 | 65 | 46 | 35 |

The final spatial ability test we used is the Purdue Spatial Visualization Test for rotations [15]. The test consists of thirty questions of increasing difficulty related to mental rotation, where the participants are asked to achieve mental rotations of 3D volumes and select the correct rotation among several propositions. Mental rotation tests are often used to measure spatial ability, and other similar tests exist [48]. In the Mapinou application, we selected 5 of the 30 questions from the original test, with varying difficulty, as the full test is expected to last 20 minutes, which would be too long for inclusion in the game.

## 2.2 Participants

Considering our end goals with this game, we want to reach as many users as possible, encompassing all existing profiles in the population. We started with a small-scale recruitment process, located in our university, where we put some posters on the walls. We also participated in several events of science outreach within the university. A button to share the game on social networks is included in the application, and we expected a minor recruitment process through the social networks of the players. At the time we started the data analysis for this paper, 958 players had started the game, for 1902 games played.

We then filtered out most of these players. First, we removed all the players who were identified as playing on a desktop computer, using the information given by their web browser. We also removed all the players who installed the game on their mobile phone but did not play a game. Table 1 shows the number of players in the data collected for this paper, the level they reached in their game completion. Reaching level 12 means that the player played at least 12 games. In total, 1250 games have been played in this dataset.

Table 2 shows the age distribution of the 196 players. Most of the players are situated between 18 and 44, with a quite even distribution between the three corresponding age categories. For now, the sample is too small in the other age categories to analyze the relation between age and pan-scalar map-using skills.

**Table 2** Age distribution of the users in this study.

| **age** | –18 | 18–24 | 25–34 | 35–44 | 45–59 | 60+ | no answer |
|---|---|---|---|---|---|---|---|
| **count** | 4 | 50 | 58 | 45 | 15 | 8 | 16 |

Table 3 shows the gender distribution for the participants, where "other" stands for different possible gender answers, including "no answer". The distribution between male and female players is fairly even.

**Table 3** Gender distribution of the users in this study.

| **gender** | female | male | other |
|---|---|---|---|
| **count** | 82 | 94 | 20 |

Finally, Table 4 shows the self-declared map usage frequency categories among our 196 participants. Most of the participants regularly use pan-scalar maps on mobile devices, either everyday (85 participants) or several times a week (82 participants). Given the usage figures for applications such as Google Maps [36] or Apple Plan, it is not surprising to have more players in these two categories.

**Table 4** Map usage distribution of the users in this study.

| **Map usage** | everyday | several times a week | several times a month | almost never | no answer |
|---|---|---|---|---|---|
| **count** | 85 | 82 | 16 | 1 | 12 |

## 2.3 Materials

In Mapinou, each level requires the exploration of a map, and we did not create this pan-scalar map; we decided to reuse an existing one. We used a pan-scalar map called Plan IGN, designed by the French National Mapping Agency. It is the default map available on the French administration cartographic platform[1], and it is freely available through APIs. In terms of style and content, Plan IGN is quite similar to Google Maps and Apple Plan.

We developed a game-construction application in which we defined 16 distinct games set in heterogeneous regions and landscapes. These 16 games are organized according to progressively increasing difficulty. In phase 1, the difficulty is determined by the degree of precision of the navigational indications provided to the user. For instance, an easier game would indicate "I am between Lyon and Saint-Etienne", while a harder game would just indicate "I am east of Lyon". In phase 2, difficulty is modulated by the number and spatial distribution of enemies, as well as by the presence and configuration of natural obstacles between the starting and ending points of the route (e.g., lakes, large rivers, mountain ranges). As one game is composed of phase 1 then phase 2, we modulated the difficulty of each phase to obtain a game difficulty that is slowly increasing as new games are reached.

[1] https://cartes.gouv.fr/

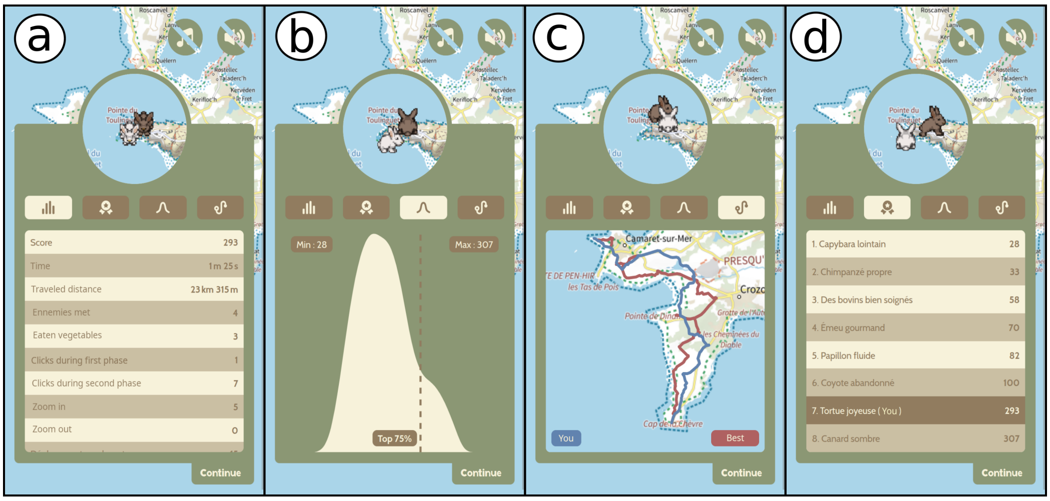


**Figure 3** 4 screen captures of the game visualizations after one level is finished: (a) summarization of the measures describing the run; (b) the position of the player score in the distribution of this specific level; (c) the comparison of the route of the player compared to the best score route; (d) the score ranking.

The game application was designed with open Javascript libraries, including Maplibre for the cartographic visualizations. The routes chosen when the rabbit moves in the game are based on the routing API from the French National Mapping Agency. The code of the application is available openly on Github[2].

We need the players to play the game several times, as we do not expect the game to be finished in a single session. As a result, we introduced several gamification features to push players into further games after the first session. For instance, Figure 3 shows several features appearing after a level is completed: the global score ranking, the visualization of the route compared to the best score's route, global statistics, and the position of the player in the distribution of scores. Completing some levels also unlocks new skins for the rabbit played in the game.

In-game auditory effects and an original musical score specifically composed by the authors are incorporated to enhance players' sense of immersion within the game environment.

## 2.4 Apparatus

The game is meant to be played on smartphones, and it is compatible with most of the devices currently in use. Users are invited to install the application on their personal smartphones, using a QR code or a link. As explained in the previous subsection, the second task of each level relies on a routing web API to compute the shortest path from the position of the rabbit to the pointed position. Without a stable internet connection, the displacement of the rabbit can be very slow. As a consequence, the game requires a stable connection and we prevent starting a trial/level otherwise.

Given our focus on the use of pan-scalar maps on mobile phones, we record the screen size of the device used to play the game and exclude devices whose screens fall outside a predefined acceptable size range, either being too small or excessively large. For now, no exclusion of participants has been performed due to screen size, as the data collected from the web browser already identifies desktop users.

[2] `https://github.com/LostInZoom/mapinou/`


**Figure 4** Screen capture of the view when the user starts level 1 of regular games, after the water-level task.

## 2.5 Procedure

After installing the application on their mobile phone, users are first ask to give informed consent. Then, they are asked to fill a short demographic questionnaire with questions about age, gender and map usage. Then, as the game mechanisms can be complex, we introduce the two tasks of each level with a tutorial, where the users can try all the in-game interactions with the map and with the rabbits. In this tutorial, the players are told that the aim is to perform each phase/task as quickly as possible.

Then, the player has to complete 4 levels composed of 4 games that count as trials in our experiment (Figure 4). Completing one game of a level unlocks the following game, and completing the four games of a level unlocks the next level. Between each level, the user has to complete one of the four spatial ability tests. Before level 1, the user starts with the water-level task, then completes the Santa Barbara Sense of Direction Scale between levels 1 and 2, then completes the PTSOT between levels 2 and 3, and finally completes the Purdue spatial visualization test for rotations between levels 3 and 4. The game was presented in French, and all participants are French speakers, though not necessarily native speakers. Within a level, the four games do not have the exact same difficulty, even if it is rather close as we tried to keep an increasing difficulty between game 1 and game 16.

## 2.6 Statistical Analysis

As mentioned earlier, in this first study based on the data collected with Mapinou, we only focus on the water-level task and the quality of the results in the game, because there are not enough players who reached the levels where the other spatial skill tests are performed. The analysis in relation to these tests will be conducted in further studies.

Because the games do not present the same difficulty, the score ranges can vary widely between games, making it difficult to compare scores or use the mean to assess a player's performance. We also noticed that our expected difficulty was not matching the actual difficulty for players: in some games that we considered difficult, many players found hacks and managed to obtain very low (good) scores, while some games that were considered as easier found the players facing more difficulty than expected. As a result, we decided to

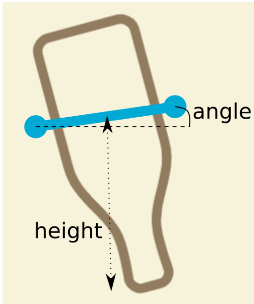


**Figure 5** Illustration of the method used to score the drawing from the water-level task.

rather use the z score instead of the raw score obtained by players. The z score can be computed with the following equation, and is a normalization of the score based on the standard deviation of scores in one specific game:

$$z = \frac{x - \mu}{\sigma} \tag{1}$$

where $x$ is the raw score, $\mu$ is the mean of the scores in a level, and $\sigma$ is the standard deviation of the scores in this level.

Regarding the water-level task, we summarized the 5 drawings with a score from 0 to 5: for each drawing, if the angle between the drawn line and the horizontal is below 10° and if the height of the drawn line is strictly between 30% and 70% of the bottle, the player scores 1 for that drawing (Figure 5); otherwise, they score 0 for that drawing; the total score is the sum of the scores for the five drawings.

Subsequently, we conduct two types of statistical analyses on the results. First, when comparing two ordinal variables, for example the water-level score and the z-score, we assess whether a relationship exists between their distributions. Because none of our distributions meets the assumption of normality, we employ Spearman's rank correlation test to evaluate these regressions.

When comparing a score with categorical data (e.g. the self-declared map usage category, or the age category), we use Kruskal-Wallis tests to check if the categories influence the score.

Finally, we want to use Mapinou in the future as a short test procedure to characterize the sample population in user studies, but it would be too long to have those users play 16 games. So we will compute the minimal sample of games to play to have a mean score representative of the potential final mean score. First, we have to compute the volatility of the scores for the players that played many games (we consider a threshold of 8 games):

$$volatility = \frac{\sum_{i=1}^{k} \sigma_i}{E} \tag{2}$$

where $k$ is the number of players who played more than 8 games, and $\sigma_i$ is the standard deviation of z scores of the $i^{th}$ player with more than 8 games played.

From the volatility, we can compute $n$ as the minimum number of games to play to use the score mean with a 95% confidence:

$$n = \frac{1.96 \times volatility}{E} \tag{3}$$

where $E$ is the expected error margin on the z score.

**Table 5** Distribution of the scores of the users at the water-level task.

| **score** | 0 | 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|---|
| **count** | 43 | 4 | 8 | 22 | 30 | 89 |

## 3 Results

Table 5 presents the first set of results, namely the distribution of water-level scores for the 196 participants in our sample. As expected, the most frequent score is 5, corresponding to five correct responses, obtained by 89 participants. An additional 30 participants obtained a score of 4. This latter result can plausibly be attributed to the difficulty of drawing a perfectly horizontal line on a touch screen. Given that our correctness criterion was a strict angular deviation threshold of 10°, several participants who might have produced correct responses using traditional pencil-and-paper methods did not reach the same level of accuracy when using the mobile application. 22% of the participants obtained a score of 0, which is plausible if we consider the failure rates obtained in past studies [49, 24], but looking at the actual answers from some of these players, we have to consider that some players just sidestepped the task by drawing quickly random lines (we recorded the time spent on each question of the water-level task). We did not find a way to automatically identify all those players, as the difference is too thin between a quick player and a player that sidestepped the task. It means that we have to be careful when analyzing the score of the players with this score.

Figure 6 shows the distribution of the mean z score of the players by the water-level score. Apart from the players with a score of zero that are scattered between good (low) z-scores and bad (high) z-scores, this plot shows a tendency of correlation: players with higher water-level scores have better/lower z-scores in the game. The Spearman's correlation is -0.185 ($p - value = 9.2667e - 03$) which confirms a weak but significant correlation. If we exclude the players who scored zero at the water-level task, the Spearman's correlation is stronger and still significant (-0.216; $p - value = 7.4507e - 03$). This result is a first indication that Mapinou might be used as a predictor for pan-scalar map use competency.

Figure 7 shows the box plot of the z-scores by age category. We ran a Kruskal-Wallis test only on the three most populated age categories, namely "18-24", "25-34" and "35-44", which is significant ($p - value : 2.6685e - 02$). we ran a post-hoc Dunn test with a Bonferroni correction, and the category "35-44" is significantly different from "25-34" ($p - value : 0.044$), but the other pairs are not significantly different.

Figure 8 shows the box plot of the z-scores by gender category. As we do not expect any homogeneity in the other category, it was not tested further. We ran a Kruskal-Wallis test on the other two gender categories (H $= 6.191$; $p - value : 1.2837 \cdot 10^{-2}$), which shows that male players are performing better than female players in the game.

The third demographic factor considered is map usage. Figure 9 presents the boxplot of the z-scores stratified by map usage category. As only the first two categories (players who use maps every day or several times per week) include a sufficient number of participants for statistical analysis, we conducted a Kruskal–Wallis test restricted to these two groups (H $=$ $5.313$; $p = 2.1172 \cdot 10^{-2}$). The results indicate that players who use maps on a daily basis achieve significantly higher performance scores than those who use maps only several times per week.

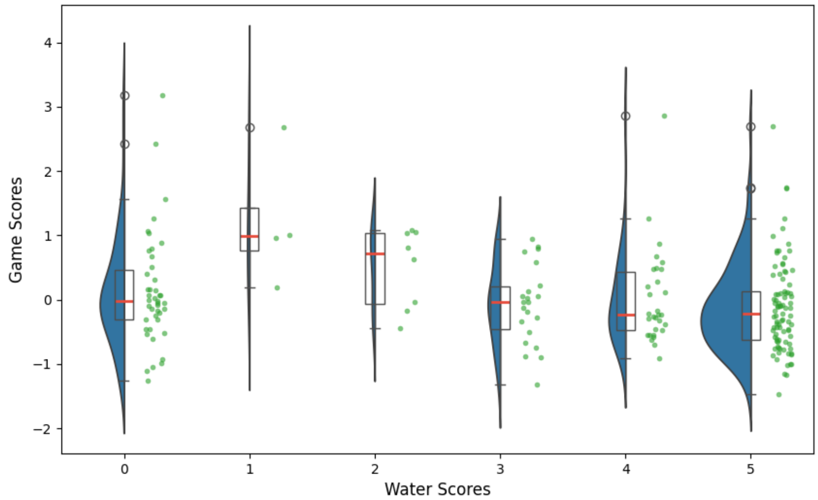


**Figure 6** Raincloud plot of the z-score of the participants by water-level score. A raincloud plot combines a box plot, a scatter plot, and a violin plot.

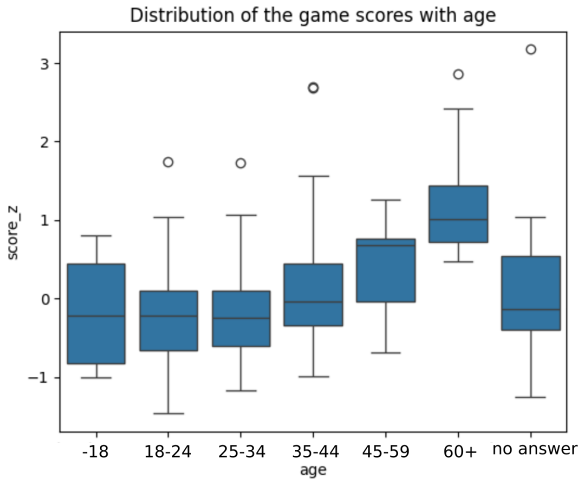


**Figure 7** Box plot of the distribution of game z-scores by declared age categories.

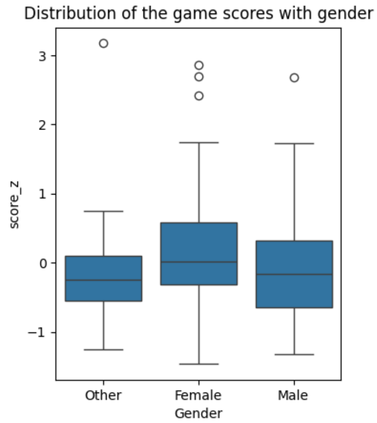


**Figure 8** Box plot of the distribution of game z-scores by declared gender. All none "Male" or "Female" answers are aggregated to "Other" in this plot.

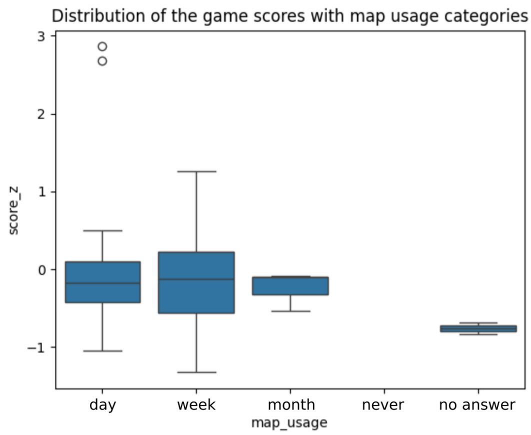


**Figure 9** Box plot of the distribution of game z-scores by declared map usage. Day means several times a day, week means several times a week, et cetera.

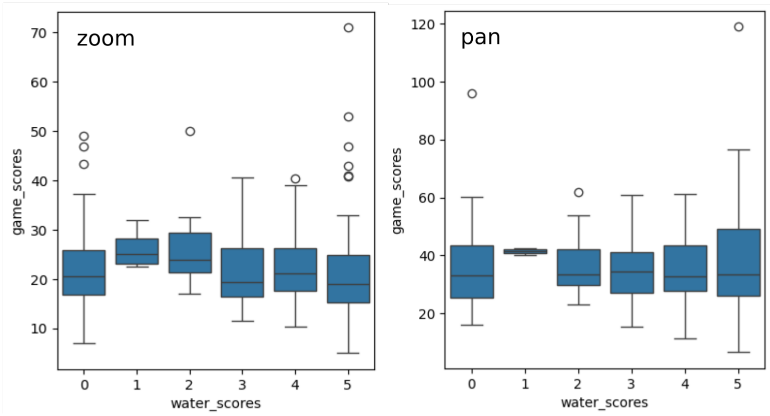


**Figure 10** Box plot of the distribution of the number of zoom and pan interactions per game by water-level score.

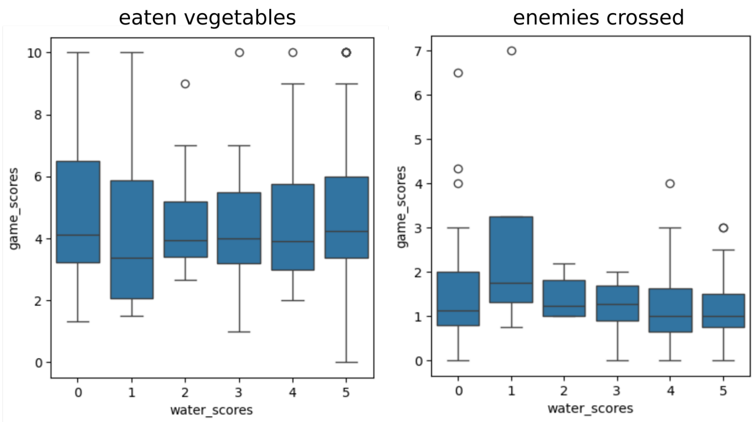


**Figure 11** Box plot of the distribution of the number of bonuses and maluses obtained in the game (vegetables and enemies) by water-level score.

The game z-score is not the only metric that is collected during the completion of a game, as we record all the interactions of the player with the map. Figure 10 shows the box plots of the mean of zoom interactions per game by the water-level score, and of the mean of pan interactions per game by the water-level score. If we put aside the players who scored zero at the water-level task, we can see a weak correlation with the number of zoom interactions, confirmed by Spearman's correlation (-0.143; $p - value = 7.698 \cdot 10^{-2}$). Regarding the number of pans, Spearman's correlation is not significant (0.025; $p - value = 0.725$).

Figure 11 presents two additional box plots: (i) the number of vegetables consumed per game as a function of water-level category, and (ii) the number of enemies crossed per game as a function of water-level category. After excluding, once again, the players who obtained a score of zero on the water-level task, no statistically significant association is observed between water-level performance and the number of enemies crossed (Spearman's $\rho = -0.147$, $p = 6.890 \times 10^{-2}$), nor between water-level performance and the number of vegetables consumed (Spearman's $\rho = 0.061$, $p = 0.39$).

Finally, with respect to the number of games required to estimate players' skills with 95% confidence, the observed volatility for players who have participated in more than eight games corresponds to a z-score standard deviation of 0.71. We then computed the required sample size for a margin of error slightly below this volatility and obtained that a minimum of three games is sufficient. When a smaller margin of error is imposed (0.5), the minimum number of games needed to achieve 95% confidence increases to seven.

## 4 Discussion

For now, the analysis of the data from the early players show a weak but significant correlation between the spatial skills measured with the water-level task, and the score in the game. But one reason why this correlation is weak is the lack of control in the study. Apparently, several players sidestepped the water-level task, maybe because it was boring compared to the game or because they did not understand it. The choice of a mobile game to study pan-scalar map-using skills was made to gather a large number of players, which is still our aim, but the drawback is the lack of control on how the users play the game and answer seriously to the spatial ability tests. From what we can see in the current results, the number of players sidestepping the water-level task is not very large (less than 5%), and we hope that with more players, the future analyses will be more robust.

With the score and the z-score, Mapinou measures the ability of players to be good at this game, which is not exactly similar to what we are primarily interested in: pan-scalar map-using skills. To perform at this game, players have to be able to search a target in a pan-scalar map, plan a route, and follow it, zoom in and out regularly, update your survey and route knowledge to collect vegetables. But being agile with your fingers and being able to very quickly chain sequences of finger interactions, is very useful to achieve a good score, like in many video games. It is questionable which type of skills are the most important to achieve good results in Mapinou, and maybe a future analysis of the speed of interaction will be necessary to address this question. There are studies in human-computer interaction about those touch-gestures on mobile devices that could be interesting to replicate with map zooming and panning tasks [31, 44, 45, 34].

Being crafty with touch-gestures on mobile devices can be somehow related to age. One of our initial hypotheses when designing Mapinou was that older users of pan-scalar maps might have more difficulties than young users. For now, this hypothesis has not been tested because the number of users older than 45 is too low to perform statistical analyses. However, our current results show that the “35-44” age category performs significantly better than the “25-34” category. This result shows that we should not expect a linear decline with age, but maybe we can expect a phenomenon of decay for older players. The results for the Sea Hero Quest mobile game show a peak of performance at 21 years old, and a global decrease as the age of the players advances [8]. Other studies show a non-linear effect of aging on spatial visualization and perspective taking cognitive competencies, and a linear effect on mental rotation [3].

Past studies on spatial abilities exhibit differences with gender [24, 6]. For instance, the results in the Sea Hero Quest mobile game show a significant gap between men and women, but the results also show that those differences highly depend on the country where the participants were born and raised, with countries such as Norway and Finland showing almost no gender difference in spatial ability, while other countries exhibit strong gender differences. According to these results, France, where all our participants live, show momderate gender differences, and this is what we can see in our results too. The distribution of z-scores are significantly different but the median of z-scores is almost identical for men and women. The difference comes from the higher number of very good scores among the male players, and the significant number of bad scores among female players. When we have more players to analyze, it would be interesting to see of this gender difference changes with age categories.

A previous study on Sea Hero Quest shows that the number of hours spent on video gaming predicts success in the game [51]. Playing video games has been shown to improve spatial skills [12, 10, 29], so we expect a similar effect on pan-scalar map using skills, and on the score in our game. We added a question in our demographic questionaire to indicate the number of hours per week spent playing video games on all devices, and we plan to study this effect in future analyses of the game data.

Socioeconomic status and educational attainment have also been shown to modulate spatial abilities [52]. Our initial recruitment procedure, which relied on posters displayed throughout the university campus, may therefore have yielded a relatively homogeneous sample in terms of education level. With a more educationally diverse sample, the proportion of participants exhibiting low water-level task performance might increase, potentially altering the pattern of results reported here. To mitigate this limitation in future data collection, we intend to diversify our recruitment strategies (e.g., via social media and public science outreach events) and to systematically collect detailed information on participants' socioeconomic status and educational background in our demographic questionnaire, in order to characterize and intentionally increase sample heterogeneity.

Finally, it has been shown that training to the use of maps has positive consequences on spatial cognition and spatial ability [47, 19]. Our results on the influence of self-declared map usage confirm this assertion, as players that use pan-scalar maps everyday have significantly better results than players who use them several times a week. We will try to collect as many players as possible with a use of pan-scalar maps that is less than several times a week to confirm this tendency with our other groups, even if it will not be easy because the game requires a mobile phone, and mapping applications are usually among the most used apps by mobile phone owners.

## 5 Conclusion

To conclude, this paper, based on the early players of Mapinou, our serious geo-game for mobile phones, shows that mobile games can be interesting tools to study the use of pan-scalar maps. Our first results show a weak but significant relation between the score at the water-level task (that is related to spatial ability) and the score in the game, which shows that players with better spatial abilities tend to perform better in the game.

To advance this work, we plan to recruit a substantially larger number of participants over the coming weeks in order to collect sufficient data for the three remaining spatial ability tests. Several communication actions are planned to favor this recruitment process. If the current findings generalize to these three additional tests, an open question is whether one of them exhibits a stronger correlation with game performance than the others, and thus could be preferentially adopted as a proxy measure of pan-scalar map abilities in subsequent user studies.

For one of the in-game spatial ability assessments, we incorporated a reduced subset (5 items) of the Purdue Spatial Visualization Test. Prior research indicates that scores on the full test are associated with participants' mental rotation abilities [15]. If the in-game scores show a substantial correlation with the scores on these 5 Purdue items, it will be necessary to verify that this reduced subset provides an adequate approximation of the full instrument. To this end, we plan to conduct a small-scale user study to evaluate the extent to which this abbreviated version serves as a valid proxy for the complete test.

Beyond the analysis of a dataset with a larger pool of players, we plan to reuse the game in future studies about pan-scalar cartography as it could be the first test that captures visual spatial ability and the ease to use pan and zoom on mobile devices. We also plan to study the Mapinou players with eye-tracking to better understand the cognitive and visual attention processes at play when zooming and panning in a pan-scalar map.

## References


1 Vyron Antoniou and Christoph Schlieder. Participation Patterns, VGI and Gamification. In *Proceeding of: 17th AGILE Conference on Geographic Information Science - Geogames and Geoplay Workshop*, Castellon, Spain, June 2014. AGILE.

2 Leilani A. Arthurs, Sarah P. Baumann, Joel M. Rice, and Shelby Dianne Litton. The development of individuals' map-reading skill: what research and theory tell us. *International Journal of Cartography*, 9(1):3–28, January 2023. doi:10.1080/23729333.2021.1950318.

3 Erika Borella, Chiara Meneghetti, Lucia Ronconi, and Rossana De Beni. Spatial abilities across the adult life span. *Developmental Psychology*, 50(2):384–392, 2014. Place: US Publisher: American Psychological Association. doi:10.1037/a0033818.

4 James R. Carter. The Many Dimensions of Map Use. In *Proceedings of 22nd International Cartographic Conference*, pages 1–9, La Coruna, Spain, 2005. ICA.

5 Jésus Castellote, Joaquin Huerta, Javier Pescador, and Michael Brown. Town conquer : a gamified application to collect geographical names. In Joaquin Huerta, editor, *Proceedings of the AGILE'2014 International Conference on Geographic Information Science*, Castellón, Spain, June 2014. AGILE.

6 A. Coutrot, E. Manley, S. Goodroe, C. Gahnstrom, G. Filomena, D. Yesiltepe, R. C. Dalton, J. M. Wiener, C. Hölscher, M. Hornberger, and H. J. Spiers. Entropy of city street networks linked to future spatial navigation ability. *Nature*, 604(7904):104–110, April 2022. doi:10.1038/s41586-022-04486-7.

7 Antoine Coutrot, Sophie Schmidt, Lena Coutrot, Jessica Pittman, Lynn Hong, Jan M. Wiener, Christoph Hölscher, Ruth C. Dalton, Michael Hornberger, and Hugo J. Spiers. Virtual navigation tested on a mobile app is predictive of real-world wayfinding navigation performance. *PLOS ONE*, 14(3):e0213272, March 2019. doi:10.1371/journal.pone.0213272.

8 Antoine Coutrot, Ricardo Silva, Ed Manley, Will de Cothi, Saber Sami, Véronique D. Bohbot, Jan M. Wiener, Christoph Hölscher, Ruth C. Dalton, Michael Hornberger, and Hugo J. Spiers. Global Determinants of Navigation Ability. *Current Biology*, 28(17):2861–2866.e4, September 2018. doi:10.1016/j.cub.2018.06.009.

9 Jeremy W. Crampton. Interactivity Types in Geographic Visualization. *Cartography and Geographic Information Science*, 29(2):85–98, January 2002. doi:10.1559/152304002782053314.

10 Jing Feng, Ian Spence, and Jay Pratt. Playing an Action Video Game Reduces Gender Differences in Spatial Cognition. *Psychological Science*, 18(10):850–855, October 2007. Publisher: SAGE Publications Inc. doi:10.1111/j.1467-9280.2007.01990.x.

11 Alinda Friedman, Bernd Kohler, Peri Gunalp, Alexander P. Boone, and Mary Hegarty. A computerized spatial orientation test. *Behavior Research Methods*, 52(2):799–812, April 2020. doi:10.3758/s13428-019-01277-3.

12 C. Shawn Green and Daphne Bavelier. Action video game modifies visual selective attention. *Nature*, 423(6939):534–537, May 2003. Publisher: Nature Publishing Group. doi:10.1038/nature01647.

13 Anita Greenhill, Kate Holmes, Jamie Woodcock, Chris Lintott, Brooke D Simmons, Gary Graham, Joe Cox, Eun Young Oh, and Karen Masters. Playing with science: Exploring how game activity motivates users participation on an online citizen science platform. *Aslib Journal of Information Management*, 68(3):306–325, 2016. doi:10.1108/AJIM-11-2015-0182.

14 Maïeul Gruget, Guillaume Touya, and Ian Muehlenhaus. Missing the city for buildings? A critical review of pan-scalar map generalization and design in contemporary zoomable maps. *International Journal of Cartography*, 9(2):255–285, January 2023. `doi:10.1080/23729333.2022.2153467`.

15 R. B. Guay. Purdue Spatial Visualization Test - Visualization of Rotations, 1977.

16 Mary Hegarty, Daniel R. Montello, Anthony E. Richardson, Toru Ishikawa, and Kristin Lovelace. Spatial abilities at different scales: Individual differences in aptitude-test performance and spatial-layout learning. *Intelligence*, 34(2):151–176, March 2006. `doi:10.1016/j.intell.2005.09.005`.

17 Mary Hegarty, Anthony E Richardson, Daniel R Montello, Kristin Lovelace, and Ilavanil Subbiah. Development of a self-report measure of environmental spatial ability. *Intelligence*, 30(5):425–447, September 2002. `doi:10.1016/S0160-2896(02)00116-2`.

18 Mary Hegarty and David Waller. A dissociation between mental rotation and perspective-taking spatial abilities. *Intelligence*, 32(2):175–191, March 2004. `doi:10.1016/j.intell.2003.12.001`.

19 Toru Ishikawa. Individual Differences and Skill Training in Cognitive Mapping: How and Why People Differ. *Topics in Cognitive Science*, 15(1):163–186, 2023. _eprint: https://onlinelibrary.wiley.com/doi/pdf/10.1111/tops.12605. `doi:10.1111/tops.12605`.

20 Susanne Jul and George W. Furnas. Critical Zones in Desert Fog: Aids to Multiscale Navigation. In *Proceedings of the 11th Annual ACM Symposium on User Interface Software and Technology*, UIST '98, pages 97–106, New York, NY, USA, 1998. ACM. event-place: San Francisco, California, USA. `doi:10.1145/288392.288578`.

21 Peter Kiefer, Ioannis Giannopoulos, and Martin Raubal. Using eye movements to recognize activities on cartographic maps. In *Proceedings of the 21st ACM SIGSPATIAL International Conference on Advances in Geographic Information Systems*, SIGSPATIAL'13, pages 488–491, New York, NY, USA, November 2013. Association for Computing Machinery. `doi:10.1145/2525314.2525467`.

22 Joel Kovarsky. The Many Uses of Maps: The Producer at the Center. *Cartographic Perspectives*, 57:12–20, 2007. `doi:10.14714/CP57.278`.

23 Maria Kozhevnikov and Mary Hegarty. A dissociation between object manipulation spatial ability and spatial orientation ability. *Memory & Cognition*, 29(5):745–756, July 2001. `doi:10.3758/BF03200477`.

24 Lynn S. Liben and Susan L. Golbeck. Sex Differences in Performance on Piagetian Spatial Tasks: Differences in Competence or Performance? *Child Development*, 51(2):594–597, 1980. Publisher: [Wiley, Society for Research in Child Development]. `doi:10.2307/1129301`.

25 Lynn S. Liben, Lauren J. Myers, and Kim A. Kastens. Locating Oneself on a Map in Relation to Person Qualities and Map Characteristics. In Christian Freksa, Nora S. Newcombe, Peter Gärdenfors, and Stefan Wölfl, editors, *Spatial Cognition VI. Learning, Reasoning, and Talking about Space*, pages 171–187, Berlin, Heidelberg, 2008. Springer Berlin Heidelberg. `doi:10.1007/978-3-540-87601-4_14`.

26 Amy K. Lobben. Tasks, Strategies, and Cognitive Processes Associated With Navigational Map Reading: A Review Perspective. *The Professional Geographer*, 56(2):270–281, May 2004. `doi:10.1111/j.0033-0124.2004.05602010.x`.

27 Ian McCallum, Linda See, Tobias Sturn, Carl Salk, Christoph Perger, Martina Duerauer, Mathias Karner, Inian Moorthy, Dahlia Domian, Dmitry Schepaschenko, and Steffen Fritz. Engaging Citizens in Environmental Monitoring via Gaming. *International Journal of Spatial Data Infrastructures Research*, 13:15–23, 2018. URL: `http://ijsdir.jrc.ec.europa.eu/index.php/ijsdir/article/view/474/416`.

28 Judith M. W. Meyer. Map Skills Instruction and the Child's Developing Cognitive Abilities. *Journal of Geography*, 72(6):27–35, September 1973. `doi:10.1080/00221347308981316`.

29 Kara Murias, Kathy Kwok, Adrian Gil Castillejo, Irene Liu, and Giuseppe Iaria. The effects of video game use on performance in a virtual navigation task. *Computers in Human Behavior*, 58:398–406, May 2016. doi:10.1016/j.chb.2016.01.020.

30 Carman Neustaedter, Anthony Tang, and TejinderK Judge. Creating scalable location-based games: lessons from Geocaching. *Personal and Ubiquitous Computing*, 17(2):335–349, February 2013. doi:10.1007/s00779-011-0497-7.

31 Alexander Ng, John Williamson, and Stephen Brewster. The Effects of Encumbrance and Mobility on Touch-Based Gesture Interactions for Mobile Phones. In *Proceedings of the 17th International Conference on Human-Computer Interaction with Mobile Devices and Services*, MobileHCI '15, pages 536–546, New York, NY, USA, August 2015. Association for Computing Machinery. doi:10.1145/2785830.2785853.

32 Jean Piaget and Bärbel Inhelder. *The Child's Conception of Space*. Routledge & Kegan Paul, London, 1956.

33 Tong Qin, Wim Fias, Nico Van de Weghe, and Haosheng Huang. Differentiating Everyday Map Tasks: Unique Attention-Related Eye Movements and Electrophysiological Signatures of Map Use. *Annals of the American Association of Geographers*, 114(7):1604–1624, 2024. doi:10.1080/24694452.2024.2353845.

34 Yosra Rekik, Radu-Daniel Vatavu, and Laurent Grisoni. Understanding users' perceived difficulty of multi-touch gesture articulation. In *Proceedings of the 16th International Conference on Multimodal Interaction*, ICMI '14, pages 232–239, New York, NY, USA, 2014. Association for Computing Machinery. doi:10.1145/2663204.2663273.

35 Robert E. Roth. An Empirically-Derived Taxonomy of Interaction Primitives for Interactive Cartography and Geovisualization. *IEEE Trans. Vis. Comput. Graph.*, 19(12):2356–2365, 2013. doi:10.1109/TVCG.2013.130.

36 Ethan Russell. 9 things to know about Google's maps data: Beyond the Map, 2019. URL: https://mapsplatform.google.com/resources/blog/9-things-know-about-googles-maps-data-beyond-map/.

37 C. Schlieder, P. Kiefer, and S. Matyas. Geogames: Designing Location-Based Games from Classic Board Games. *Intelligent Systems, IEEE*, 21(5):40–46, September 2006. doi:10.1109/mis.2006.93.

38 Angela Schwering, Jakub Krukar, Jana Seep, and Yousef Qamaz. Individualization in Spatial Behaviour and Map Reading. *AGILE: GIScience Series*, 4:1–5, June 2023. doi:10.5194/agile-giss-4-41-2023.

39 Linda See, Tobias Sturn, Christoph Perger, Steffen Fritz, Ian McCallum, and Carl Salk. Cropland Capture: A Gaming Approach to Improve Global Land Cover. In Joaquin Huerta, Sven Schade, and Carlos Granell, editors, *Connecting a Digital Europe through Location and Place. Proceedings of the AGILE'2014 International Conference on Geographic Information Science*, Castellón, Spain, June 2014. AGILE.

40 Hugo J Spiers, Antoine Coutrot, and Michael Hornberger. Explaining World-Wide Variation in Navigation Ability from Millions of People: Citizen Science Project Sea Hero Quest. *Topics in cognitive science*, 15:120–138, 2023. Publisher: Wiley. doi:10.1111/tops.12590.

41 Csaba Szigeti-Pap, Dávid Kis, and Gáspár Albert. Understanding Map Misinterpretation: Factors Influencing Correct Map Reading and Common Errors. *ISPRS International Journal of Geo-Information*, 12(12), November 2023. doi:10.3390/ijgi12120479.

42 Guillaume Touya and Justin Berli. The FogDetector: A User Survey to Measure Disorientation in Pan-Scalar Maps. In Roger Beecham, Jed A. Long, Dianna Smith, Qunshan Zhao, and Sarah Wise, editors, *12th International Conference on Geographic Information Science (GIScience 2023)*, volume 277 of *Leibniz International Proceedings in Informatics (LIPIcs)*, pages 73:1–73:6, Dagstuhl, Germany, 2023. Schloss Dagstuhl – Leibniz-Zentrum für Informatik. ISSN: 1868-8969. doi:10.4230/LIPIcs.GIScience.2023.73.

43 Guillaume Touya, Maïeul Gruget, and Ian Muehlenhaus. Where Am I Now? Modelling Disorientation in Pan-Scalar Maps. *ISPRS International Journal of Geo-Information*, 12(2):62, February 2023. Number: 2 Publisher: Multidisciplinary Digital Publishing Institute. `doi:10.3390/ijgi12020062`.

44 Jessica J. Tran, Shari Trewin, Calvin Swart, Bonnie E. John, and John C. Thomas. Exploring pinch and spread gestures on mobile devices. In *Proceedings of the 15th international conference on Human-computer interaction with mobile devices and services*, MobileHCI '13, pages 151–160, New York, NY, USA, August 2013. Association for Computing Machinery. `doi:10.1145/2493190.2493221`.

45 Shari Trewin, Cal Swart, and Donna Pettick. Physical accessibility of touchscreen smartphones. In *Proceedings of the 15th International ACM SIGACCESS Conference on Computers and Accessibility*, ASSETS '13, pages 1–8, New York, NY, USA, October 2013. Association for Computing Machinery. `doi:10.1145/2513383.2513446`.

46 Jean D. M. Underwood. Skilled map interpretation and visual-spatial ability. *Journal of Geography*, 80(6):55–58, February 1981. `doi:10.1080/00221348108980235`.

47 David H. Uttal. Seeing the big picture: map use and the development of spatial cognition. *Developmental Science*, 3(3):247–264, 2000. _eprint: https://onlinelibrary.wiley.com/doi/pdf/10.1111/1467-7687.00119. `doi:10.1111/1467-7687.00119`.

48 Steven G. Vandenberg and Allan R. Kuse. Mental Rotations, a Group Test of Three-Dimensional Spatial Visualization. *Perceptual and Motor Skills*, 47(2):599–604, December 1978. `doi:10.2466/pms.1978.47.2.599`.

49 Michele Andrisin Wittig and Mary J. Allen. Measurement of adult performance on Piaget's water horizontality task. *Intelligence*, 8(4):305–313, October 1984. `doi:10.1016/0160-2896(84)90014-X`.

50 Thomas Wolbers and Mary Hegarty. What determines our navigational abilities? *Trends in Cognitive Sciences*, 14(3):138–146, March 2010. Publisher: Elsevier. `doi:10.1016/j.tics.2010.01.001`.

51 Emre Yavuz, Chuanxiuyue He, Sarah Goodroe, Chris Ganstrom, Antoine Coutrot, Michael Hornberger, Mary Hegarty, and Hugo J. Spiers. Video gaming, but not reliance on GPS, is associated with spatial navigation performance. *Journal of Environmental Psychology*, 96:102296, June 2024. `doi:10.1016/j.jenvp.2024.102296`.

52 Emre Yavuz and Hugo J. Spiers. Determinants of individual navigation ability. *Nature Reviews Psychology*, 5(4):273–289, April 2026. Publisher: Nature Publishing Group. `doi:10.1038/s44159-026-00544-3`.