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Article

Measuring Efficiency and Accuracy in Locating Symbols on Mobile Maps Using Eye Tracking

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Abstract: This study investigated the impact of smartphone usage frequency on the effectiveness and accuracy of symbol location in a variety of spatial contexts on mobile maps using eye-tracking technology while utilizing the example of Mapy.cz. The scanning speed and symbol detection were also considered. The use of mobile applications for navigation is discussed, emphasizing their popularity and convenience of use. The importance of eye tracking as a valuable tool for testing the usability of cartographic products, enabling the assessment of users' visual strategies and their ability to memorize information, was highlighted. The frequency of smartphone use has been shown to be an important factor in users' ability to locate symbols in different spatial contexts. Everyday smartphone users have shown higher accuracy and efficiency in image processing, suggesting a potential link between habitual smartphone use and increased efficiency in mapping tasks. Participants who were dissatisfied with the legibility of a map looked longer at the symbols, suggesting that they put extra cognitive effort into decoding the symbols. In the present study, gender differences in pupil size were also observed during the study. Women consistently showed a larger pupil diameter, potentially indicating greater cognitive load on the participants.

Keywords: mobile maps; eye tracking; daily smartphone usage; spatial contexts; locating symbols; mobile navigation

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1. Introduction

The use of mobile mapping applications is currently one of the most popular methods of navigating in urban spaces. Widespread access to smartphones and a wide range of mobile navigation applications allow each of us quick and easy access to geographic information. Mobile maps, like paper ones, allow the user to browse, search for points of interest and calculate routes, but their significant advantage, as indicated by users, is real-time information about the user's current position [1]. This allows you to plan your route and navigate faster and easier. Mobile map applications allow you to optimize your route on the fly. Many factors are taken into account, including the user's position and traffic volume [2], for example, so you can navigate efficiently through unfamiliar terrain.

Mobile maps encounter many problems, e.g., difficulties in reading a map's symbology correctly. For tourist maps, it is important to make them attractive to the user by using an original graphic design [3]. Navigation features such as routes and point symbols should be higher up in the visual hierarchy [4]; however, poorly designed symbols can be difficult for users to interpret, especially considering that such maps usually do not include a legend [5]. Inadequately selected graphics can also overwhelm the user, making a map difficult to use. The problem is exacerbated when you consider the smaller screens of smartphones and tablets. When designing the user experience (UX), it is important to take these limitations into account and design applications for mobile devices first, and only then for larger screens [6]. It is possible that the frequency of smartphone use has an impact on the ability to find symbols on mobile maps. There is therefore a need to investigate this effect and determine whether more experienced users are better able to perform map-related tasks. Analyzing eye movements can be helpful in evaluating this impact, as it can be used to examine aspects such as the speed of scanning and finding symbols on a map, as well as the degree of cognitive load. This study will allow us to learn more about the differences in the way people with different levels of smartphone experience use a map. This will allow you to design applications that are more user-friendly and take users' habits into account.

Krassanakis and Cybulski [7] note in their paper that the cartographic community has recognized the importance of research related to visual perception and cognition, such that experimental techniques from other fields such as psychology can be used to investigate the fundamental elements of cartographic communication. The creation of effective and efficient maps can rely on the results of experiments in which the map is treated as a stimulus and the perceptual process as a response when viewing the map. They emphasize the significant impact of the use of eye-tracking techniques on cartography due to the large amount of research using eye-tracking technology in this field. The use of eye-tracking tools in usability studies of cartographic products helps to determine the users' visual strategy and whether the users remember any of it, as well as what attracts the users' attention and whether the respondents noticed a particular point or area [8].

Eye tracking metrics have consistently served as valuable tools in various research studies, with their presentation and correlation with performance measures contributing to a comprehensive understanding of efficiency and usability. Numerous investigations across diverse fields have utilized eye-tracking technology to unravel intricate patterns of visual behavior and glean insights into cognitive processes underlying human–computer interactions [9]. Researchers have employed fixation- and saccade-based metrics to assess the effectiveness of animated and interactive maps, the allocation of visual attention, and the cognitive load associated with different tasks [10,11].

Roth [6] also points out that mobile maps should also be examined in terms of the speed of movement, as a cartographic generalization based only on the scale of the map display may not be sufficient for users on the move. This is because users in motion perceive a larger area of the map in a given period of time than with a static map. This suggests that not taking this aspect into account when designing a map can lead to users being overwhelmed by the amount of cartographic content.

In view of the above problems, the following research questions arise:

1. How does the frequency of smartphone usage impact users' efficiency and accuracy in locating symbols within diverse spatial contexts on mobile maps, and what are the potential cognitive mechanisms underlying this relationship?
2. To what extent does the average daily smartphone usage time moderate the outcomes of map-related tasks, specifically in terms of scanning speed and the detection of symbols?
3. What are the gender differences in pupil size during map-related tasks, how do these differences relate to variations in cognitive workload, and what insights do these differences provide into the potential cognitive demands of map-based activities for different genders?

The scientific goal of this study is to systematically investigate and analyze the factors influencing user performance in mobile-map-related tasks, with a specific focus on the detection of pictorial symbols in various spatial contexts during navigational tasks. Especially, we would like to reveal the potential cognitive mechanism or at least expose elements of it, such as characteristic eye movement features. This is possible thanks to the application of eye-tracking technology, which allows for the precise monitoring and analysis of users' eye movements and gaze patterns, helping to understand gaze duration, saccade patterns, and pupil dilation.

2. Related Work

Liao et al. [12], in their work on the differences in visual attention in pedestrian navigation when using 2D and 3D maps, found that there are serious difficulties in conducting research with an eye-tracking tool under field conditions. Internal conditions, on the other hand, provide users with a quiet and distraction-free environment, which also provides more control for the person conducting the experiment. Therefore, they decided to simulate field situations in a laboratory environment. The surveys conducted on the participants confirmed that it is possible to simulate a real indoor environment and thus test the effects of maps on pedestrian navigation. They also show that changes in stress on the human nervous system led to changes in pupil diameter. Therefore, it is possible to reliably determine the degree of cognitive load based on the change in pupil diameter [13].

As Cybulski et al. [14] note in their study, not accounting for individual differences in mobile device use and familiarity with mobile devices may have an impact on participants' outcomes and preferences. Therefore, it is useful to consider the average daily usage time of smartphones in studies on the effectiveness and correctness of locating symbols in different map contexts and to check whether there is any correlation.

The scanning speed, understood as the sequence of all fixations and saccades on the screen, is used to determine the users' scanning and visual performance. Al-Showarah et al. [15] compared the influence of age on smartphone/tablet use in an eye-tracking study. They found that younger users with more experience using a smartphone had shorter scanning times than older users with less experience. It is worth checking whether this correlation also exists in a more homogeneous age group of respondents who differ in their average daily usage time of mobile devices.

Motion simulation in mobile app recordings is similar to animated maps. As a result, similar problems occur, e.g., problems with the user retaining large amounts of information that appear in subsequent scenes [16]. Symbols appear on the screen, move and disappear, which can make it difficult to read the map. Therefore, eye-tracking research is of great value as it makes it possible to determine the way users view a map, which helps to explain the effectiveness and efficiency of the map.

Building upon Skaramagkas et al.'s [17] findings, it is essential to underscore that an enlarged pupil diameter could signify heightened engagement in cognitive or emotional processes. This observation aligns with the established literature suggesting that variations in pupil size are reflective of the intensity of mental and emotional activities [18]. In the specific context of map-reading tasks, where cognitive demands fluctuate based on factors such as task complexity, spatial information processing and user engagement, monitoring pupil dilation becomes a valuable metric for gauging the cognitive load or emotional involvement of individuals [19].

Usability testing for personalized user characteristics, such as age, gender or experience, has been proposed in various studies [1,20,21]. Scan path speed measured during cartographic tasks involving satellite images and presented through saccadic amplitude revealed more demanding scanning processes during the peripheral search in the study of Krejtz et al. [22]. Saccadic amplitude was also analyzed by Putto et al. [23] while participants were searching and selecting different geometrical objects based on elevation visualization, and in that study, the largest saccadic amplitude was observed for contour lines. Based on saccadic velocity, Kiefer et al. [24] were able to recognize participants' activities on a cartographic background.

Differences between males and females in map use were studied some time ago by Gilmartin and Patton [25]. Their findings concern children and adults in tasks such as route planning or symbol identification. The only differences found among children were that boys' performance was significantly better than girls. Montello et al. [26] presented differences between males and females in various map-based tasks. They showed that male participants were better at newly acquired spatial information, while female participants outperformed males in static object/location memory tasks. Spatial orientation in wayfinding tasks based on 3D maps was studied by Liao and Dong [27] in the context of sex differences. They found that male participants' fixation duration and fixation count distribution were more platykurtic than those of female participants.

3. Methodology

3.1. Materials

In our study, we decided to use the mobile app Mapy.cz. It is a Czech map service that allows you to use web maps. You can use it to view interactive maps, plan routes using various means of transportation and search for points and objects of interest. Another function is help with navigation for pedestrians and cars. The app focuses on the territory of the Czech Republic, but also extends to other countries in Europe and the world. Due to the display of many topographical details and access to hiking and cycling trails, it is often used for tourist purposes, especially in mountainous regions. The Mapy.cz service is owned by the Czech portal Seznam.cz and uses its own data as a reference database. Outside the Czech Republic and Slovakia, the maps are supplemented by data from OpenStreetMap. The app is characterized by cartographic symbols with a high degree of complexity.

As it is difficult to conduct eye-tracking studies in the field, the researchers decided to simulate urban navigation in a laboratory environment using smartphone screen recordings of a map application. This creates an environment that is free from external influences and allows users to focus on the task at hand. This ensures that there are no disturbances that could disturb the test subjects and hinder the recording of eye movements. This results in similar lighting conditions, which are important for the eye-tracking tool to work properly, and we also provide greater control for the person conducting the examination. An additional advantage of this method is that each user looks at the same set of recordings, which ensures better comparability of the data obtained.

Five one-minute videos recorded on a smartphone while using the app were used for the study. Each video consists of three fragments, each showing a different section of the route covered on foot (Figure 1). A part of the Old Town of Toruń was chosen as the study area. The factor that influenced the choice of this area is that this area is highly urbanized and rich in various objects represented with cartographic symbols. In a less urbanized area with a lower density of objects, the user would have fewer symbols to consider. The difficulty of the task would therefore be significantly lower. As a result, the process of scanning by sight would take less time, and the subject would have more time to look at the symbols more often and for longer. This could blur the differences in the users' visual strategy. Furthermore, this type of application is used much more frequently for navigation in urban areas. The routes were chosen so that different types of symbols were presented in different spatial situations. Some of the symbols were located on the street, while others were in the polygons marking the outlines of the buildings. The symbols varied in color and shape. During later processing, the recordings were accelerated and the interface was removed. Increasing the speed should improve the dynamics and smoothness of the recordings so that the user has the impression of being in motion. The degree of acceleration was chosen so that the movement appears natural. The app's interface was removed so as not to distract users from the cartographic content. In this way, we can be sure that the people being examined do not focus their eyes on elements that are not the subject of the examination.

Once the results of the study participants were collected, the mobile AOIs (Areas of Interest) had to be determined in order to obtain the quantitative data from the eye tracker required for the analysis. They are used to determine the time to first fixation on key elements of the task and to measure the number and duration of these fixations. For each video, an AOI was set on the relevant symbol. For the first, second and fourth questions, a single symbol represented the correct answer to the question asked. In the third question, the situation was different, as the question asked for the missing symbol that did not appear in the movie. In this case, three different AOIs were determined for the other symbols mentioned in the question; they were the wrong answers.

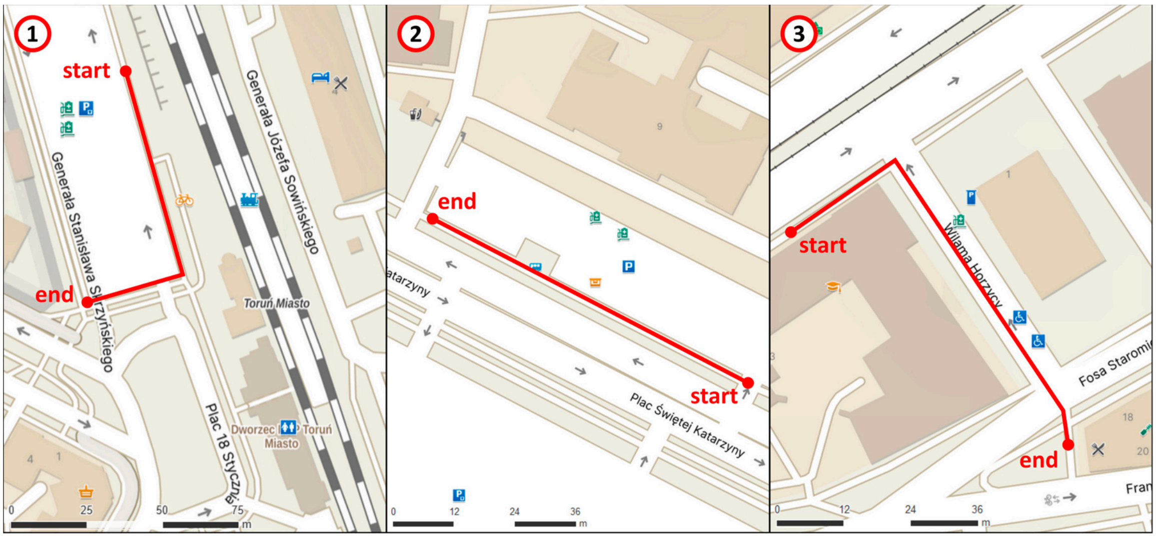

Figure 1. An exemplary compilation of three fragments of the route that make up one of the videos.

3.2. Participants

In total, 58 people (40 men and 18 women) with an average age of 21.39 years (SD = 3.42 years) took part in the experiment. The participants were mainly students at the Adam Mickiewicz University in Poznań. A total of 20 participants knew about and had used Mapy.cz before participating in the study, but all of them had experience with map apps on smartphones and used a smartphone for an average of 4 h 37.4 min per day (SD = 2 h 2 min). None of the respondents recognized the area (routes) where the videos were recorded. In terms of physical condition, none of the participants suffered from eye diseases or color vision disorders. The study complied with the applicable regulations of the Ethics Committee of the Adam Mickiewicz University (non-invasive observation with equipment) and did not require additional consent. All participants took part in the experiment voluntarily and were assured of anonymous data collection.

3.3. Apparatus

A Gazepoint GP3 HD eye tracker with a sampling rate of 150 Hz was used to collect data related to eye tracking. Calibration was performed using the 5-point method. The accuracy of the viewing angle of the eye tracker was 0.5°. The cell phone used to display the downloaded videos was a Samsung Galaxy M22 with a 6.4-inch screen. It was placed on a stand to prevent the display from moving (Figure 2). The average distance between the participants' eyes and the eye tracker was approximately 61.3 cm (SD = 2 cm). In light of prior cartographic research, encompassing studies that have validated the appropriateness of low-cost eye-tracking equipment [28,29], the choice of a 150 Hz sampling frequency with a spatial accuracy of 0.5 degrees can be deemed sufficient for conducting scientific experiments involving the display of symbols on mobile devices.

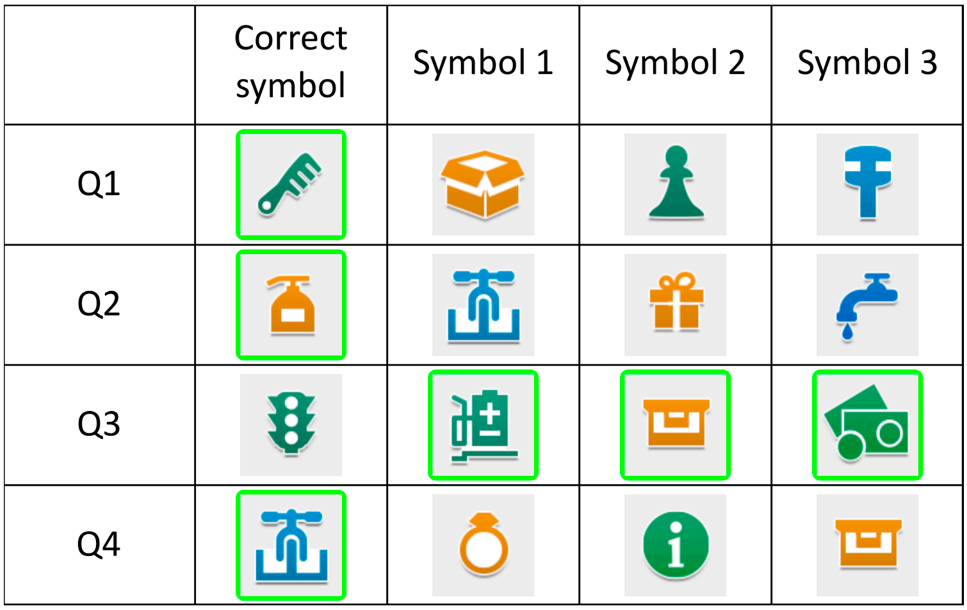

Figure 2. A compilation of symbols that provide possible answers to questions about the videos. The symbols for which the AOI has been determined are marked with a green frame.

3.4. Procedure

The experimental procedure began with an explanation of the purpose of the study. The participants were told which elements of the map were crucial for the study. The next step was to perform a calibration with an eye tracker. The participants then went through an introductory question to familiarize themselves with the structure of the study (video and question) and could ask a question if they had any doubts. Once they had familiarized themselves with the structure of the study, the participants moved on to the actual study. They watched four videos, each of which was followed by the questions listed below in the following order:

Q1—Which of these symbols appeared in the video?
Q2—Which of these symbols was in the building?
Q3—Which of these symbols did not appear in the video?
Q4—Which of these symbols was not in the building?

There were four possible answers for each question, which were represented in the form of symbols (Figure 2). The participants gave oral answers to each question. The aim of these questions was to check whether the respondent could remember certain symbols and whether they could correctly read the spatial relations between them and the underlying objects in exemplary map contexts.

After watching the videos and answering the questions, the experimenter asked all participants about the following:

(a) How readable do you think the map was?
(b) How comprehensible do you think the symbols on the map were?
(c) Was there anything you found particularly difficult when using the map?
(d) Which mobile map applications do you use?
(e) Are you familiar with the Mapy.cz application?
(f) How often do you use navigation applications on your smartphone?
(g) What is your average daily smartphone usage time per week?

The interview was well structured, and the participants answered the prepared questions. These questions were used to collect qualitative data on the subjective assessment of the map and to divide the participants into groups.

3.5. Analysis

We obtained three types of data that needed to be further processed and analyzed. These data included data collected with the Gazepoint GP3 HD eye tracker, quantitative response data and qualitative interview data. The eye-tracking data were divided into the following: related to the AOI (symbol or symbols) or related to the whole video. Before discussing the stages of analysis, we felt it necessary to describe the individual elements included in each group of data.

3.5.1. Eye Tracking Data Associated with the AOI

The eye tracking data retrieved from the Gazepoint GP3 HD eye tracker consist of a time series of multiple gaze points. In the context of the AOI-related data, we identified the following parameters:

- Time until the main task element is perceived (AOI; in s)—This is the time until the first fixation for the specified AOI. This allows us to determine how quickly the respondent unconsciously or consciously perceived a key element for the task.
- Fixation duration in AOI (in s)—This is the total time of all fixations for the specified AOI. This allows us to determine how much time the respondent had to decode the symbol during the video. A higher value may reflect a lower level of cognitive processing [30].
- Number of fixations in the AOI (counts)—This is the total number of fixations in the AOI. This allows us to determine how many times the respondent looked at the AOI while processing information from the video.

In the context of analyzing eye-tracking data for areas of interest (AOIs), we focused on fixations. The metrics we selected are considered markers for visual searches when reading maps [31,32] and support the analysis of users' visual experience [14].

3.5.2. Eye-Tracking Data for the Entire Video

When it comes to the cognitive processing of maps and symbols in particular, the overall spatial context is also important. Therefore, the authors have defined parameters that are important for visual searches as well as for individual videos:

- The average duration of fixation (in s) is the arithmetic mean of all fixation durations. As with the fixation duration in AOIs, the longer the value, the more time respondents spent decoding map elements, which may reflect a deeper level of cognitive processing [30].
- The total fixation count is the total number of fixations for a particular video. This allows us to determine how many times the respondent has stopped their eyes on an element while watching it.
- The mean amplitude of the saccades (in °) is the average amplitude of all saccades, i.e., the range of the participants' visual exploration [33].
- The average scan rate (°/s) is the ratio between the length of the saccade connecting the end of one fixation to the beginning of the second fixation and the time difference between the beginning of one fixation and the end of the other.
- The average pupil diameter (in mm) can be equated with the cognitive load when absorbing and remembering spatial information from movies. Studies have shown that cognitive load can be reliably reflected in changes in pupil size [13,34].

3.5.3. Response Data

The process of acquiring and storing spatial knowledge can be confronted with questions about the visual stimulus under consideration. Specifically, these are the following metrics:

- Response time (in s)—This is the time from the moment the question appears to the verbal articulation of the answer by the respondent. It reflects the process of searching for stored spatial information. In addition, this time can also be combined with measures of effectiveness and productivity [10,35].

- Correctness of the answers (in % for all questions, and 0/1 for individual questions)—This is the ratio between the correct answers and the number of questions. It illustrates the correctness of the process of searching for remembered spatial information [36].

Since not all selected parameters were normally distributed, we used the Mann–Whitney U (for two groups), ANOVA and Kruskal–Wallis (more than two groups), and Spearman's rho (two numbers) to test for statistical significance.

4. Results

We decided to divide the results according to the questions asked in the last part of the study, i.e., after watching the videos, excluding the following questions: was there anything you found particularly difficult when using the map, and which mobile map applications do you use? These questions were open-ended and did not form any groups for statistical analysis.

4.1. Are You Familiar with the Mapy.cz Application?

In total, 20 participants in the study stated that they were familiar with the Mapy.cz application, which was reflected in the following results regarding the correctness and speed of responses (Table 1).

Table 1. Correctness and response time divided into people who declared and did not declare knowledge of the Mapy.cz application.

	Q1		Q2		Q3		Q4	
Mapy.cz	**Correctness (%)**	**Response Time (s)**	**Correctness (%)**	**Response Time (s)**	**Correctness (%)**	**Response Time (s)**	**Correctness (%)**	**Response Time (s)**
Known	85	5.285 (5.719)	20	9.625 (6.35)	68.4	7.18 (4.75)	63.16	6.925 (2.58)
Unknown	92.1	4.825 (1.70)	28.9	7.92 (7.81)	89.5	6.125 (4.183)	73.7	5.935 (3.428)

The statistical analysis yielded the following statistical results:

- Q3—People who are familiar with the Mapy.cz application give statistically significantly fewer correct answers to question 3 ($p < 0.05$ *);
- Q3—People who are familiar with the Mapy.cz application give statistically significantly slower answers to question 3 ($p < 0.05$ *);
- General correctness—People who are familiar with the Mapy.cz application answer all questions less correctly ($p < 0.05$ *);
- Average response time—People who are familiar with the Mapy.cz application answer all questions more slowly on average ($p < 0.05$ *).

Statistically significant results on the timing and correctness of responses in relation to knowledge of the Mapy.cz application for Q3 are shown in the following figure (Figure 3).

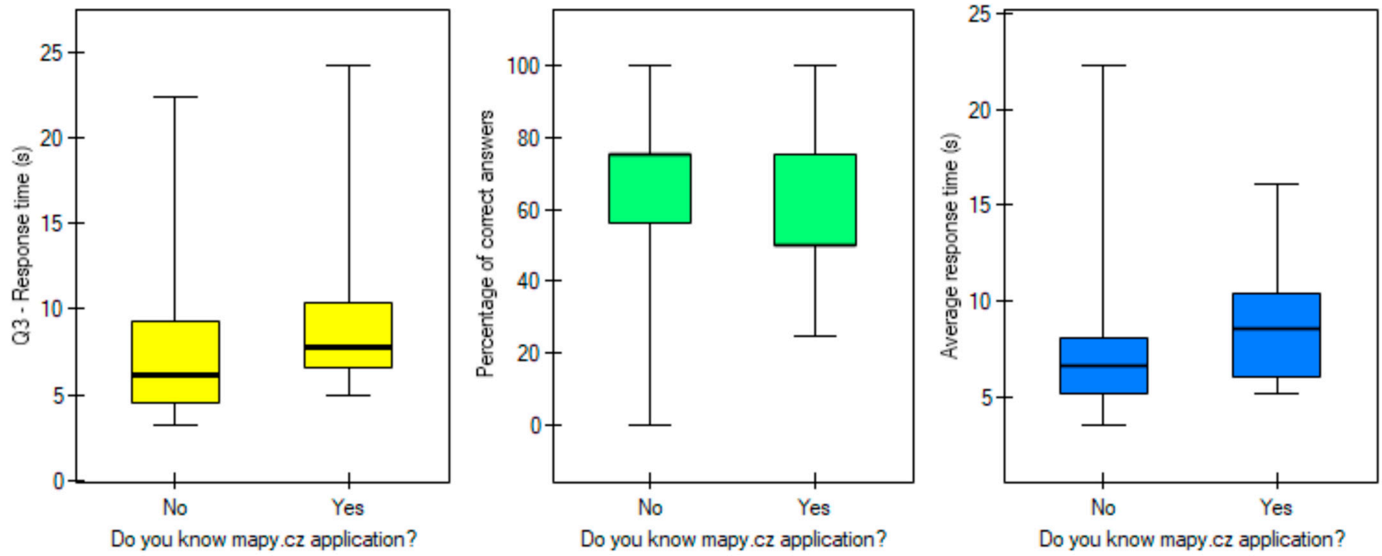

Figure 3. Statistically significant results for the response time (Q3), the percentage of correct answers and the average response time depending on familiarity with the application Mapy.cz.

- Q4—People who are familiar with the Mapy.cz app have a statistically longer average saccade when watching video number 4 ($p < 0.05$);
- Q3 Symbol 2—People familiar with the Mapy.cz application were statistically quicker to notice Symbol 2 in the video ($p < 0.05$);
- Q3 Symbol 3—People familiar with the Mapy.cz application were statistically quicker to notice Symbol 3 in the video ($p < 0.05$ *).

Statistically significant results regarding the mean saccade length and the time to first fixation in relation to the participants' knowledge of the Mapy.cz application are shown in the following figure (Figure 4).

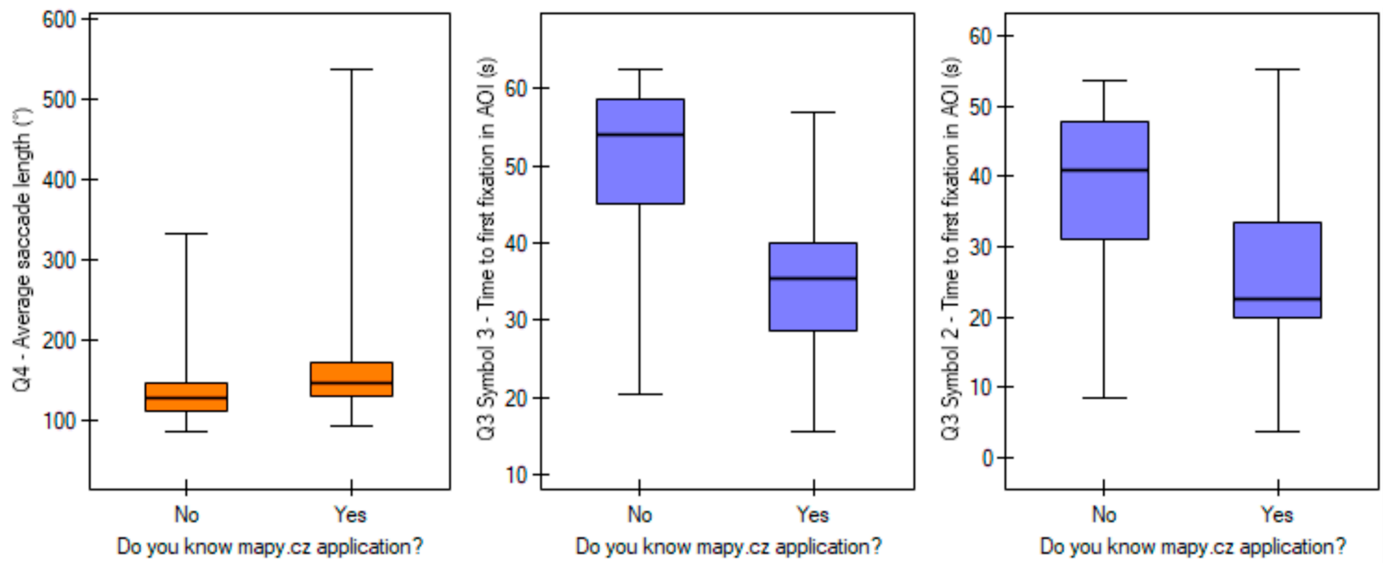

Figure 4. Statistically significant results for average saccade length (Q4) and time to first fixation in the AOI (Q3 Symbol 2 and 3) in relation to knowledge of Mapy.cz application.

4.2. What Is Your Average Daily Smartphone Usage Time per Week?

Participants reported using their smartphone for an average of 4 h and 37.4 min per day (SD = 2 h and 2 min). These results were collected directly from the respondents' devices. All respondents were able to indicate their average daily smartphone usage time based on the settings (e.g., Android and iOS's digital wellbeing feature). Statistically significant correlations with this information were found in the following cases:

- Q4—The longer the average daily time spent on the smartphone, the later the correct symbol in question 4 was noticed ($p < 0.05$, r = 0.324934). This correlation is also shown in the following figure (Figure 5).
- Q3—The longer the average daily time spent on the smartphone, the longer the average scanning speed when watching movie 3 ($p < 0.05$, r = 0.329498).

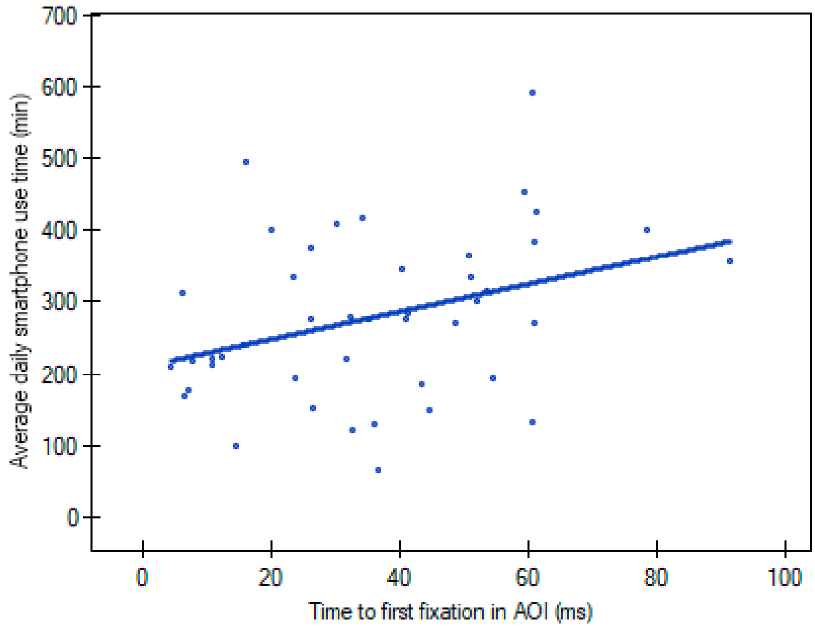

Figure 5. The mean correlation (r = 0.324934) between average daily smartphone usage time and time to first fixation in the AOI (Q4).

4.3. How Often Do You Use Navigation Applications Your Smartphone?

Regarding the frequency of the use of navigation applications on their smartphone, respondents answered as follows: every day—21; once a week—32; and once a month or less often—5. Statistical results observed between these groups include the following:

- Q2—People who stated that they use navigation applications on their smartphone every day were statistically more likely to give the correct answer to question 2 ($p < 0.05$);
- Q2—People who say they use navigation applications on a smartphone every day statistically looked at the correct symbol for less time (AOI) ($p < 0.05$);
- Q3 Symbol 1—People who stated that they used smartphone navigation once a month or less often looked at symbol 1 (AOI) for a shorter time ($p < 0.05$).

The differences between the total AOI observation time for Q2 and Q3 Symbol 1 in terms of the usage frequency of navigation applications on a smartphone are shown in the following figure (Figure 6).

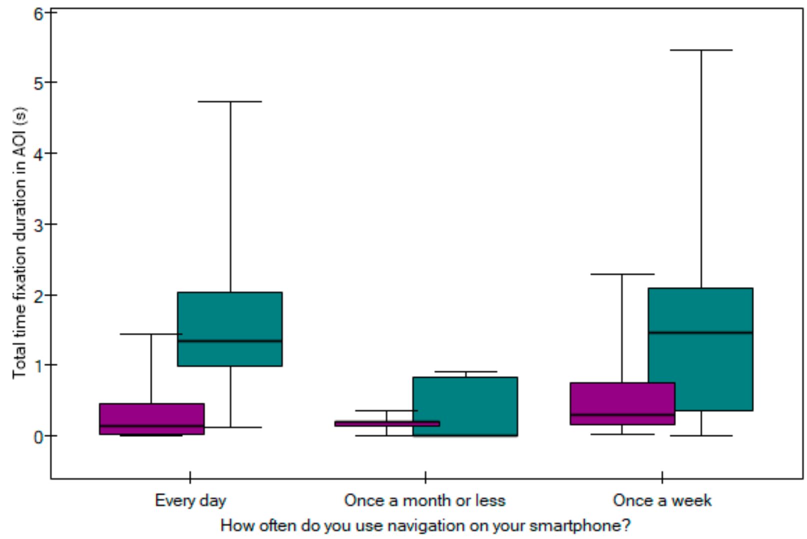

Figure 6. Differences between the groups in the total fixation time duration in the AOI for Q2 (purple) and Q3 Symbol 1 (green).

4.4. How Readable Do You Think the Map Is?

Respondents answered the above question as follows: very readable—5; well readable—44; moderately readable—7; and poorly readable—2. None of the study participants described the map as very poorly readable. Despite the significant feedback that the maps are easy to read, we observed the following statistically significant results:

- Q3 Symbol 3—People who describe the map as poorly readable statistically look longer at Symbol 3 in task 3 ($p < 0.05$);
- Q3 Symbol 3—People who describe the map as poorly readable statistically look at Symbol 3 more often in task 3 ($p < 0.05$);
- Q3 Symbol 2—people who describe the map as well and moderately readable statistically later notice symbol 2 in task 3 ($p < 0.05$).

The differences between the time to first fixation on the AOI in relation to the subjective assessment of the readability of the map for Q3 Symbol 2 are shown in the following figure (Figure 7).

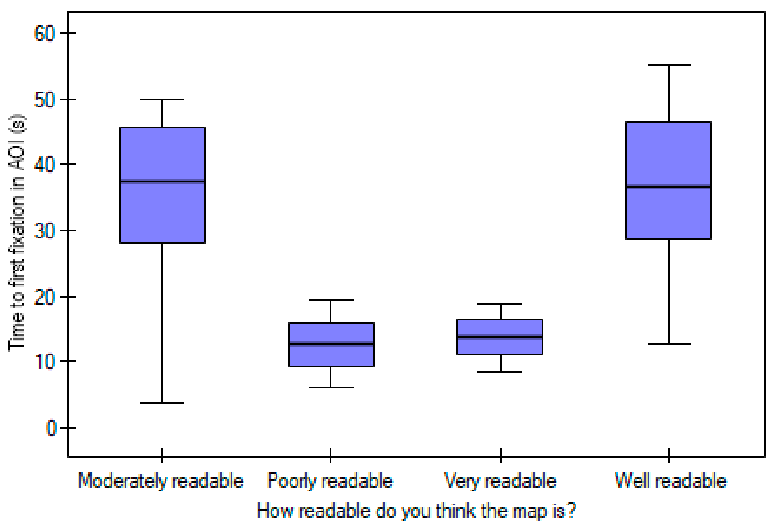

Figure 7. Differences between the groups with regard to the time to first fixation in the AOI for Q3 Symbol 2.

In addition, it was examined whether there are relationships between the answers to the question: How comprehensible do you think the symbols on the map are? Unfortunately, no statistically significant result was found for these data. An interesting correlation was found when assessing the differences between men and women, namely that women had a larger average pupil diameter than men when watching all the movies ($p < 0.005$) (Figure 8).

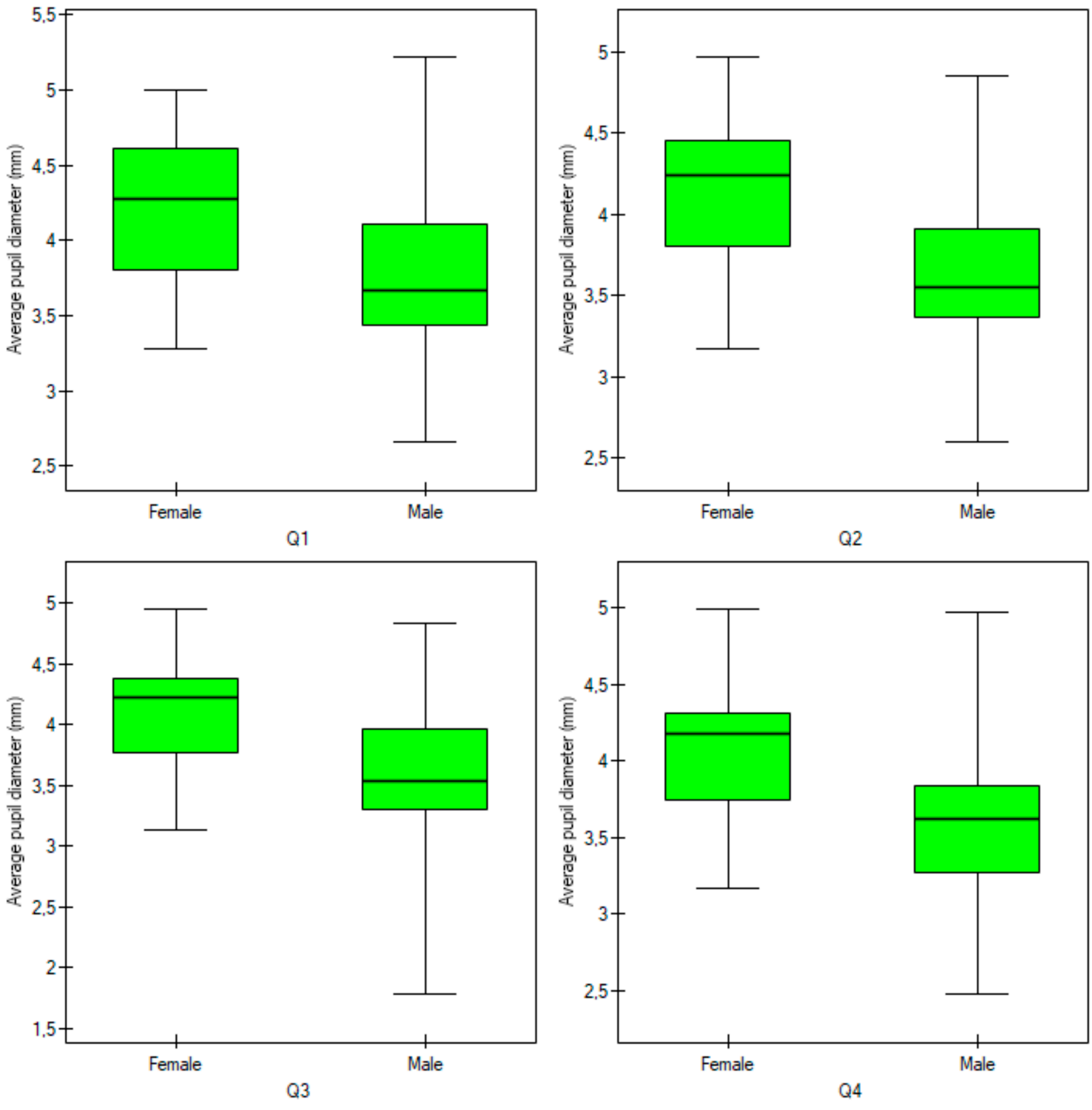

Figure 8. Differences in average pupil diameter for female and male during tasks.

5. Discussion

In general, the participants faced tasks of varying difficulty levels. The most challenging task involved locating a point situated inside a building. This observation suggests that users utilizing navigation applications in this scenario may not have anticipated the need to focus on interior details, as the video depicted a person moving outside the building. The complexity of the task highlights potential user expectations and the significance of contextual factors in influencing navigation behavior. This observation aligns, to some extent, with the overarching principles of visual theory. The context in which a user operates and the visual information presented on the map during navigation prove to be of significant importance. This finding resonates with insights from psychological research, where the search for an element within its natural context is known to enhance the ease of identification [37].

The frequency of smartphone usage proved to be a noteworthy factor impacting the search for a symbol situated outside its contextual setting, particularly within a building. Participants who reported daily smartphone use exhibited a notably higher likelihood of providing the correct answer in this context. Additionally, their eye-tracking data indicated a shorter fixation time on the correct symbol, suggesting a more efficient visual processing mechanism among individuals engaging in daily smartphone use. This observation suggests a potential link between habitual smartphone use and enhanced effectiveness in tasks involving locating symbols within diverse spatial contexts. This suggests that individuals with daily smartphone use are more adept at navigating and interpreting digital maps [38], particularly when confronted with symbols situated within buildings.

When asked about an absent symbol on the map, individuals who characterize the map as having poor legibility statistically exhibited prolonged gaze durations and more frequent gazes at symbols that were present. This suggests a correlation between perceived map legibility and users' visual engagement with symbols [39]. The extended and frequent gaze patterns observed in individuals dissatisfied with the map's legibility imply that they may be exerting additional cognitive effort in deciphering symbols due to perceived challenges in map readability.

Question number 4 extended beyond the immediate context, requiring participants to identify, after watching the movie, the symbol that was not situated within a building. Although the inquiry posed to users pertains partially to elements outside the contextual setting, the sense of the question focuses on the symbols present on the map within the context of the moving user [40]. Despite its apparent deviation from the immediate context, the question maintained a success score above 60%.

The most straightforward task in the research involved locating a symbol positioned on the map, irrespective of any contextual inquiries related to the symbol. Due to its simplicity, this task is likely to be the easiest for users. This observation aligns with the notion that tasks requiring the mere identification of a symbol's location on a mobile map, without the added complexity of contextual considerations or multiple-feature symbols, tend to be more effective [14].

Longer saccades in users familiar with the map application may indicate a lower utilization of cognitive resources. This suggests that processing activity is reduced [41]; however, it is considered a common trait among more novice users whose search spans the entire image, resulting in a less organized approach. On the other hand, experts who exhibit shorter saccades engage in a more targeted search, moving from one focal point to the next, which are closely situated on the map. Consequently, this leads to a less chaotic search pattern [42]. Moreover, the quicker responses from participants unfamiliar with mapy.cz might suggest less successful users; however, their higher success rate contradicts this assumption [43]. The key parameter here would be to assess the level of knowledge of the content of Mapy.cz.

The study also observed that a parameter such as the average daily smartphone usage time moderately impacts the outcomes during map observation in two tasks. Smartphone usage for a prolonged duration influenced the delayed detection of the symbols' relation to the feature of building, while concurrently accelerating scanning speed during the observation of movie number 3. Despite the moderate correlation of this relationship, it aligns with the findings of [15], suggesting that more experienced users who use smartphones more frequently tend to have faster scanning times.

Significant differences in pupil size were observed between women and men during the study. The findings revealed that, across all films, women exhibited a significantly larger pupil diameter compared to men. Pupillary responses, including alterations in pupil size, have been linked to fluctuations in mental workload during information processing. Numerous studies have employed pupil size as an indicator of users' cognitive load in map-based task [12,19]. Drawing upon research, such as Liao et al.'s [44] work on map reading and tracking, the observed differences may suggest that for women, the task at hand was more cognitively demanding. For future investigations, a user-centered design approach can be integrated into the study design, especially when considering maps for mobile devices [45–47]. Due to the fact that the size of the pupil is determined by physiological as well as emotional factors [17], there are potential research paths using EEG (electroencephalography) that could integrate biometric user factors in the context of changing cartographic content [48].

6. Conclusions

This study discusses the widespread use of mobile map applications for navigation, emphasizing their popularity due to the ubiquity of smartphones and the convenience of real-time geospatial information. Mobile maps offer users the ability to browse, search for locations and plan routes, with the added advantage of real-time user positioning; however, challenges such as the correct interpretation of map symbols and the importance of visual design in maintaining user engagement are acknowledged. The design should consider the smaller screens on mobile devices. Eye-tracking tools are proposed as valuable instruments for usability studies of cartographic products, enabling the assessment of users' visual strategies and their ability to recall information; however, it is worth remembering the limitations of this study, which include the selection of the sample and the specificity of the selected map application.

This research delves into specific findings related to users' performance in map-related tasks and addresses posed research questions. Firstly, it acknowledges the impact of habitual smartphone usage on users' efficiency and accuracy in locating symbols within diverse spatial contexts on mobile maps. This study reveals that frequent smartphone use significantly enhances users' performance in these tasks, suggesting a link between usage habits and improved cognitive processing during map-related activities, as suggested by Meng [49].

Secondly, this research explores the correlation between average daily smartphone usage time and task outcomes, specifically in terms of scanning speed and symbol detection. The findings demonstrate a moderate correlation, indicating that increased smartphone usage is associated with improved performance in map-related tasks. This aligns with the broader literature on usability testing for personalized user characteristics, where factors such as saccadic amplitude or fixation count [23,24] play crucial roles in influencing user performance during cartographic tasks.

Finally, this study delves into sex differences in pupil size during map-related tasks and examines their relationship with variations in cognitive workload. The consistent observation of larger pupil diameters in women suggests a higher cognitive workload for female participants during map-related activities. This insight adds to the existing knowledge on sex differences in map use, as demonstrated in prior research by Gilmartin and Patton [25], Montello et al. [26] and Liao and Dong [27]. These studies highlight the role of sex differences in influencing performance aspects such as spatial information acquisition and symbol identification on mobile device. The incorporation of these findings enriches our understanding of the cognitive demands associated with map-based activities.

The participant selection process, which resulted in 40 men and 18 women, lacks equal gender representation, potentially introducing a gender-related bias into this study's results. This imbalance may limit the generalizability of our findings. Addressing this limitation, future research endeavors should strive for a more balanced and representative participant composition to ensure the broader applicability of the study's outcomes.

This research significantly advances our understanding of map-reading tasks by providing valuable insights into how smartphone usage frequency influences users' efficiency and accuracy. This information is crucial for designing user-friendly map applications that consider users' habits and enhance navigational skills. By exploring the cognitive mechanisms underlying the relationship between smartphone usage and map-related tasks, the study sheds light on the mental processes involved. Additionally, the identification of gender differences in pupil size contributes to our understanding of the cognitive demands of map-based activities for men and women.

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References

1. Sarjakoski, L.T.; Nivala, A.M. Adaptation to Context—A Way to Improve the Usability of Mobile Maps. In *Map-Based Mobile Services*; Meng, L., Reichenbacher, T., Zipf, A., Eds.; Springer: Berlin, Germany, 2005. [CrossRef]
2. Ricker, B.; Hedley, N.; Daniel, S. Fuzzy boundaries: Hybridizing Location-based Services, Volunteered Geographic Information and Geovisualization Literature. *Geogr. Compass* **2014**, *8*, 490–504. [CrossRef]
3. Medynska-Gulij, B. Point Symbols: Investigating Principles and Originality in Cartographic Design. *Cartogr. J.* **2008**, *45*, 62–67. [CrossRef]
4. van Tonder, B.; Wesson, J. Design and Evaluation of an Adaptive Mobile Map-Based Visualisation System. In *Human-Computer Interaction—INTERACT 2009*; Lecture Notes in Computer Science 2009; Gross, T., Gulliksen, J., Kotzé, P., Oestreicher, L., Palanque, P., Prates, R.O., Winckler, M., Eds.; Springer: Berlin/Heidelberg, Germany, 2009; Volume 5726. [CrossRef]
5. Robinson, A.C.; Pezanowski, S.; Troedson, S.; Bianchetti, R.; Blanford, J.; Stevens, J.; Guidero, E.; Roth, R.; MacEachren, A.M. Symbol Store: Sharing map symbols for emergency management. *Cartogr. Geogr. Inf. Sci.* **2013**, *40*, 415–426. [CrossRef]
6. Roth, R. What is Mobile First Cartographic Design? In *ICA Joint Workshop on User Experience Design for Mobile Cartography*; International Cartographic Association: Bern, Switzerland, 2019.
7. Krassanakis, V.; Cybulski, P. Eye Tracking Research in Cartography: Looking into the Future. *ISPRS Int. J. Geo-Inf.* **2021**, *10*, 411. [CrossRef]
8. Krassanakis, V.; Cybulski, P. A review on eye movement analysis in map reading process: The status of the last decade. *Geod. Cartogr.* **2019**, *68*, 191–209. [CrossRef]
9. Goldberg, J.H.; Wichansky, A.M. Eye Tracking in Usability Evaluation: A Practitioner's Guide. In *The Mind's Eye*; Hyönä, J., Radach, R., Deubel, H., Eds.; Elsevier: Amsterdam, The Netherlands, 2003; Volume 200, pp. 493–516. [CrossRef]
10. Çöltekin, A.; Heil, B.; Garlandini, S.; Fabrikant, S.I. Evaluating the Effectiveness of Interactive Map Interface Designs: A Case Study Integrating Usability Metrics with Eye-Movement Analysis. *Cartogr. Geogr. Inf. Sci.* **2009**, *36*, 5–17. [CrossRef]
11. Dong, W.; Liao, H.; Xu, F.; Liu, Z.; Zhang, S.B. Using eye tracking to evaluate the usability of animated maps. *Sci. China Earth Sci.* **2014**, *57*, 512–522. [CrossRef]
12. Liao, H.; Dong, W.; Peng, C.; Liu, H. Exploring differences of visual attention in pedestrian navigation when using 2D maps and 3D geo-browsers. *Cartogr. Geogr. Inf. Sci.* **2017**, *44*, 474–490. [CrossRef]
13. Smerecnik, C.; Mesters, I.; Kessels, L.; Ruiter, R.; Vries, N.; de Vries, H. Understanding the positive effects of graphical risk information on comprehension: Measuring attention directed to written, tabular, and graphical risk information. *Risk Anal.* **2010**, *30*, 1387–1398. [CrossRef] [PubMed]
14. Cybulski, P.; Medyńska-Gulij, B.; Horbiński, T. Users' Visual Experience During Temporal Navigation in Forecast Weather Maps on Mobile Devices. *J. Geovis Spat. Anal.* **2023**, *7*, 32. [CrossRef]
15. Al-Showarah, S.; AL-Jawad, N.; Sellahewa, H. Effects of User Age on Smartphone and Tablet Use, Measured with an Eye-Tracker via Fixation Duration, Scan-Path Duration, and Saccades Proportion. In *Universal Access in Human-Computer Interaction. Universal Access to Information and Knowledge, Proceedings of the 17th International Conference of UAHCI 2023 and HCII 2023, Copenhagen, Denmark, 23–28 July 2023*; Lecture Notes in Computer, Science; Stephanidis, C., Antona, M., Eds.; Springer: Cham, Switzerland, 2023; Volume 8514, pp. 3–14. [CrossRef]
16. Cybulski, P. Effectiveness of Memorizing an Animated Route—Comparing Satellite and Road Map Differences in the Eye-Tracking Study. *ISPRS Int. J. Geo-Inf.* **2021**, *10*, 159. [CrossRef]

17. Skaramagkas, V.; Giannakakis, G.; Ktistakis, E.; Manousos, D.; Karatzanis, I.; Tachos, N.S.; Tripoliti, E.; Marias, K.; Fotiadis, D.I.; Tsiknakis, M. Review of Eye Tracking Metrics Involved in Emotional and Cognitive Processes. *IEEE Rev. Biomed. Eng.* **2021**, *16*, 260–277. [CrossRef] [PubMed]
18. Foroughi, C.K.; Sibley, C.; Coyne, J.T. Pupil size as a measure of within-task learning. *Psychophysiology* **2017**, *54*, 1436–1443. [CrossRef]
19. Kiefer, P.; Giannopoulos, I.; Duchowski, A.; Raubal, M. Measuring Cognitive Load for Map Tasks Through Pupil Diameter. In Proceedings of the 9th International Conference on Geographic Information Science, Montreal, QC, Canada, 27–30 September 2016; Miller, J., O'Sullivan, D., Wiegand, N., Eds.; Springer: Cham, Switzerland, 2016; Volume 9927. [CrossRef]
20. Griffin, A.L.; White, T.; Fish, C.; Tomio, B.; Huang, H.; Sluter, C.R.; Bravo, J.V.M.; Fabrikant, S.I.; Bleisch, S.; Yamada, M.; et al. Designing across map use contexts: A research agenda. *Int. J. Cartogr.* **2017**, *3*, 90–114. [CrossRef]
21. Montello, D.R. Cognitive Map-Design Research in the Twentieth Century: Theoretical and Empirical Approaches. *Cartogr. Geogr. Inf. Sci.* **2002**, *29*, 283–304. [CrossRef]
22. Krejtz, K.; Çöltekin, A.; Duchowski, A.; Niedzielska, A. Using Coefficient to Distinguish Ambient/Focal Visual Attention During Cartographic Tasks. *J. Eye Mov. Res.* **2017**, *10*, 1–13. [CrossRef]
23. Putto, K.; Kettunene, P.; Torniainen, J.; Krause, C.M.; Sarjakoski, L.T. Effects of Cartogrpahic Elevation Visualization and Map-reading Tasks on Eye Movements. *Cartogr. J.* **2014**, *51*, 225–236. [CrossRef]
24. Kiefer, P.; Giannopoulos, I.; Raubal, M. Using eye movements to recognize activities on cartographic maps. In Proceedings of the 21st ACM SIGSPATIAL International Conference on Advances in Geographic Information Systems, Orlando, FL, USA, 5–8 November 2013; pp. 488–491. [CrossRef]
25. Gilmartin, P.P.; Patton, J.C. Comparing the Sexes on Spatial Abilities: Map-Use Skills. *Ann. Assoc. Am. Geogr.* **1984**, *74*, 605–619. [CrossRef]
26. Montello, D.R.; Lovelace, K.L.; Golledge, R.G.; Self, C.M. Sex-Related Differences and Similarities in Geographic and Environmental Spatial Abilities. *Ann. Assoc. Am. Geogr.* **1999**, *89*, 515–534. [CrossRef]
27. Liao, H.; Dong, W. An Exploratory Study Investigating Gender Effects on Using 3D Maps for Spatial Orientation in Wayfinding. *ISPRS Int. J. Geo-Inf.* **2017**, *6*, 60. [CrossRef]
28. Ooms, K.; Dupont, L.; Lapon, L.; Popelka, S. Accuracy and Precision of Fixation Locations Recorded with the Low-Cost Eye Tribe Tracker in Different Experimental Setups. *J. Eye Mov. Res.* **2015**, *8*, 1–24. [CrossRef]
29. Ooms, K.; Krassanakis, V. Measuring the Spatial Noise of a Low-Cost Eye Tracker to Enhance Fixation Detection. *J. Imaging* **2018**, *4*, 96. [CrossRef]
30. Just, M.A.; Carpenter, P.A. Eye fixations and cognitive processes. *Cogn. Psychol.* **1976**, *8*, 441–480. [CrossRef]
31. Lloyd, R.E. Visual search processes used in map reading. *Cartographica* **1997**, *34*, 11–32. [CrossRef]
32. Lloyd, R.E. Attention on maps. *Cart. Perspect.* **2005**, *52*, 28–57. [CrossRef]
33. Dong, W.; Wu, Y.; Qin, T.; Bian, X.; Zhao, Y.; He, Y.; Xu, Y.; Yu, C. What is the difference between augmented reality and 2D navigation electronic maps in pedestrian wayfinding? *Cartogr. Geogr. Inf. Sci.* **2021**, *48*, 225–240. [CrossRef]
34. Backs, R.W.; Walrath, L.C. Eye movement and pupillary response indices of mental workload during visual search of symbolic displays. *Appl. Ergon.* **1992**, *23*, 243–254. [CrossRef] [PubMed]
35. Garlandini, S.; Fabrikant, S.I. Evaluating the efectiveness and efciency of visual variables for geographic information visualization. In *Spatial Information Theory*; Hornsby, K.S., Claramunt, C., Denis, M., Ligozat, G., Eds.; Springer: Berlin, Germany, 2009; p. 5756. [CrossRef]
36. Horbiński, T.; Zagata, K. The Cognitive Skills in Interpretation of Spatial Situations in the League of Legends game. *Simul. Gaming* **2023**, *54*, 322–347. [CrossRef]
37. Wolfe, J.M. Visual Search: How Do We Find What We Are Looking For? *Annu. Rev. Vis. Sci.* **2020**, *6*, 539–562. [CrossRef]
38. Gottwald, S.; Laatikainen, T.E.; Kyttä, M. Exploring the usability of PPGIS among older adults: Challenges and opportunities. *Int. J. Geogr. Inf. Sci.* **2016**, *30*, 2321–2338. [CrossRef]
39. Ahmadpoor, N.; Smith, A.D.; Heath, T. Rethinking legibility in the era of digital mobile maps: An empirical study. *J. Urban Des.* **2021**, *26*, 296–318. [CrossRef]
40. Neider, M.B.; Zelinsky, G.J. Scene context guides eye movements during visual search. *Vis. Res.* **2006**, *45*, 614–621. [CrossRef] [PubMed]
41. Popelka, S.; Brychtova, A.; Brus, J.; Voženílek, V. Advanced Map Optimalization Based on Eye-Tracking. In *Cartography—A Tool for Spatial Analysis*; Bateira, C., Ed.; IntechOpen: London, UK, 2012. [CrossRef]
42. Keskin, M.; Ooms, K.; Dogru, A.O.; De Maeyer, P. Exploring the Cognitive Load of Expert and Novice Map Users Using EEG and Eye Tracking. *ISPRS Int. J. Geo-Inf.* **2020**, *9*, 429. [CrossRef]
43. Havelková, L.; Gołębiowska, I.M. What Went Wrong for Bad Solvers during Thematic Map Analysis? Lessons learned from an eye-tracking study. *ISPRS Int. J. Geo-Inf.* **2020**, *9*, 9. [CrossRef]
44. Liao, H.; Wang, X.; Dong, W.; Meng, L. Measuring the influence of map label density on perceived complexity: A user study using eye tracking. *Cartogr. Geogr. Inf. Sci.* **2019**, *46*, 210–227. [CrossRef]
45. Bartling, M.; Resch, B.; Reichenbacher, T.; Havas, C.R.; Robinson, A.C.; Fabrikant, S.I.; Blaschke, T. Adapting mobile map application design to map use context: A review and call for action on potential future research themes. *Cartogr. Geogr. Inf. Sci.* **2022**, *49*, 237–251. [CrossRef]

46. Dillemuth, J. Map Design Evaluation for Mobile Display. *Cartogr. Geogr. Inf. Sci.* **2005**, *32*, 285–301. [CrossRef]
47. Nivala, A.M.; Sarjakoski, T.L. User Aspects of Adaptive Visualization for Mobile Maps. *Cartogr. Geogr. Inf. Sci.* **2007**, *34*, 275–284. [CrossRef]
48. Keskin, M.; Ooms, K. Possibilities of eye tracking and EEG integration for visual search on 2D maps. In Proceedings of the 3rd International Workshop on Eye Tracking for Spatial Research, Zurich, Switzerland, 14 January 2018. [CrossRef]
49. Meng, L. Missing Theories and Methods in Digital Cartography. In Proceedings of the 21st International Cartographic Conference, Durban, South Africa, 10–16 August 2003; Available online: https://icaci.org/files/documents/ICC_proceedings/ICC2003/Papers/244.pdf (accessed on 18 January 2024).