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Using Eye Tracking to Explore Differences in Map-Based Spatial Ability between Geographers and Non-Geographers

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Abstract: In this article, we use eye-tracking methods to analyze the differences in spatial ability between geographers and non-geographers regarding topographic maps, as reflected in the following three aspects: map-based spatial localization, map-based spatial orientation, and map-based spatial visualization. We recruited 32 students from Beijing Normal University (BNU) and divided them into groups of geographers and non-geographers based on their major. In terms of their spatial localization ability, geographers had shorter response times, higher fixation frequencies, and fewer saccades than non-geographers, and the differences were significant. For their spatial orientation ability, compared to non-geographers, geographers had significantly lower response times, lower fixation counts and fewer saccades as well as significantly higher fixation frequencies. In terms of their spatial visualization ability, geographers' response times were significantly shorter than those of non-geographers, but there was no significant difference between the two groups in terms of fixation count, fixation frequency or saccade count. We also found that compared to geographers, non-geographers usually spent more time completing these tasks. The results of this study are helpful in improving the map-based spatial ability of users of topographic maps.

Keywords: eye tracking; knowledge background; spatial ability; map cognition

1. Introduction

Spatial ability, as derived from the cognitive map concept introduced by the American cognitive psychologist Tolman, is defined as "the ability of perceiving, learning, remembering, reasoning, and transmitting spatial information" [1]. As a prototype, the cognitive map was defined as a type of mental representation that serves an individual to acquire, code, store, recall, and decode information about the relative locations and attributes of phenomena in their everyday or metaphorical spatial environment [2]. The components of spatial ability include spatial localization, spatial orientation and spatial visualization, which affect the initial assessment of a map, previous experience and memory, and the processes of acquiring knowledge of the relative positions, dependencies, and laws of change in things and phenomena in the physical world [3], especially in geography. For example, in our daily lives, there are circumstances in which we need to locate ourselves on a map based on our surroundings. In the Chinese "Super Brain" program, the Contours Identify Mountains project, designed by Dong et al. requires the participant to recognize and locate a point on a contour map based on photos of the Lushan Mountain. This project is considered as a typical task that reflects the importance of spatial ability and has helped to draw the public's attention to such abilities (http://news.sciencenet.cn/htmlnews/2017/4/372990.shtm).

Spatial ability training and enhancement is a key area of focus in geography. Geography focuses primarily on how to use maps to present spatial localization information and the development of spatial orientation and spatial visualization abilities [4]. Therefore, cognitive maps play an important role in reflecting and interpreting spatial capabilities because forming cognitive maps can effectively improve people's efficiency when using concrete maps. For example, research has found that people who often use maps can form better cognitive maps, which provide more information about the environment and one's location in context [5]. They are widely used as theoretical tools to interpret the results of spatial ability tests administered to subjects at the environmental scale and can objectively reflect the spatial ability of an individual [6]. Golledge et al. [7] explored the spatial capabilities of non-geographers and geographers of different genders in different groups using cognitive sketch maps and CAD software and found that female geographers generally had higher spatial capabilities than male geographers. Uttal et al. [8] conducted a meta-analysis of studies related to training and spatial abilities published from 1984 to 2009 and found that spatial ability is malleable and that training is durable and transferable. Although these studies concluded that training can improve spatial ability, experimental data remain lacking regarding whether spatial cognitive processes differ between geographers and non-geographers. Recently, Ooms et al. [9] used eye tracking to explore the cognitive processes of expert and novice users when they were interacting with maps, which indicates that eye tracking has the potential to be used to evaluate map-based spatial ability.

Here, we report a study using eye tracking to explore differences in map-based spatial ability between geographers and non-geographers. In this study, we collected eye movement data from 32 undergraduate students in the same grade with different majors attending BNU (BNU). We used response time, fixation count, fixation frequency and saccade count to evaluate differences in map-based spatial localization, map-based spatial orientation, and map-based spatial visualization by geographers and non-geographers.

The remainder of this paper is structured as follows. In Section 2, we present background information on spatial ability and related concepts and summarize eye-tracking studies of map reading and wayfinding. Then, we describe our eye-tracking experiment in Section 3. In Section 4, we analyze quantitative eye-tracking data to assess whether differences exist between geography and non-geography majors in spatial ability, specifically in terms of topographic-map-based spatial localization, spatial orientation, and spatial visualization capabilities, and we provide a general discussion. Finally, conclusions and suggestions for future work are presented in Section 5.

2. Background and Related Work

2.1. Spatial Ability

Spatial abilities include spatial localization, spatial orientation, and spatial visualization capabilities [10]. These capabilities form the basis for spatial thinking in our daily lives and are of considerable importance in science, technology, engineering, math, and other professional fields. Spatial localization has been defined as "the ability to orient oneself with respect to local, relational, or global frames of reference"; spatial orientation has been defined as "the ability to visualize how to view the structure of the same area from different perspectives"; and spatial visualization has been defined as "the ability to make two-dimensional or three-dimensional changes such as the rotation, twisting, and turning of space objects through imagination" [3].

A previous study found that different professional backgrounds may promote differences in spatial abilities [11] that are key to further education in various majors. Downs and Liben [12] found that teaching about map projection and coordinate systems can improve recipients' understanding of shape and angle of rotation as well as the interconversion of spherical and two-dimensional coordinate systems, thereby improving spatial orientation ability. Compared to non-geographers, geographers tend to pay more attention to the relevant aspects of topographic maps [13]. Geographers perform better and faster at the task of determining the shortest distance between two locations [14].

Geographers and non-geographers also act differently when given problem-solving tasks. Geographers can more easily extract global ocean data from maps without being influenced by subordinate elements such as notes, while non-geographers are easily distracted by those elements [15]. Geographers tend to have a significant cluster-formed capability for high-functioning recognition of spatial distribution (such as the relationship between different map themes) along with multiple map comparisons [16]. Taking geo-technology courses such as those focused on geographic information system (GIS) and cartography may also help college students improve their spatial skills [17–19]. Wang et al. [20] found that using a WebGIS-based teaching assistant system for geography field practice can also greatly aid in geography instruction and the development of spatial ability. These studies provide evidence that different knowledge backgrounds can contribute to differences in spatial ability.

In a quantitative study of spatial ability, Hegarty et al. [21] recruited students of cognitive psychology at the University of California, Santa Barbara, as providers of behavioral samples. They used statistical methods including factor analysis and correlation to develop a multi-item self-reported spatial ability measurement scale: The Santa Barbara Sense of Direction (SBSOD) Scale. Hegarty et al. [22] later used this spatial capability scale and performed spatial capability tests in the real environment. They performed structural equation modeling to calculate the contributions of each spatial capability index to overall spatial capability. In addition, they evaluated the reliability and validity of the SBSOD scale from an empirical perspective. However, Ishikawa and Montello [23] noted that previous experiments conducted on spatial capabilities did not account for individual differences, resulting in inconsistent conclusions. If individual differences were accounted for in the experimental design, the results would be more consistent. Yet, a comprehensive subjective and objective evaluation system has not yet emerged.

2.2. Eye-Tracking Methods to Evaluate Map-Based Spatial Cognition

Although previous studies have investigated topographic map reading, they have seldom provided insight into the underlying cognitive process. As an intuitive way to understand how people see maps, eye tracking is frequently used in studies of cognitive processes and has provided a new approach for map cognition research. The movement of the eye reflects the processing of visual information occurring in the brain [24]. Therefore, eye tracking can be used to effectively study the visual interpretations of users when sensing complex visual scenes and performing cognitive tasks [25,26] providing a valuable and reliable way to study the cognitive mechanisms of the brain [27].

In the past decade, research on visual cognition based on eye tracking has gained attention [28] and been applied to many topics in cartography. In addition, the use of eye movement methods to study map-based spatial cognition has received widespread attention [29]. In an eye-tracking experiment, Ooms et al. [30] found that experts and novices had similar abilities in terms of memorizing maps. Dong and Liao [31] found that participants presented with 3D maps were less effective and less efficient than participants who were presented with 2D maps for map reading and that those who were presented with 3D maps experienced a higher cognitive workload. In addition, Liao et al. [32] found that when using a 3D geo-browser, participants were likely to have inefficient knowledge acquisition due to information overload and obstructed views. Eye-tracking methods can also reveal the amount of cognitive processing required to interpret a map and the regions that required cognitive resources [33–36]. In reading complex maps, areas with different information complexity may cause greater information processing difficulty as well as reduced concentration, resulting in longer fixation duration and less fixation [37–39]. Experts are more likely to follow a specific visual search pattern [40,41]. Research on the visual perception of pedestrian navigation maps using eye-tracking methods has attracted considerable attention and represents a scientific frontier in the fields of cognitive science and geographic information science [42–44]. Thus, eye tracking provides us with an intuitive way to reveal the cognitive differences underlying spatial ability between geographers and non-geographers.

3. Empirical Study

3.1. Participants

Thirty-two undergraduate and graduate students (16 geographers and 26 females) aged 19 ± 2 years from Beijing Normal University (BNU) participated in the experiment. The participant sample rates of the study were greater than 80% to ensure enough sampling.

The participants were divided into two groups according to their major and the courses they had taken. Both groups had taken required courses such as advanced mathematics, programming, and general physics. Specifically, geographers all took courses closely related to geography such as Surveying and Cartography, Geology and Geomorphology, GIS and Geography Field Practice, which have been proved to improve spatial ability [20,45]. Non-geographers took their own professional courses such as The Constitution, Principles of Economics, and General Psychology.

All geographers had received both theoretical and practical geographic education in college for more than two years and frequently used topographic maps in their daily lives; thus, they had enough background knowledge for the experiment and were skilled at reading topographic maps. The non-geographers were students who had majored in science in high school (without training in geography) and rarely used either digital or paper maps in their daily lives. The tasks were presented in Chinese, and all the participants were native Chinese speakers, so cultural difference should not be a problem. All of them volunteered to participate, and they all have good eye health.

3.2. Apparatus

This experiment used a Tobii T120 eye tracker (www.tobii.com) with a sampling rate of 60 Hz and a 22-inch monitor. The hardware had a recording accuracy of 0.5° and a drift of ≤0.1°. The spatial resolution of the recorder was 0.2°, and head movement error was within 0.2°. The monitor used to display the topographic maps had a screen resolution of 1280 × 1024 pixels. The experiment occupied a dedicated room in BNU with appropriate lighting and no disruptions. Though this value did not come from clearly established rules, a participant sample rate of 80% was determined to be acceptable given that the experiment was well controlled and the recording duration lasted for 20–30 min.

3.3. Materials

We analyzed many questions on topographic map interpretation in the Chinese College Entrance Examination bank, focusing on four main question types that assess the acquisition of information regarding altitude, profile, slope, and terrain. We then selected three representative examination questions and their respective topographic maps (Figure 1).

A pilot study was conducted to ensure that each topographic map used in this study met four criteria. First, the examination questions must not be too difficult for non-geographers to solve. Second, the topographic map must be in focus with no irrelevant information. Third, prior knowledge should not be required to answer the questions. Fourth, all the necessary information must be obtainable directly from the map.

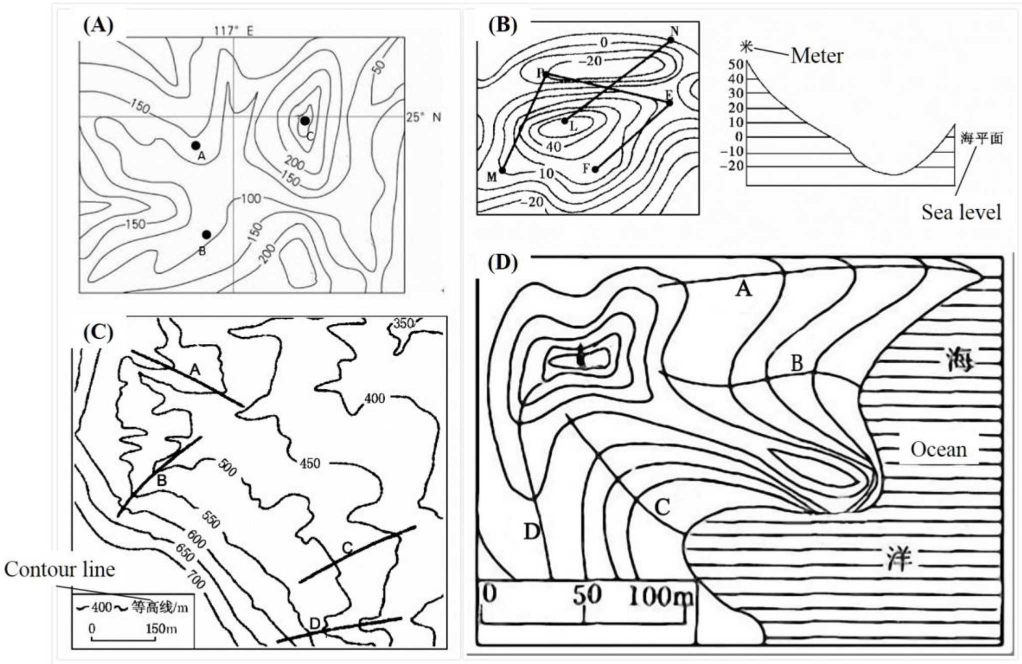

Figure 1. Example topographic maps for each task (**A**) Task #1, (**B**), Task #2 (**C**), Task #3, (**D**) Task #4.

3.4. Procedure

Before the experiment, we showed pictures of mountain peaks and valleys to the non-geographers and explained the definitions of peak and valley. These brief explanations were designed to ensure that they would not be confused and waste time recalling what peaks and valleys are. Next, each participant was required to complete a questionnaire about background information, such as gender and the frequency of using maps. Subsequently, a pretest was conducted. In the pretest, topographic maps unrelated to the formal experiment and questions were shown to the participants. The participants were instructed to tell the answers to the experimenter. During the pretest, the participants could ask the experimenter any questions they had, while in the formal experiment, they could not. The purpose of the pretest is to avoid generating invalid data because of improper operations (such as accidentally turning over the page, which cannot then be turned back over) by letting the participants become familiar with the procedure of the test.

At this point, the formal experiment began. The test included four types of questions and 12 questions in total (see below), and all the questions are carefully selected based on a pilot study to ensure a moderate difficulty of the whole test. In the test, the questions and the corresponding topographic maps were shown to the participants alternately. The subjects were first shown the question page, and when they remembered the question, they clicked the mouse to the map page. Once they decided on their answer, they clicked the mouse again to the next page, which showed the same question again. The participants were required to give their answer to the experimenter verbally. There was no time limit for the test, and the eye movement of the participants was recorded throughout.

The four tasks are described in detail below.

- Task #1 (Point localization with contour lines): Imagine you are in a topographic map-reading test. There are several points marked with letters on the map. Please tell the experimenter which marked point has the highest altitude as soon as you come up with an answer. When you have finished answering the question, please click the left mouse button.
- Task #2 (Section line orientation based on contour map): Imagine you are in a topographic map-reading test. There are several lines marked on the left side map, and the ends of each line are marked with a letter. There is also a sectional view on the right side. Please tell the

experimenter which of the marked lines matches the sectional view as soon as you come up with an answer. You should also tell the experimenter which end of the line matches the left side of the sectional view. When you have finished answering the question, please click the left mouse button.

- Task #3 (Slope visualization from contour map): Imagine you are in a topographic map-reading test. There are several lines marked with letters on the map. Please tell the experimenter which marked line has the steepest slope as soon as you come up with an answer. When you have finished answering the question, please click the left mouse button.
- Task #4 (Terrain determination by visualizing contour map): Imagine you are in a topographic map-reading test. There are several regions marked with letters on the map. Please describe to the experimenter the terrain of each marked region as soon as you come up with an answer. When you have finished answering the question, please click the left mouse button.

In Task #1, participants were required to determine the altitude of the marked point. Participants were instructed to relocate points (Figure 1A) within a 2D topographic map and estimate the altitude using the altitude data marked on the contour lines. This task can be used to verify participants' spatial localization ability.

In Task #2, participants were required to determine which hatch line matched the terrain reflected on the right. In this task, participants were instructed to compare the direction of each hatch line (Figure 1B) with the direction the presented terrain was facing. This task can be used to verify the participants' spatial orientation ability.

In Task #3 and Task #4, participants were required to interpret the topographic map and try to determine which of the indicated areas had the steepest slope (Figure 1C), or what type of landform the indicated area represented (Figure 1D). The participants were instructed to visualize a 2D map as 3D model inside their heads to determine the answer, which means that these tasks can be used to verify participants' spatial visualization ability.

3.5. Analysis Framework

To compare the differences in interpretation of the topographic maps, this experiment used the eye-tracking data to analyze the reading and interpreting process of the subjects (including the accuracy of the answers, response time, processing metrics and search metrics) (Table 1); the data obtained were used in a series of qualitative and quantitative analyses, and we mainly analyze their differences from four aspects to demonstrate a more comprehensive analysis on spatial ability. Considering that key information may be distributed throughout the topographic map, we selected the whole map as the area of interest (AOI) for statistical analysis.

Table 1. Quantitative metrics for analyzing participants' performance and visual behavior.

General Performance	Measures of Processing	Measure of Search
Response time (seconds)	Fixation Count Fixation frequency (fixation per second)	Saccades

Qualitative analysis includes the use of gaze series parameters (fixation count, fixation frequency) to draw an intuitive single gaze point heat map and gaze sequence diagrams; from these data, we could obtain a general understanding of the map-reading process of the subjects and analyze their map-reading habits. Response time (in seconds) means how long did the participant take to finish the task, which measures how rapidly the participant can complete the task. Fixation count indicates the number of visual components of the stimuli. Fixation frequency (fixations per second, fix/s), which was calculated by dividing the number of fixations by response time, is closely related to mean fixation duration. Saccades means how many times the participant took glance at the material, which indicate the effort invested in searching on a display. The longer the response time, the more difficult it is to extract information, or the more attractive the region is [46]. The greater the fixation number, the more visual information the reader has processed. The higher the fixation frequency, the higher the efficiency of information processing is [9]. The greater the saccades, the more visual searching the reader has performed [47].

We used EXCEL (Microsoft Corporation, CA, USA) and SPSS (IBM Corporation, Armonk, NY, USA) software to statistically analyze the experimental data (the accuracy of the answer, gaze time, etc.) to compare the ability of subjects with different backgrounds to obtain valid information quickly and accurately during the interpretation of topographic maps.

4. Results and Discussion

4.1. Map-Based Spatial Localization Ability

Task #1 (Point localization with contour lines) indicates the spatial localization ability of each participant. The results (Table 2) show that the response time of geographers (M = 12.992 s, SD = 10.379) was significantly shorter ($p = 0.006 < 0.01$, t = −3.024) than that of non-geographers (M = 18.335 s, SD = 16.271), indicating that geographers are more efficient at extracting and understanding the key information. Fixation count exhibited no significant difference ($p = 0.050$, t = −2.058) between geographers (M = 67.214 s, SD = 55.182) and non-geographers (M = 81.286 s, SD = 65.118), and there were no significant differences in fixation count within or between groups. The fixation frequency of geographers (M = 14.875 counts/s, SD = 6.727) was significantly higher ($p = 0.015 < 0.05$, t = 2.61) than that of non-geographers (M = 13.438 counts/s, SD = 4.420). Geographers had significantly fewer saccades (M = 28.431, SD = 9.639) than non-geographers (M = 39.217, SD = 18.313) ($p = 0.006 < 0.01$, t = −2.76). All the box plots are displayed in Figure 2.

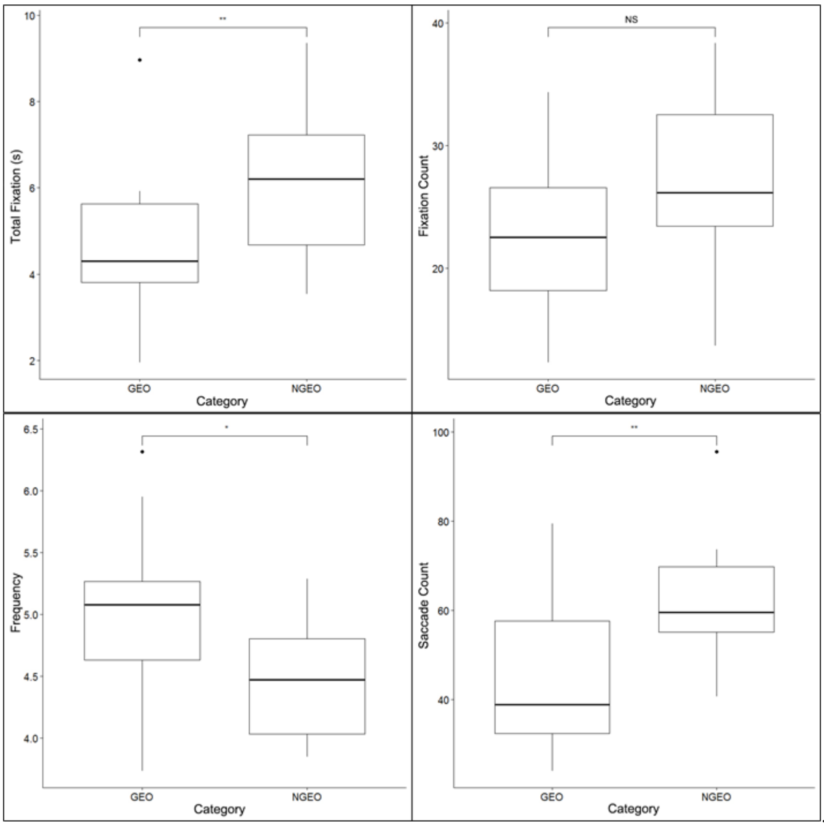

Figure 2. Box plots of point localization with contour lines (* $p < 0.05$, ** $p < 0.01$, NS = not significant).

Table 2. Descriptive and inferential statistics of quantitative measures of all tasks.

	Descriptive								Inferential	
	GEO (M ± SD)				NGEO (M ± SD)				*t*-Test	
									t	*p*
Total time (s)	188.000 ± 53.086				245.140 ± 7.168				−2.50	0.019 *
Accuracy (%)	89.881 ± 6.682				77.976 ± 10.645				−3.14	0.002 **
	Task #1 (M ± SD)		Task #2 (M ± SD)		Task #3 (M ± SD)		Task #4 (M ± SD)		*t*-Test	
	GEO	NGEO	GEO	NGEO	GEO	NGEO	GEO	NGEO	t	*p*
Response time (s)	12.992 ± 10.379	18.335 ± 16.271	8.906 ± 11.221	12.561 ± 15.870	8.359 ± 8.656	11.327 ± 10.162	6.326 ± 12.622	17.696 ± 30.493	−2.52	0.022 *
Fixation count	67.214 ± 55.182	81.286 ± 65.118	38.039 ± 46.574	50.500 ± 56.540	40.000 ± 52.068	44.583 ± 34.025	42.923 ± 51.139	59.083 ± 76.040	−2.64	0.008 **
Fixation frequency (fix/s)	14.875 ± 6.727	13.438 ± 4.420	13.210 ± 12.821	12.549 ± 7.837	12.698 ± 8.306	12.063 ± 10.788	13.696 ± 6.903	11.736 ± 4.657	2.61	0.015 *
Saccades	28.431 ± 9.639	39.217 ± 18.313	62.766 ± 19.891	85.029 ± 26.829	31.085 ± 11.029	50.004 ± 24.593	45.824 ± 17.787	61.244 ± 14.336	−2.76	0.006 **

M = mean, SD = standard deviation. ** $p < 0.01$, * $p < 0.05$.

From the spatial distribution of fixation shown in Figure 3, we can see that compared with non-geographers, geographers exhibited a more regular gaze sequence, and their fixation points were more concentrated around key information. The non-geographer's fixation points were more dispersed, and their gaze sequence was disordered; their fixation points included irrelevant information such as the latitude and longitude. The geographers tended to focus on the marked area first, then glance at the nearby areas, searching for useful information to solve the problem. However, the non-geographers did not follow a specific search pattern. Their gaze wandered over the whole map, accumulating as much information as they could from the map to help them solve the problem. Geographers were more focused on these marked points, whereas the fixation of non-geographers was more dispersed.

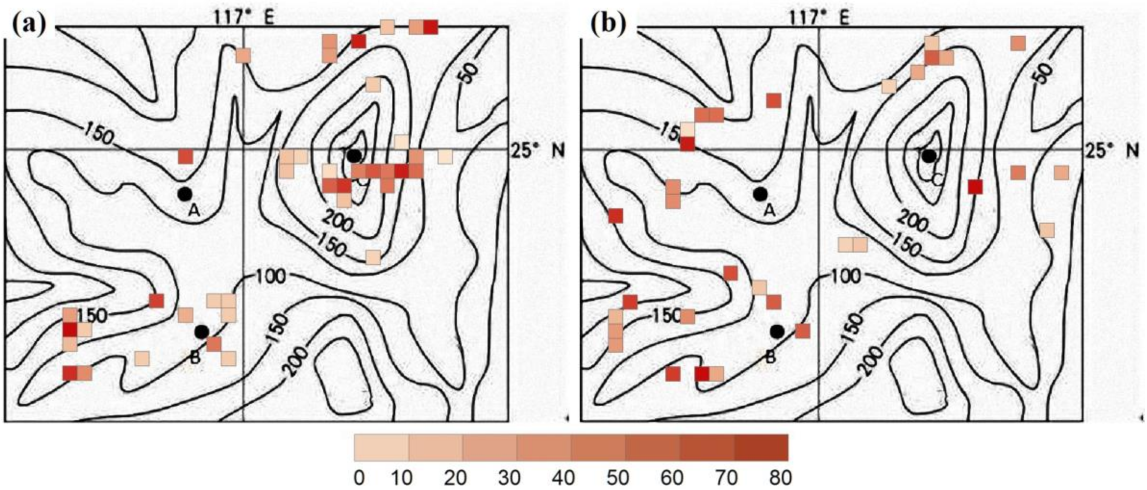

Figure 3. Spatial distribution of fixations on point localization with contour lines (task #1): (**a**) Geographers and (**b**) non-geographers.

4.2. Map-Based Spatial Orientation Ability

Task #2 (Section line orientation based on contour map) shows the spatial orientation ability of each participant. The results (Table 2) show that the response time of geographers (M = 8.906 s, SD = 11.221) was significantly shorter ($p = 0.022 < 0.05$, t = −2.52) than that of non-geographers (M = 12.561 s, SD = 15.870). Geographers exhibited a lower fixation count (M = 38.039 counts, SD = 46.574) than did non-geographers (M = 50.500 counts, SD = 56.540), which was the result of the significantly higher ($p = 0.008 < 0.01$, t = −2.64) fixation frequency of geographers (M = 13.210 counts/s, SD = 12.821) than of non-geographers (M = 12.549 counts/s, SD = 7.837). Geographers had significantly fewer saccades (M = 62.766, SD = 19.891) than non-geographers (M = 85.029, SD = 26.829) ($p = 0.006 < 0.01$, t = −2.76). All the box plots are displayed in Figure 4.

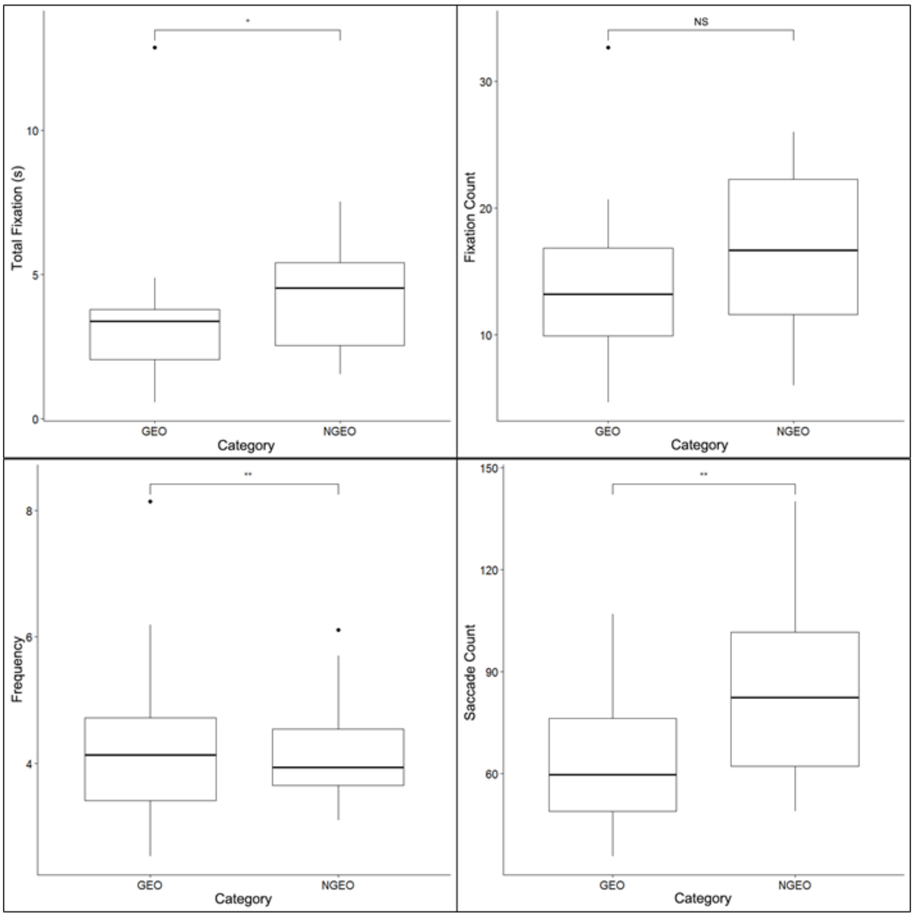

Figure 4. Box plots of section line orientation based on contour maps (* $p < 0.05$, ** $p < 0.01$, NS = not significant).

From the spatial distribution of fixations shown in Figure 5, we can see that during the spatial orientation process, geographers spent relatively more time fixing their eyes on the information regarding altitude and the section line in question. In comparison, non-geographers' eye points seemed rather scattered. Geographers paid more attention to the relevant areas and spent more time on those areas (in comparison with other part of the map) to extract the necessary information than did non-geographers. This result indicated that geographers are more skilled at identifying the key information for the analysis. Compared with non-geographers, geographers showed fewer retracements between the topographic map and the section line (7 vs. 12), fewer fixations and a shorter fixation duration on the section line, and fewer saccades (38 vs. 64). It can be concluded that geographers are more effective in extracting, processing, and remembering the exact information needed to answer the question than their non-geographer peers.

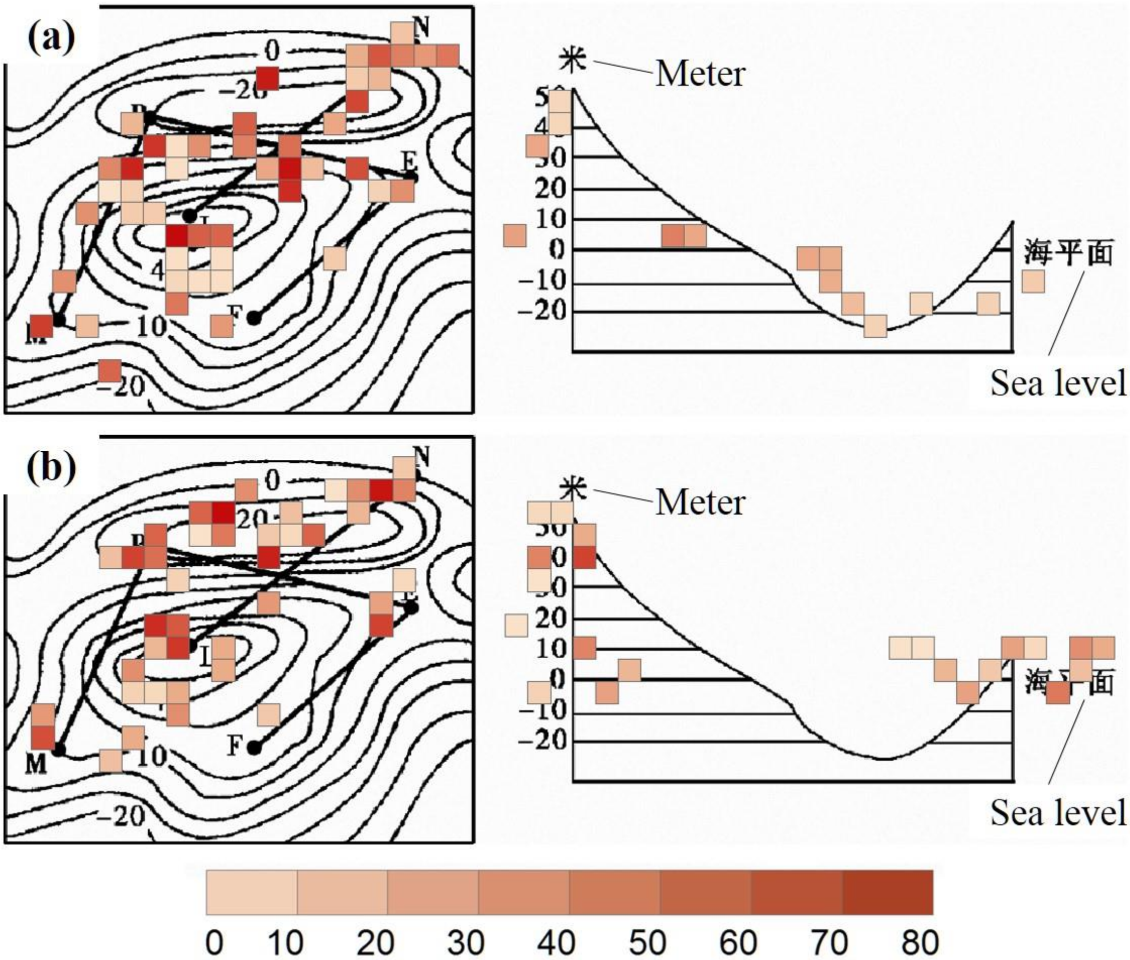

Figure 5. Spatial distribution of fixations on section line orientation based on contour map (task #2): (**a**) Geographers and (**b**) non-geographers.

4.3. Map-Based Spatial Visualization Ability

In task #3, the results (Table 2) showed that the response time of geographers (M = 8.359 s, SD = 8.656) was significantly shorter (p = 0.026 < 0.05, t = −2.23) than that of non-geographers (M = 11.327 s, SD = 10.162). The fixation counts of geographers (M = 40.000 counts, SD = 52.068) were fewer than those of non-geographers (M = 44.583 counts, SD = 34.025), but the difference was not significant (p = 0.257 > 0.05, t = −1.133). Geographers exhibited a faster fixation frequency (M = 12.698 counts/s, SD = 8.306) than did non-geographers (M = 12.063 counts/s, SD = 10.788), but again, the difference was not significant (p = 0.605 > 0.05, t = 0.524). Geographers had fewer saccades (M = 31.085, SD = 11.029) than those non-geographers (M = 50.004, SD = 24.593), but this difference was not significant (p = 0.098 > 0.05, t = −1.654). All the box plots are displayed in Figure 6.

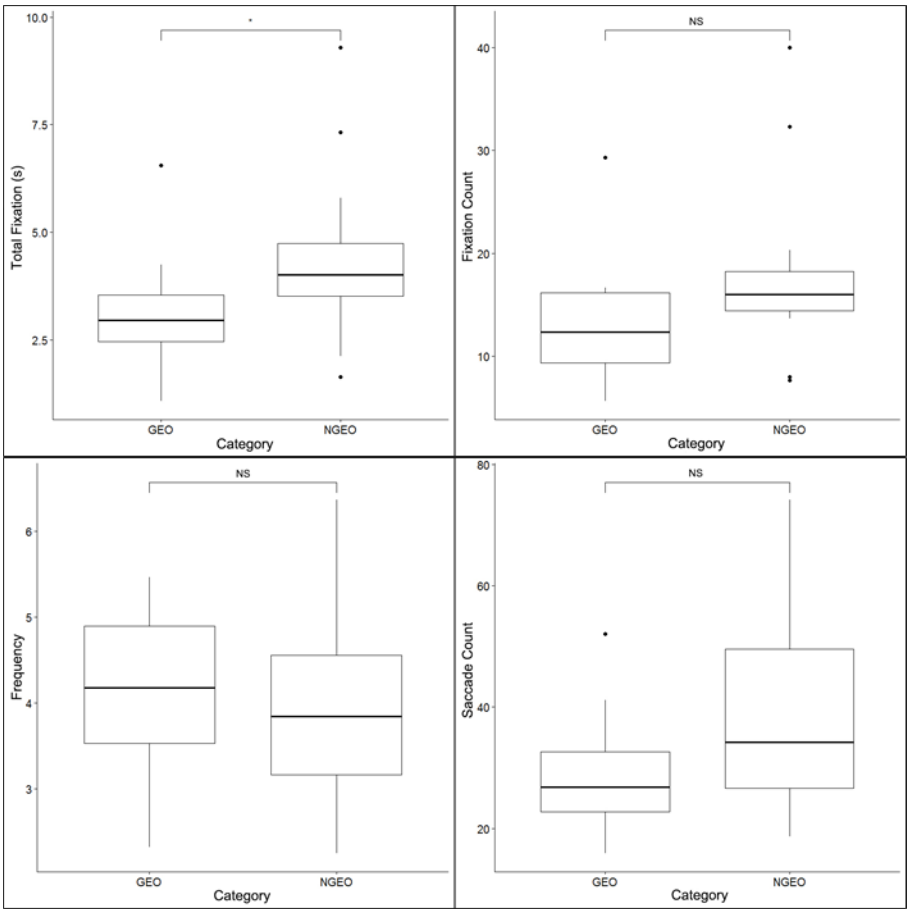

Figure 6. Box maps of slope visualization converted from contour map (* $p < 0.05$, ** $p < 0.01$, NS = Not significant).

From the spatial distribution of fixations shown in Figure 7, we can see that geographers can grasp the key information more successfully. Geographers showed a high level of efficiency in map reading and observation, which resulted in a unified gaze sequence, while non-geographers do not have a unified order of attention; most of them glance at the maps and use their intuition to identify the key problem-solving information. Geographers were more focused on the key points, which indicates that geographers have a better understanding of what information is needed to solve the problem and that they can remove redundant information, reduce interference in map cognitive processing, shorten the time required for extracting the main information and improve the accuracy of the solution. Subjects with a geography background tended to show a certain degree of regularity when scanning the contour maps, unlike those subjects without a background in geography.

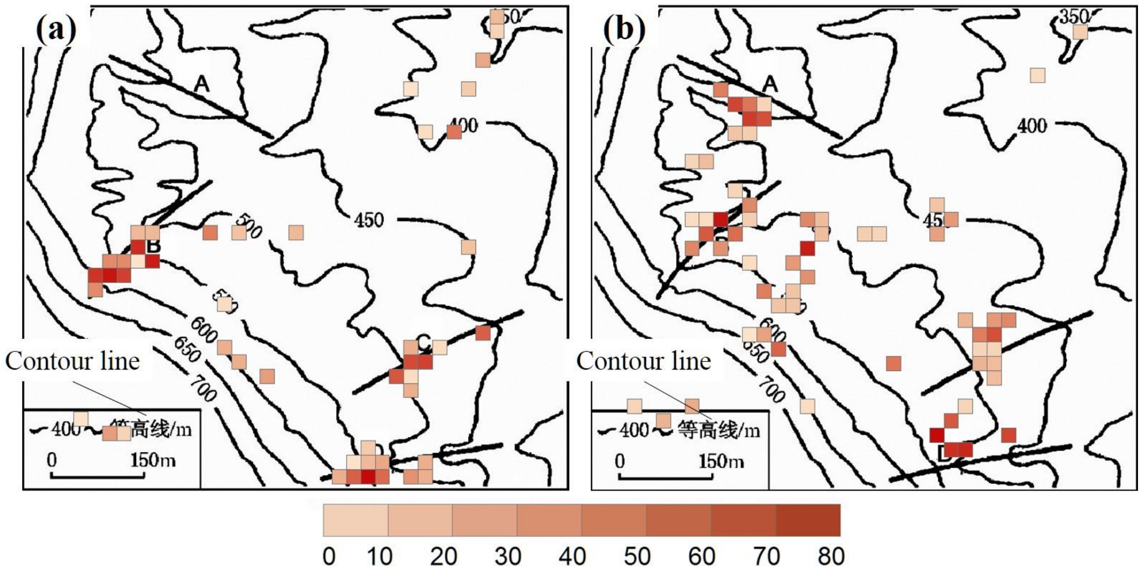

Figure 7. Spatial distribution of fixations on slope visualization from the contour map (task #3): (**a**) Geographers and (**b**) non-geographers.

In task #4, the results (Table 2) showed that geographers required less time (M = 6.326 s, SD = 12.622) to complete the task than did non-geographers (M = 17.696 s, SD = 30.493), and the difference was significant ($p = 0.006 < 0.01$, t = −2.766). Geographers had a higher fixation count (M = 42.923 counts, SD = 51.139) than did non-geographers (M = 59.083 counts, SD = 76.040), and the difference was significant ($p = 0.008 < 0.01$, t = −2.64). Geographers had a lower fixation frequency (M = 13.696 counts/s, SD = 6.903) than did non-geographers (M = 11.736 counts/s, SD = 4.657), and the difference was significant ($p = 0.015 < 0.05$, t = 2.612). Geographers had significantly fewer saccades (M = 45.824, SD = 17.787) than non-geographers (M = 61.244, SD = 14.336) ($p = 0.006 < 0.01$, t = −2.757). All the box plots are displayed in Figure 8.

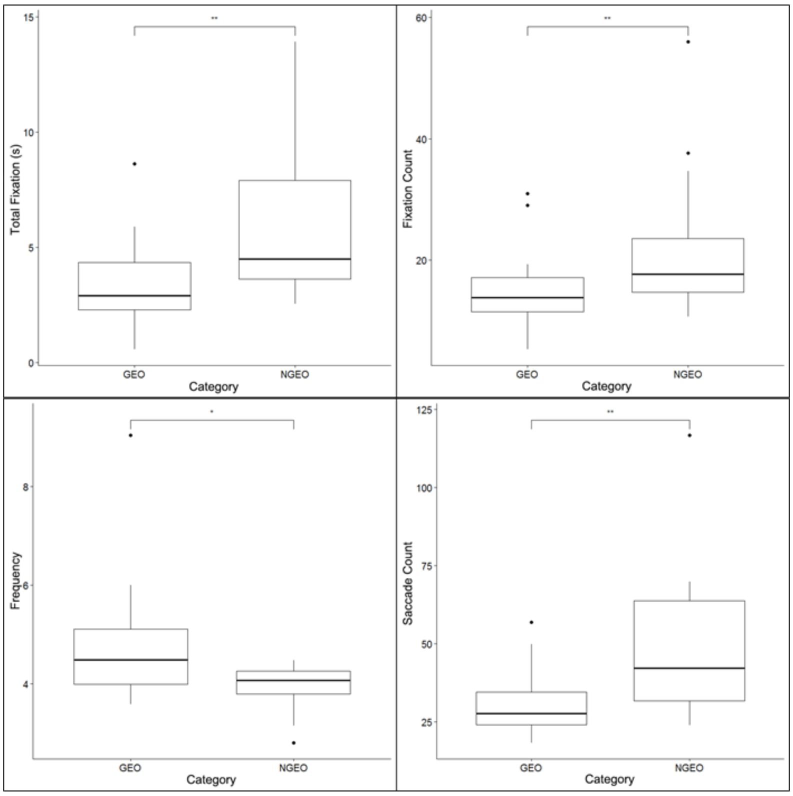

Figure 8. Box plots of terrain determination by visualizing a contour map (* $p < 0.05$, ** $p < 0.01$, NS = not significant).

From the spatial distribution of fixations shown in Figure 9, we can see that, compared to non-geographers, geographers paid more attention to searching for information from the area that was relevant to the question, as shown by the higher concentrations in the marked areas and the lower concentrations in the irrelevant areas of the heat map. While reading the maps, geographers followed a pattern with great concentration on the task-relevant area to obtain the information they needed, whereas non-geographers scanned the whole map to determine where they might find useful information. As a result, non-geographers created a more disorderly gaze plot with several irrelevant gaze points.

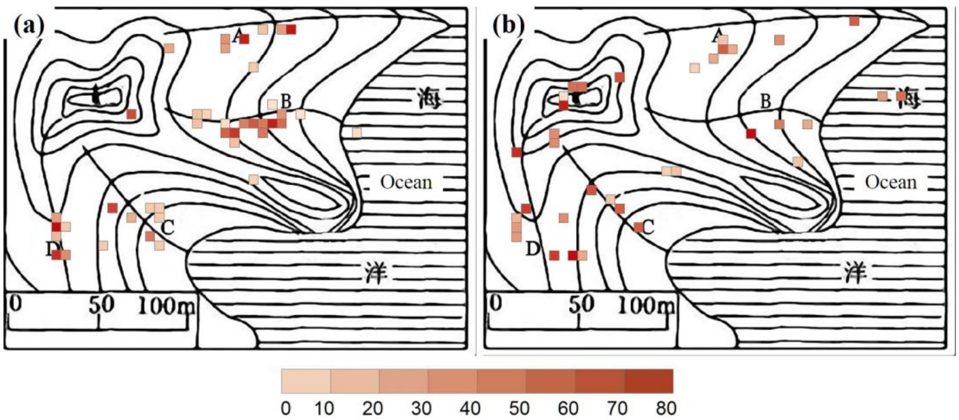

Figure 9. Spatial distribution of fixations on terrain determination by visualizing contour map (task #4): (**a**) Geographers and (**b**) non-geographers.

4.4. General Discussion

Total response time differed significantly between geographers and non-geographers ($p = 0.019 < 0.05$, $t = -2.497$), and the accuracy of geographers was significantly higher ($p = 0.002 < 0.01$, $t = -3.140$) than that of non-geographers. As only six males participated in the study, only total time and accuracy were analyzed separately for each gender. For males, the average accuracy was 86.11%, and female participants had an average accuracy of 83.33%. Both genders reached a maximum accuracy of 100%, but the minimum accuracy of female participants was 58.33%, which was 8.34% lower than that of male participants. Regarding total time, male participants spent on average 262.17 s to complete all the tasks, whereas female participants spent on average 204.14 s to do so. The maximum total time of the male participants was 349 s, which was 19 s longer than that of the female participants. The minimum total time of the male participants was 181 s, which was 67 s longer than that of the female participants.

In the spatial localization task (Task #1), geographers had faster responses in locating all the points and determining the altitudes using the contour lines, and the fixation frequencies of geographers were significantly higher than those of non-geographers. These results indicated that the geographers were better at extracting the critical information and absorbing it. Furthermore, geographers were more focused on the key information and demonstrated better regularity in scanning the topographic maps, and they yielded fewer saccades in the search for information. However, the fixation counts of the two groups were not significantly different, which is consistent with the results of an experiment conducted in 2001 [48]. Furthermore, Charness et al. [49] found that when participants were required to determine their localization on a contour map, experts are more focused on task-related points, which supports our conclusion regarding the focusing ability of geographers.

In the spatial orientation task (Task #2), geographers spent less time than non-geographers determining which direction the section line was facing. In addition, geographers created a lower fixation count along with a higher fixation frequency, which showed that geographers were more efficient at extracting and understanding the key information. However, the difference in fixation frequency between geographers and non-geographers was not significant. Geographers also exhibited greater concentration on marked key areas as well as less distraction, which resulted in fewer saccades. Geographers focus more on task-relevant areas than on task-irrelevant areas in dynamic stimulus processing and sorting [13]. This type of effect has also been observed in photo-learning-based deduction [50], surgical assistant nurse behavior [51] and airport security X-ray judgment [52].

In the spatial visualization tasks (Task #3 and Task #4), geographers were quicker than non-geographers to respond regarding the three-dimensional map they visualized based on the given two-dimensional contour map; geographers also had a lower fixation count and a higher fixation frequency. This finding indicates that geographers were significantly more effective at extracting key information and determining the landform of the mapped area, and geographers can gain more information from a given map in less time, which was related to the previous training in reading thematic maps. Geographers also showed higher concentration on the marked area as well as a lower saccade count. Geographers were more focused on the key information, while the non-geographers focused on both key information and the irrelevant areas, such as the scale and redundant contour lines. Even though the theory is easy to understand, compared to geographers, non-geography subjects require more time before responding, which may indicate hesitation and uncertainty [53]. In addition, the initial focus of both groups was approximately the same. However, the order of the next gaze was quite different. Geography subjects exhibited a more efficient order in their reading of the map and a more consistent gaze sequence. However, the non-geography subjects did not display such a logical order of attention, and most of them glanced at the maps and used their intuition to find the key problem-solving information.

5. Conclusions and Further Work

In this article, the results of the four tasks show that compared to non-geographers, geographers have a shorter map-reading time, higher accuracy, greater focus on key information points, lower counts of viewpoints, and faster extraction speed for key points. These findings indicate that geographers are more effective and more efficient at solving geographical problems. Additionally, teaching associated with the GIS platform and software can fully integrate teachers' professional knowledge and creativity as well as the understanding of their students [54]. However, because the geography-major participants had received extensive geography training, it is difficult to identify how each geography course individually influenced the spatial ability. In addition, we selected the participants based on their major alone, and the gender ratio of the participants was imbalanced. Thus, it is difficult to determine whether inherent (determined by genetic or gender factors) spatial ability or acquired geographical training led to the differences in spatial ability. Further studies will include cross-temporal tracking experiments to investigate a specific geography training course as well as regularly administered spatial ability tests to estimate how the specific geography training influences the spatial ability according to the time invested in training. We also aim to conduct an experiment that involves more complex map-use tasks and that addresses the effect of gender.

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