Eye Tracking Research on Solving Strategies of Students' Geospatial Dimension Transformation

Yitong Guo1,a, Yitong Guo1,*

1East China Normal University, College of teacher education, Shanghai, China
*aemail: guoyitongdl@163.com

* Corresponding author’s e-mail: guoyitongdl@163.com

Abstract: Geospatial dimension transformation is an important link with solving geospatial problems. Identifying the problem-solving strategies of geospatial dimension transformation and judging the difference between success rate of each strategy will help to improve the success rate of geospatial dimension transformation through strategic selection. The experimental task requires the subjects to select the actual landscape standing at a certain point on the map and looking at a certain angle. The research is based on heat maps and eye movement contrails of the subjects, and the research combined with the speech reports on the problem-solving process. The students' strategies for solving the problem of geospatial dimension transformation are identified. It is found that there are three strategies: landmark, road and hybrid, among which the road strategy has the highest success rate in completing the task and solving the problem.

1. Introduction
Spatiality is not only the basic attribute of geography, but also the unique feature that distinguishes geography from other disciplines. In the process of geography learning and problem solving, it is often necessary to use spatial representation tools such as maps to move, rotate, and deform geographical things in mind, and transform them into more suitable geospatial forms to explore the relationship between geospatial things. This is geospatial transformation, which includes dimension transformation, shape transformation, scale transformation, direction transformation, distance transformation and so on (Zhang Lifeng et al., 2019). Dimension transformation is an important link with geospatial transformation, but the process of spatial dimension transformation of human beings is very complex, difficult to analyze directly, and even unstable under different tasks, which require indirect observation by solving a specific problem. This paper provides a task that requires the subjects to select the actual landscape standing at a certain point on the map and looking at a certain angle. Based on the analysis of eye movement instrument and eye movement data, the transformation process of the sample's geospatial dimension is analyzed, aiming at solving two problems. What kinds of strategies do the subjects show in completing the task of geospatial dimension transformation? Which geospatial dimension transformation strategy has a higher success rate?

2. Methods

2.1. Procedure
As a mature research tool for neuroscience, eye tracker can directly reflect the visual key points of participants. Thus the research objectively analyzes the perception process and thinking process of
participants. The applied research based on eye movement has become very common (Deng Zhu, 2005; Zhang Weidong et al., 2009; Sun, Y. et al., 2020). In this study, EyeControlV2.0 was used to record the data at a sampling rate of 100Hz. When the eye movement fixation time was longer than 100ms, the eye tracker would generate a fixation point. The eye movement contrail showed the position and sequence of fixation points on each test material, which reflected the eye movement process. The heat maps could reflect the participants' interest in the visual objects. This type of eye tracker can use a number of eye movement data (such as Table 1), which can be used to find the eye movement characteristics, and help to determine different strategies to solve the problem of sample transformation in geospatial dimension. The method of strategy classification is that the researcher identifies and judges the eye movement process of the sample, and combines the speech report on the problem solving process. At the same time, the method of data clustering is used to divide the strategy types. According to a number of data recorded by the eye tracker, IBMSPSS23.0 software is used to cluster samples and get the strategy types of samples. However, this method only serves as a verification test of manual classification.

2.2. Participants
This study has passed the experimental ethics examination of the Human Subject Protection Committee of East China Normal University, with the approval number of HR055-2020, and the experiment has obtained the written permission of the sample school. The recruitment of experimental samples is targeted for senior high school students. On December 17th, the researcher directly went to the class to carry out recruitment propaganda, explained the experimental requirements and principles of the recruits, and emphasized again that the experiment had no health hazards, other risks were controllable, and the experiment had learned benefits, and promised that the personal information about the experimental samples would be kept strictly confidential, and that they could quit at any time in the middle of the experiment according to their wishes. After that, the platform for signing parents' informed consent and the platform for signing students' informed consent was announced, and finally, 12 high school students were recruited as experimental samples. Both students and parents signed informed consent forms and expressed their willingness to participate in the experiment.

All participants' naked eye vision is normal, because no valid data is recorded in one sample, valid data of 11 samples are finally obtained. According to the knowledge of geography teachers in schools and their academic achievements, samples can be divided into two categories with obvious differences in spatial thinking ability. Type A is used to represent samples of very good spatial thinking foundation, and Type B is used to represent categories with general spatial thinking foundation. Serial numbers such as A01, B01 and so on.

3. Data Analysis

3.1. Experimental task
The experimental task is to transform the content expressed by a 2D map into 3D actual landscape. Assume that participants are standing at the position of the arrow on the map (Figure 1) and facing the direction indicated by the arrow, and ask them to imagine the actual landscape they see, and make a choice of four actual landscape options (Figure 2).
3.2. Types of strategies for solving geospatial dimension transformation problems

The eye movement data are automatically recorded by the eye tracker in the experiment are shown in Table 1. The researcher identified and judged the eye movement process of 11 samples, mainly focusing on fixation location, heat maps, eye movement contrail, etc., and combined with the speech report on the problem solving process of the samples. Finally, three geospatial dimension transformation strategies are identified: landmark, road and hybrid. The classification of the strategies is shown in Figure 3. Target Area of Interest (AOI).

| Metrics                        | B02  | A02  | A03  | B04  | B05  | A06  | B06  | A01  | B01  | B03  | A04  |
|--------------------------------|------|------|------|------|------|------|------|------|------|------|------|
| 1. Fixation duration (s)       | 2.80 | 5.33 | 20.38| 35.33| 11.53| 15.10| 6.83 | 7.27 | 14.82| 1.36 | 16.86|
| 2. Fixation count              | 9.00 | 18.00| 63.00| 131.00| 24.00| 48.00| 14.00| 26.00| 46.00| 8.00 | 57.00|
| 3. Time to first fixation      | 0.00 | 0.00 | 0.00 | 0.28 | 47.74| 0.72 | 0.72 | 0.83 | 0.42 | 7.20 | 1.58 |
| 4. Entry saccade number        | 5.00 | 2.00 | 20.00| 24.00| 6.00 | 19.00| 5.00 | 6.00 | 19.00| 2.00 | 16.00|
| 5. Fixation count entry before | 0.00 | 0.00 | 0.00 | 1.00 | 1.00 | 2.00 | 2.00 | 3.00 | 1.00 | 2.00 | 3.00 |
| 6. First fixation duration (s) | 0.46 | 0.18 | 0.28 | 0.26 | 0.18 | 0.20 | 0.12 | 0.21 | 0.17 | 0.21 | 0.20 |
| 7. AOI max fixation duration   | 0.55 | 0.83 | 1.28 | 0.83 | 1.90 | 1.12 | 1.03 | 0.55 | 0.68 | 0.27 | 1.00 |
| 8. AOI mean fixation duration  | 0.31 | 0.30 | 0.32 | 0.27 | 0.48 | 0.31 | 0.49 | 0.28 | 0.32 | 0.17 | 0.30 |
| 9. AOI fixation points         | 0.15 | 0.72 | 0.50 | 0.71 | 0.62 | 0.57 | 0.67 | 0.67 | 0.51 | 0.44 | 0.70 |
| 10. AOI dwell time             | 0.09 | 0.67 | 0.36 | 0.56 | 0.63 | 0.53 | 0.65 | 0.67 | 0.47 | 0.45 | 0.64 |
11. Mean fixation duration (s) | 0.50 | 0.32 | 0.44 | 0.34 | 0.47 | 0.34 | 0.50 | 0.28 | 0.36 | 0.17 | 0.32

12. Stimulus materials duration (s) | 86.56 | 18.25 | 79.35 | 78.08 | 70.25 | 32.05 | 37.76 | 61.44 | 40.45 | 22.98 | 42.52

13. Fixation number on all AOIs | 61.00 | 25.00 | 124.00 | 18.00 | 184.00 | 83.00 | 21.00 | 39.00 | 87.00 | 18.00 | 80.00

14. Fixation time on all AOIs (s) | 30.88 | 7.94 | 55.31 | 62.84 | 18.41 | 28.24 | 10.55 | 10.81 | 30.91 | 2.99 | 25.68

15. All AOIs average fixation duration (s) | 0.51 | 0.32 | 0.45 | 0.34 | 0.47 | 0.34 | 0.50 | 0.28 | 0.36 | 0.17 | 0.32

16. Number of Saccades | 62.00 | 25.00 | 127.00 | 185.00 | 39.00 | 84.00 | 21.00 | 39.00 | 91.00 | 18.00 | 82.00

17. Saccade distance (cm) | 21.35 | 9.57 | 71.43 | 106.84 | 20.30 | 58.42 | 15.58 | 22.18 | 64.27 | 8.65 | 50.69

Data onto Table 1 are entered into SPSS software, and the sample objects are clustered by using the average connected distance clustering method of groups. Within 5 steps, the system can cluster three categories of samples (as shown in Figure 4): the first category includes B02, B03, A01, B06, B05, the second category includes A06, B01, B04, A03, and the third category only has A02. Among them, A02 gets the correct answer the fastest, which may be that some extreme values affect the clustering results and make them separate into classes. From the SPSS clustering results, it is in good agreement with the clustering results obtained by researchers based on manual identification and combined with interviews, which show that manual classification is also supported by the data set recorded by an eye tracker to a certain extent. Finally, it proves that the classification of the final sample strategies is scientific.

![Figure 3 Classification of sample geospatial dimension conversion strategies](image1)

![Figure 4 Sample strategy classification diagram obtained by using SPSS cluster analysis](image2)

3.2.1. Landmark

Landmark geospatial dimension converters usually only correspond to landmark buildings (including the names of buildings, the actual landscapes represented by legend colors, the orientation of buildings, etc.) in 3D real scenes one by one. B03 first paid attention to the park in the 2D map, then searched for the landmark parks in the options to exclude the options, and finally determined that the final option was 2 by locating the landmark Starlight gate in the real 3D scene.

B03 subjects described their thinking process:

"I noticed the park next to me, so I interpreted its location, and then I simply glanced at the options. I probably ruled out 3 and 4 first because they didn't see the park, and then I interpreted the position after 1. At that time, I saw a starlight gate, which was probably like a hypermarket, so I chose 2 later. "

4
Figure 5 Eye movement hot spots and eye movement trajectories of B03 subjects

B05 first saw the landscape around the black arrow: Starlight gate and square. Then, in the third picture of the 3D real-life map, there is a building on the east side of the road, which is inconsistent with the arrow on the east side of 2D map. He is very keen to see that there is Guosheng Life Plaza on the west side of the road in the fourth picture, which corresponds to the landmark names in the 2D map. Finally, he saw some landmarks on the east side of the road in a 2D map, and verified with the fourth picture, and finally determined that the correct option is 4.

B05 subjects described their thinking process:

"That is to say, standing in the position of the arrow, and then looking at what the landscape around it is, there is this Guosheng Life Square above this, and then here is this Guosheng Life square, so it corresponds. The first tree here is wrong, and the second picture doesn't seem to be in this mall."

Figure 6 Eye movement hot spots and eye movement trajectories of B05 subjects

B03 and B05 both focus on using a certain landscape in the 2D map for geospatial dimension transformation, and this strategy often relies too much on landmarks. B03 found that the landmarks he chose did not appear in the 3D real-life mapped when considering landmarks and their orientation, so he missed the correct option. The method of corresponding landmark names has some limitations.

3.2.2. Road

Road geospatial dimension converters usually only use the roads (including road names, extending directions, T-junctions, etc.) in the 2D map to correspond one-to-one in real 3D scene. B04 and A03 noticed that the arrow was just a T-junction when they got the 2D map, extending for north to south,
connecting to the west and closing to the east. Then, they searched for roads to the first to fourth pictures respectively, and found that the east-west connectivity of roads to the fourth picture was the most consistent with the 2D map, so they chose 4.

"I first found out where the arrow is in the first picture, and then I looked at the following four options. First of all, I can see in the first picture that its road should be horizontal, but from the above picture, it seems that there is still a road ahead, so 1 is wrong, then 2 is wrong, because the above image shows a road to the west, while 2 is a road to the east, so 2 is wrong. Then look at the third picture. The third picture can be seen as a horizontal road, while there is no road on the right side of the above picture, so I can only choose 4." (Sample B04)

"I saw that this road was north-south, then 1 were east-west, so I didn't choose. There is no road to the right side of the arrow, and then 2 and 3 are not selected." (Sample A03)

Road geospatial dimension converters do not use specific point landmarks or area landscapes, but pay attention to line roads. Their fixation duration is longer and the fixation count is more than that of landmark geospatial dimension converters (as shown in Table 2), which indicates that road converters need to deal with more visual information, spend longer time interpreting information (Dong Weihua et al.,2008), and think more comprehensively and carefully.

Table 2 Comparison of eye movement indicators

| Types    | Sample No | Fixation duration | Fixation count |
|----------|-----------|-------------------|----------------|
| Road     | A03       | 20.3780           | 63             |
|          | B04       | 35.3250           | 131            |
| Landmark | B05       | 11.5310           | 24             |
|          | B03       | 1.3560            | 8              |

Figure 7 B04 subjects’ eye movement hot spots and eye movement trajectories

3.2.3. Hybrid

Hybrid geospatial dimension converters usually choose to use landmarks combined with roads to transform geospatial dimensions. The subjects generally use the road as a frame, and then use landmarks for precise positioning. The subjects searched for landmarks in the road, excluded them from the 3D real-life map with the road as the frame, and selected typical landmarks in verification. A02 is the fastest student to get the correct answer to the 11 subjects, and its eye movement heat map and eye movement contrail are shown in Figure 9. Subjects first see buildings on the east side of Figure 2, and roads to the west side are closed. The road connectivity on the east side of Figure 3 is inconsistent with the 2D map, so 1,2 and 3 are excluded, and then subjects to choose 4 because they see Changfeng park on the
right side of the arrow.

"I saw that this road was north-south, then I was east-west, so I didn't choose. Then I saw Changfeng park on the right side of this topic. There is no road to the right side, and then 2 and 3 are not selected. So finally choose 4." (Sample A02)

The eye movement contrail of A02 who use the hybrid strategy to transform the geospatial dimension has a certain sequence, with little fixation points, and almost all important information is captured by fixation points.

Figure 8 A02 subjects’ eye movement hot spots and eye movement trajectories

As shown in Figure 10, the eye movement contrail of A04 is disorganized and there are many retroversions, which show that the students' spatial memory ability is not good. The subject first searched for landmarks in the road, and noticed that the arrow was located at the fork road, and there was a building on the northwest side of the fork road that didn't conform to the first picture. Then the subject noticed the green area on the east side of the arrow, and judged that it should be a green belt landscape, so he searched for green belts in the 3D real-life map and finally chose the second picture. The subject ignored the orientation when looking for the green belt in the 3D real-life map, and only the landscape location represented by the landmark color led to the wrong choice. Finally, the subject's gaze moved to the northeast corner of the 2D map, found the road to the park, and rationalized the road to the east sides with the second picture, indicating that the subject ignored the size of the 3D real-life map, which eventually caused spatial confusion. Because of the need to consider road and landmark, the subjects' problem-solving process is more complicated, which has certain requirements for the level of geospatial thinking.

A04 subjects described their thinking process:

"What I saw at that time was the arrow. The first thing I saw was that this road was a fork in the road, and then I saw that there was a building on an intersection of an oblique angle, and the right side of it might look like a green belt. The second picture is more like green, so I chose the second one." (Sample A04)

Figure 9 A04 subjects’ eye movement hot spots and eye movement trajectories
4. Discussion

Based on the eye movement heat maps and eye movement contrails of the subjects, combined with the speech reports of their problem-solving process, three geospatial dimension transformation strategies are identified: landmark, road and hybrid. B05, B03, A01, B02 and B06 adopted landmark problem solving strategies, A03, B04 and B01 adopted road problem solving strategies, and A02, A04 and A06 adopted hybrid problem solving strategies.

In the experiment, all the subjects choose the problem-solving strategy with self-centered coordinating (assuming that they stand at the black arrow in the figure). The landmark problem-solving strategy mainly uses visual spatial memory to transform from the visual characteristics of the environment, such as the color and shape of landmarks. Only by combining these visual characteristics with specific spatial information (the location of landmarks) can the problem be solved more effectively. However, due to the randomness of the subjects’ search for landmarks, the correct rate of using this strategy is only 60%.

Road problem-solving strategies require the subjects to grasp the road characteristics macroscopically, embody the linear spatial organization ability and orientation discrimination ability of the subjects, and use self-centered coordinates for good prediction ability (Giusberti, N. F., 2006). The road geospatial dimension transformation strategy is the most accurate (the correct rate is 100%) in this situation. The hybrid problem-solving strategy combines landmark and road-based problem-solving strategies (the correct rate is 67%), and considering more factors, it often takes more time to solve problems, which often leads to confusion in thinking. The subjects that adopt this strategy have the highest success rate when they take the idea of "taking roads as the framework and landmarks as the key" to transform the geospatial dimension.

In the initial recruitment of samples, the teacher considered the spatial thinking ability of the candidates according to their understanding of the students, and divided the spatial thinking level of the samples after determining the samples. A is a high grade and B is a low grade. In fact, there are significant differences in spatial thinking ability between the two levels of samples. Considering the basic situation of type A and B samples and the success rate in solving problems, it is decided to adopt the following solution level assignment method: Group A samples are assigned 1 point for right assignment and -1 point of wrong assignment; Group B samples get 2 points for correct assignment and 0 points for wrong assignment. The average solution level reflects the comprehensive level of the success rate of this strategy type sample, and the road-based problem solving strategy is obviously higher than the landmark-based and the hybrid problem solving strategy.

The ability will be interfered by strategies, and the success rate of problem solving will be affected by the poor strategy chosen by the subjects with high spatial thinking ability. For example, the average solution level of the high-level subjects using the hybrid geospatial dimension transformation strategy is only 0.33; However, the subjects with low spatial thinking ability will improve the success rate of problem solving because they choose appropriate strategies. For example, the average solution level of low-level subjects using road-based geospatial dimension transformation strategy is as high as 1.67.

| Types | Sample No. | Right/Wrong | Correct rate | Proportion of users | Solution level | Average solution level |
|-------|------------|-------------|--------------|---------------------|----------------|-----------------------|
| Landmark | B05 | right | 60% | 46% | 2 | 1 |
| | B03 | wrong | | | 0 | |
| | A01 | wrong | | | -1 | |
| | B02 | right | | | 2 | |
| | B06 | right | | | 2 | |
| Road | A03 | right | 100% | 27% | 1 | 1.67 |
| | B04 | right | | | 2 | |
| | B01 | right | | | 2 | |
| Hybrid | A02 | right | | | 1 | |

Table 3 Basic situation of subjects using different strategies
5. Result
In this experiment, through reading pictures and solving problems, it is recognized that there are three types of strategies in the task of solving the problem of geospatial dimension transformation: landmark type, road type and hybrid type. According to the correct rate and the average answer level, it is best to take the road as a reference when completing this kind of geospatial dimension transformation problem. Because this strategy is not limited by landmark names, colors, etc., and it is easier to observe. It does not require high spatial thinking ability of the subjects themselves as well.

6. Conclusions
This paper identifies three types of strategies in solving the problem of geospatial dimension transformation: landmark, road and hybrid type. It is best to take roads as reference when completing this kind of geospatial dimension transformation problem. The research of eye tracking technology provides a new idea for the study of geospatial dimension transformation, and reflects the process of instant cognitive processing in the process of problem solving to a certain extent. Through the real-time measurement of eye movement, researchers can obtain the empirical data of individual problem information processing, thus revealing the cognitive mechanism of individual in the process of problem solving to a certain extent.

Acknowledgments
This paper is one of the phased achievements of the 2019 Annual Planning Fund Project of Humanities and Social Sciences Research of the Ministry of Education, "Experimental Research on Measurement, Development Mechanism and Improvement of Teaching Tendency of Middle School Teachers' Core Literacy".

References
[1] Zhang, L.F., Guan, J., Zhang, X. (2019) Research on the Strategies of Cultivating Junior Middle School Students' Geographic Space Transformation. Geography teaching, 04:29-31.
[2] Deng, T. (2005) Research on the Theory, Technology and Application of Eye Movement Psychology. Journal of Nanjing Normal University (Social Science Edition), 01:90-95.
[3] Zhang, W.D., Liang, Q., Fang, H.L. (2009) Study on the Eye Movement of the Appreciation of Urban Greening Landscape. Psychological Science, 04:801-803.
[4] Sun, Y.Y., Lu, X.X., Wang, Y. (2020) Using eye tracking to explore differences between high and low map-based spatial ability. Journal of Geography, 6: 215–225.
[5] Nori, R., Giusberti, F. (2006) Predicting cognitive styles from spatial abilities. The American journal of psychology, 01:67-86.
[6] Dong, W.H., Liao, H., Yan, Z.C. (2019) New progress in cartographic eye movement and visual cognition research since 2008. Acta Geographica Sinica, 74(03):599-614.