Analysis on the characteristics of eye movement and the evaluation of psychological perception for forest waterscape space

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Abstract. For landscape architects, how to provide a highly quality forest landscape for visitors has always been an important topic. This study based on the results of previous field observation, combined with eye tracking technology and psychological perception questionnaire, and used the Wilcoxon rank sum test, T test and Spearman's rho correlation analysis in SPSS 23.0 to statistically analyze the data. The main purpose is to clarify the relationship between visual behavior characteristics and psychological perception evaluation of the forest waterscape space where tourists have more behavioral evaluations during forest walk. Main results are as follows: 1. There are differences eye movement behaviors of different types of forest waterscape space, especially in the visual span; 2. There are significant differences visitor's psychological evaluation of different types of forest waterscape in five indices, which in whether the landscape content is changing, whether the color is rich, whether the color is bright, whether the space is open and whether you can see the distant landscape; 3. There is a correlation between human eye movement behavior and psychological perception evaluation in different types of forest waterscape spaces. The scenes with a large number of fixations also have higher satisfaction, and fixations count have positively correlated with the spatial perception evaluation results, which including plant diversity, landscape richness, permeability and the layering. That is to say, richness of landscape elements and color, permeability of the space and the regularity of the forest waterscape space affect the participants' eye movement observation mode. Through the above analysis, we suggest that in the planning and design of forest waterscape space should be considerate the characteristics of different landscape elements, meanwhile we should pay attention to the interspersion of appropriate heterogeneous landscape space.

Keywords: Forest Waterscape Space; Behavior Assess; Eye-tracking; Psychological Perception

1. Introduction
With the development of society and economy, people's awareness and demand for forests are also changing. More and more people are walking towards forests in their spare time and returning to nature [1-2]. That also shows that forests are gaining more and more attention in people's daily leisure activities. Therefore, how to provide a high-quality forest walking space for more visitors is an important subject that landscape planning and designers must face [3-5].
Previous research shows that experts no longer simply study the economic value of forest landscapes, but focus more on the research and analysis of forest landscape resources, such as the research about Deng R.G., Liu D., Ernest B., Zohre, etc., analyzed the relationship between visitor evaluation and the landscape environment [6-14]. Their research pointed out that it is necessary to understand the state of the forest and its landscape before planning and designing the forest. While we also demand to investigate participant needs, landscape preferences, and overall evaluation. Through these surveys, designers can grasp the preferences and needs of participant for forest space, thereby linking the subjective evaluation of visitors with the environment itself [15].

In our previous observations of visitor behaviors of Japanese Akasawa National Recreational Forest as an example (Figure 1), we found that when visitor walking in the forest landscape space, the water-rich space can attract their interest and arouse their behavior evaluation [16]. However, in such a landscape space, which aspects of the landscape have aroused the visitor's attention and caused a stop behavior, and whether the visitor's observation of the waterscape space will be affected by the spatial form needs to be further studied. Because understanding people's observation and perception for the space of landscape can help landscape architects better using elements of landscape to layout and plan landscape space [17].

![Figure 1. Assessment behavior of tourists in the walking space of forest landscape.](image)

For another, earlier research, Ernest B., Guan H., etc. used questionnaires to analyze the visitor's evaluation, their preferences, and their needs for the landscape [7, 18-19]. However, Zhang Z. and other researchers believe that this method lacks quantitative analysis, and the eye-tracking technology which can combined qualitative and quantitative data can be used to further explore the relationship between person and landscape environment. At the same time, Shao H., De Lucia J.V., Dupont et al. pointed out that eye tracking is feasible for landscape research in their research [20-23].

Therefore, as the basis of the following study, this study through the psychological evaluation questionnaire and eye-tracking technology to analyze the relationship between the characteristics of human eye-movement behavior and the perception evaluation of psychological in differ forest space of waterscape.

The research is mainly carried out from the following aspects: (1) Analyzes the characteristics for the behavior of visitors’ eye-movement in differ forest space of waterscape and whether there are differences; (2) Analysis the differences of perception evaluation for psychological in differ forest space of waterscape; (3) Clarify the psychological evaluation factors that affect the human eye observation behavior in the forest waterscape space.
2. Materials and methods

2.1. Study area
The forest waterscape space in this study refers to the forest landscape space rich in water space. According to the state of the water, the forest water space is divided into two types: static waterscape space and dynamic waterscape space. After on-site inspection and screening, Dandong Phoenix Mountain National Scenic Area and Benxi Greenstone Valley National Forest Park were finally used as the research objects (Figure 2).

(1) Dandong Phoenix Mountain National Scenic Area: It covers an area of approximately 216 square kilometers, with high mountains and forests, waterfalls and springs, and rich dynamic waterscape space. It also is a typical scenic area in eastern Liaoning, which located in Dandong, Liaoning Province, China.

(2) Benxi Greenstone Valley National Forest Park: It covers an area of about 20 square kilometers, with undulating terrain and diverse vegetation. It is a typical mountain-type forest park, which located in Benxi, Liaoning Province, China.

Figure 2. Study area bitmap.

2.2. Materials
Previous studies have shown that photos of landscape space can effectively replace the investigation of the on-site environment [24-27]. On the other hand, we choose photos of landscape space for indoor experiments can create a good experimental environment for the participants, and can also avoid the impact of objective conditions such as weather conditions, temperature, and sound on the experiment caused by the on-site environment. Therefore, in this study, we used landscape photos as experimental materials for eye-tracking experiments.

2.3. Subjects
Studies by Guo S.L. et al. [28-29] have shown that college students have certain tourism experience and landscape aesthetic judgment ability. It is feasible and representative to select students for the experiments of eye-tracking. Meanwhile, in order to increase the richness of sample, that is, to ensure the group contained as many predilections as possible and had a wide aesthetic range. Therefore, we selected 63 students from Shenyang Agricultural University with a background in forestry, civil engineering, horticulture, economic management and other professional subjects as the research objects, and the final effective data was 53. Participants are voluntary participants, with naked eyes or corrected visual acuity above 1.0, normal color vision, no color blindness and other eye problems. At the same time, participants were not allowed to wear false eyelashes, draw eyeliners, and the participant's head remained essentially stationary during the experiment.
Participants are voluntarily to take part in the experiment, and their naked or corrected vision are both above 1.0. They also require has normal color vision, no color blindness and other eye problems. Meanwhile, during the experiment, the participants were not allowed to wear false eyelashes, draw eyeliner, and they need to require keep their head still. as still as possible.

2.4. Eye tracking experiment
The laboratory sound insulation effect is good, and experiments are carried out in group. The projector (Epson XGA 2800) with a resolution of 1024×768 was used to play the experimental materials on the screen of 140×190cm. And participants used German head-mounted SMI Glass2 eye tracker with the 120 Hz/s sampling frequency to watch the experimental materials 3m in front of the screen. We adopt the 5-point calibration, before the experiment beginning. In this experiment, participants needed to watch two pictures and one blank picture in the form of POWERPOINT, and they needed to spend 50s/person to obtain the data of eye movement. The specific experimental process of eye-tracking is shown in Figure 3.

![Figure 3. Eye movement experiment process.](image)

2.5. Data collection

2.5.1. Photo samples collection. We used the camera of Olympus EM 5 SLR to take photos with a height of 170 cm at the distance of 10 meters from the object's space revetment [25], to collect spatial samples, in October 1st to October 3rd, 2017, the maple viewing season, sunny, 10: 00-11: 00 am.

2.5.2. Eye tracking data collection. We used German SMI Glass2, eyetracker, to record the participants' eye behavior during they viewing landscape pictures.

2.5.3. Questionnaire data collection. After the participants finished the experiment of eye-tracking, the experimental materials were displayed again, and they asked to fill out the questionnaire of preference assessment (7-point Likert-type scale) for each landscape photo, where 1 point is the worst and 7 points is the best. The whole experiment lasted about 75s.

2.5.4. Establishment of questionnaire evaluation system. The evaluation index for the space of forest divided to four parts, which including landscape change, color, space, and overall evaluation. This study is mainly based on the previous evaluation system for landscape [30-31]. Meanwhile, we combined the space of characteristics and avoided causing psychological load to participants during the experiment.

2.6. Data analysis
After testing the data for normal distribution with SPSS 23.0, the following analysis methods were determined:

1) Wilcoxon rank sum test: Analyze the differences of participants' psychological evaluation in differ forest space of waterscape.
2) T test: Analyze the differences of participants' behavior of eye movement in differ forest space of waterscape.

3) Correlation analysis: Analyze the relationship between participants' psychological evaluation and participants' behavior of eye movement through the Spearman's rho.

3. Results

3.1. Eye movement characteristics when visitors observe different forest space of waterscape

3.1.1. Characteristics of fixation in differ forest space of waterscape. The heat map can intuitively represent the participants' fixation results, and use different colors to show the participants' attention to a scene or element and its distribution. Among them, red represents the area where the fixation duration is longest, and blue represents the area where the fixation duration is shorter.

Through the analysis of the heat map and spatial distribution map of fixation (Figure 4), as a whole, participants' focus area is mainly the lower center of the scene in differ forest space of waterscape. From the spaces' elements, we can see that the participants' attention is mainly focus on the building and the part of static water surface in the static waterscape space, while in the space of dynamic waterscape, except for elements of architectural represented by the bridge and the person, the participants' fixation points are more concentrated on the surface of flowing water and landscape stones rather than relatively static water surface nearby. That is, people's fixation points are different in differ forest space of waterscape, and the recognition of landscape architectural elements shows a high tendency in both scenes.

Figures 2 and 3 display the aggregate data collected at every 20 m distance on the trails, locations where more than half of the visitors displayed evaluative behaviors, subjects for evaluation, stream conditions, trail conditions, illumination levels and viewpoints as introduced in the brochure distributed previously among the tourists. Following are the analyses of visitors' evaluative behaviors based on four different environmental conditions, which include stream conditions, forest stands, trail conditions and relative illumination.

![Figure 4. Gaze behavior in differ forest space of waterscape.](image-url)
3.1.2. Differences in eye movement indicators in differ forest space of waterscape. In order to analyze whether there is a statistical difference in the eye movement observation patterns of the participants in the waterscape space, we selected three eye movement indicators: total fixation time, fixation count, visual span of lateral and portrait [22,23,32].

The T test in SPSS was used to analyze the differences of indicators for participants eye-movement in differ forest space of waterscape (Table 1). From the analysis results, we can founded that the participants eye-movement indicators also show differences in differ forest space of waterscape (P <0.05), especially the indicator of average visual span in the space of dynamic waterscape is greater than the static waterscape. That is to say, when viewing dynamic waterscape, participants have more information content at one time because of the rich landscape elements, and pay more attention to exploring the scene as a whole; while in the static waterscape, the amount of information obtained by each fixation is relatively small and participants pay more attention to detail.

| Table 1. Differences in indicators of eye movement in differ forest space of waterscape. |
|---------------------------------------------------------------|
| **Levine ANOVA test** | **Mean t test** |
|                            |   F   |  Sig. |   t  |  d  |  Sig. |
|--------------------------|-------|-------|------|-----|-------|
| Total fixation time      | 0.489 | 0.486ns| 0.037| 104 | 0.971ns |
| Fixation count           | 0.375 | 0.542ns| 0.505| 104 | 0.615ns |
| Lateral visual span      | 3.244 | 0.075ns| 2.184| 104 | 0.031*  |
| Portrait visual span     | 5.520 | 0.021* | 7.601| 104 | 0.000** |
| N                        | 106   | 106   | 106  | 106 | 106    |

*significant in 5% difference, **.significant in 1% difference, ns: no significant difference.

3.2. Psychological perception of visitor's when observing different forest space of waterscape

3.2.1. Evaluation characteristics and evaluation differences in differ forest space of waterscape. We used the Wilcoxon rank sum test in SPSS 23.0 to make a difference analysis of participants' psychological perception evaluation in the two waterscape spaces (Figure 5). The results show that the participants' psychological evaluations are also different in differ forest space of waterscape. There are significant differences in the five indicators which include “The changement of landscape content”, “The richness of color”, “The Brightness of color”, “The openness of the space”, and “The visibility of distant landscapes”.

Among them, in the space of static waterscape, participants prefer “The visibility of distant landscapes” and “The openness of the space”. That is, people prefer the permeability of space in the space of static waterscape. While in the space of dynamic waterscape, people prefer the indicators about space changement and color including “The changement of landscape content”, “The richness of color” and “The Brightness of color”.

3.2.2. Participants' preferences in differ forest space of waterscape. In the questionnaire, we compiled the participants' descriptions the preferences of the two forest spaces of waterscape (Figure 6). It can be seen that the descriptive words used by participants to describe different types of waterscape spaces are basically similar, but the frequency of use of descriptive words are differently. When describing the dynamic waterscape space of the forest, the high-frequency words used by participants to describe the landscape elements they prefer in the space are water (90.57%), color (45.28%), building (39.62%), stone (28.30%), and plants (20.75%); while describing the static waterscape space of forest, are mainly concentrated in water (71.70%), mountains (30.19%), reflections (15.09%), plants (15.09%), and building (13.21%). In other words, participants' attention to the elements is basically similar in the space of forest waterscape, but as the characteristics of the landscape waterscape space change, the degree of attention to its elements will also vary.
Figure 5. Psychological perception evaluation analysis, PSD: The diversity of plant species; LCC: The changement of landscape content; LTD: The three-dimension of near-middle landscape; TCR: The richness of color; TCB: The Brightness of color; TSO: The openness of the space; VDL: The visibility of distant landscapes; TSN: The neatness of space; SSH: The sense of hierarchy in space; TSS: The satisfaction of space; ** significant in 1% difference.

Figure 6. The favorite elements in the forest waterscapes.

3.3. Relationship between human behavior of eye movement and cognitive evaluation of psychological in differ forest space of waterscape

3.3.1. Relationship between behavior of eye movement and cognitive evaluation index of psychological in the space of forest waterscape. Analyze the relevant results of participants' eye movement and psychological cognitive evaluation in landscape space (Table 2). First, we can see that the change of the scene is significantly negatively related to the landscape content ($P = -0.329$), color richness ($P = -0.461$), and color brightness ($P = -0.309$), and is significantly positively related to the
space openness ($P = 0.716$) and landscape permeability ($P = 0.390$). In other words, the characteristics of the waterscape affect the participants’ perception preferences.

Secondly, there has significant correlation between participants' satisfaction of psychological perception assessment and the count of eye movement fixation ($P = 0.259$). That is, the higher satisfaction of participant in the scene, the higher fixations count produced by the eye movement, and it is also the same results in the study by Huang et al. [32]. In addition, the number of fixations of eye movement of the participants were also significantly positively correlated to other indicators in psychological evaluation, include diverse with the plants ($P = 0.195$), rich landscape content ($P = 0.307$), sense of landscape depth ($P = 0.222$), and sense of landscape hierarchy ($P = 0.247$), which means that participants prefer diverse plants, rich landscape content, strong depth and rich landscape hierarchy in the scene.

Third, the lateral visual span of the participants’ was significantly positively related to the sense of landscape depth ($P = 0.319$) and color richness ($P = 0.262$) in psychological evaluation. The portrait visual span of eye movement was significantly positively related to the richness of landscape content ($P = 0.248$) and color richness ($P = 0.328$), while it was significantly negatively related to the spatial openness ($P = -0.474$), landscape permeability ($P = -0.313$) and spatial uniformity ($P = -0.213$).

In addition, we can also see from Table 2 that the landscape elements, the richness of colors, the permeability and regularity of the space affect the participants’ observation mode of the waterscape space. The water landscape space with strong sense of depth, rich content, diverse colors and closed space, is more welcomed by the participants. This may due to the space have rich landscape information, and the participant is more willing to actively explore the corners of what they consider “interesting” in a wide range. However, the forest waterscape space with weak sense of depth, single content, single color, better permeability, open and neat space, have less landscape information, and the participants’ attention is focused on some certain place where considered “interesting” in small range.

Table 2. Correlation results between the behavior of eye movement and the cognitive evaluation of psychological in forest waterscapes.

|                  | PSD        | LCC        | LTD        | TCR        | TCb        | TSO        | VDL        | TSN        | SSH        | TSS        |
|------------------|------------|------------|------------|------------|------------|------------|------------|------------|------------|------------|
| Palace (1 in DWC, 2 is SWC) | -0.128**  | -0.329***  | -0.132**   | -0.461***  | -0.309**   | 0.716***   | 0.390***   | 0.174***   | 0.111***   | -0.123***  |
| Total fixation time | -0.171***  | -0.219***  | -0.153**   | -0.260***  | -0.002    | 0.026      | -0.083***  | -0.213***  | -0.020***  | -0.178***  |
| Fixation count    | 0.195**    | 0.307**    | 0.222**    | 0.175**    | 0.107**    | 0.074      | 0.213**    | 0.070**    | 0.247**    | 0.259**    |
| Lateral visual span | 0.133**   | 0.182**    | 0.319**    | 0.262**    | 0.126**    | -0.133***  | 0.041**    | -0.089**   | 0.033**    | 0.012***   |
| Portrait visual span | 0.121**   | 0.248**    | 0.139**    | 0.382***   | 0.146**    | -0.474**   | -0.313**   | -0.213**   | -0.036**   | 0.112***   |

*Significant in 5% correlation, **Significant in 1% correlation, ns: no significant correlation.

DWC: Dynamic waterscape ; SWC: Static waterscape; PSD: The diversity of plant species; LCC: The changement of landscape content; LTD: The three-dimension of near-middle landscape ; TCR: The richness of color; TCB: The Brightness of color; TSO: The openness of the space; VDL: The visibility of distant landscapes; TSN: The neatness of space ; SSH: The sense of hierarchy in space; TSS: The satisfaction of space

3.3.2. Relationship between the behavior of eye movement and the cognitive evaluation of psychological in forest waterscapes. By matching the higher rate of fixation for elements in the participants' hot spots with the preferred landscape elements they answered the questionnaire of psychological perception, we found that there is a corresponding relationship between the elements of landscape collected by experiment, attracted the participants' visual appeal of the subjects and the favorite elements in the scene answered by questionnaire. (Table 3).
In forest space of dynamic waterscape, the same changeable objects attracted the fixation and attention of the participant: water, building, stone, plant, etc. And the participant’s attention mainly focused on waterscape and building.

In forest space of static waterscape, waterscape and building are also the main objects both in visual concentration and perception assessment of participants. The objects of mountain, reflection and plant were not the main visual attention for participants, but the heat map showed that the visual attention of descriptive words for participants was mainly around the building.

These observations indicate that landscape architectural elements in the forest waterscape space also affect participants' appreciation and fixation behavior of the landscape. This result is the same trend as the research by Lien Dupont [24,25] that the existence of architectural elements affects people's observation behavior of landscape space.

**Table 3.** Relationship between eye movement behavior and descriptive words in forest waterscapes.

| Objects which focused gaze (Descending) | Dynamic waterscape | Static waterscape |
|----------------------------------------|--------------------|-------------------|
| Specific words (Descending)            | Waterscape, Building, Stone, Plant | Waterscape, Building, Stone |
|                                       | Waterscape, Color, Building, Stone, Plant | Waterscape, Mountain, Reflection, Plant, Building |

**4. Conclusions**

Eyes are the window for the mind, and people's cognition of landscape is largely the result that the eyes get information from the observation of landscape space. Eye-tracking experiments can tell us how visitors appreciate the landscape and which elements in the landscape space attract our attention. At the same time, the questionnaire of psychological perception can help us understand the reasons for their watching and their feelings after appreciate the landscape. In addition, combination the objective data obtained from experiments of eye-tracking and subjective data obtained from questionnaires of psychological perception is also a combination of qualitative and quantitative, which can not only reveal what relationship exists between human visual behavior and psychological cognition in the space of forest waterscape. It also promotes the objectivity of the research from the perspective of the objective analysis of the landscape.

Based on the conclusions of the previous behavior observation method, combined with eye tracking technology and psychological perception questionnaires, to analyze the relationship between the characteristics of visual behavior and the evaluation of psychological in the space of forest waterscape where visitors have more behavior evaluation during the forest walking, and reveal the interaction between the visitor and the water landscape in a deeper level. The main conclusions are as follows:

1. From the eye movement behavior, the visitor's eye movement behavior is different with the change of the waterscape space type. On the whole, the fixation area of the participants is the lower center of the scene. From the point of the degree of participants' attention to the elements in the scene, they tended to viewing elements of landscape such as the surface of waterscape and stones of landscape in space of static waterscape, and elements such as architecture, the surface of waterscape and stones of landscape in space of dynamic waterscape. In addition, we found that although they are both waterscape spaces, when watching dynamic waterscape, participants pay more attention to exploring and obtaining information in a large range as a whole; while observing the static waterscape, participants were inclined to explore and watch things from a local and small scale.

2. From the psychological evaluation, participants' psychological cognitive assessment is different in different forest space of waterscape. Participants are more inclined to choose a forest waterscape space with rich landscape content, colorful and bright, open space and better landscape permeability.

Among them, in static waterscape people are more inclined to the sense of transparency, while in dynamic waterscape, and people prefer the change of space and color. This is different from the research by Zohre [12] and others that the lake waterscape of the city is the most favored, while the
river waterscape of the natural space landscape is the least favored. In our study, the static waterscape space and the dynamic waterscape space were also well received by the participants, and the satisfaction of the dynamic waterscape space was slightly higher. That may due to different seasons and methods of collecting space samples.

Our results are also contrary to the results by Huang et al. [33], the brighter scenes produced less visual fixation. Our research results show that the brighter part of the space is more attractive, produces longer fixation, and two indicators of “whether the color of the space is bright” and “whether the color is diverse” have received high ratings in the participants' psychological evaluation. This is in line with the results of research by Zhang Z. and others [20], people have a higher tendency to evaluate the beauty of high-brightness and high-saturation forest landscapes.

In addition, from the perspective of participants' preferences in the evaluation of psychological perception in differ forest space of waterscape, the participants' preferences are basically similar, but with the change of spatial characteristics of forest waterscape, the preference degree of each element will be different.

(3) From the related results of human eye movements and psychological evaluation of landscape space, the characteristics of waterscape affect the participants' perceptual preferences. Participant has higher satisfaction in scenes with more fixation counts, and they prefer the diverse plants, rich landscape content, better permeability, and strong hierarchy in the scene.

On the other hand, it is found in our research that participants' evaluation of landscape elements, color richness, spatial permeability and regularity affect their observation patterns of forest waterscape space. In the forest dynamic waterscape space, people are more willing to actively explore places on a large scale they consider "interesting", but in the static waterscape space with weaker depth, single content, single color, better permeability, and an open and neat space, people are more willing to focus on a small range of some details they considered "interesting".

(4) From the relationship between human eye movements and descriptive words on the landscape space, there is a corresponding relationship between them, and the favorable architectural landscape affects people's fixation behavior.

According to the above survey and analysis results, we suggest that we should according the characteristics of differ landscape elements to plan or design the space of forest waterscape. And we should intersperse appropriate heterogeneous landscape space. Meanwhile, we select undergraduate and postgraduate as the subject of the eye-tracking experiments, and no objective analysis of groups such as office workers, the elderly and children. Therefore, in future research, we will enrich the survey objects and further study the relationship between forest landscape space and visitors.

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Conflict of Interest
All authors declare no conflict of interest in this manuscript.

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