The Thresholds of Greening Unit Serving Set as an Arousal Task Based on EEG and Eye Movement

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Research Article

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Abstract

Monotony is the most prominent characteristic feature of the prairie highway. Monotony can cause a decrease in the level of arousal, leading to lower vigilant. This study sets the greening unit as an arousal task to withstand the monotony and examines the different landscapes' effects on EEG(electroencephalograph) and eye movement for drivers. 26 participants took part in a simulated driving experiment. Three scenes correspond to other greening units, respectively, one set as the control group without greening. The results show that the greening unit will improve driver vigilance and external eye movement control preponderance. The type of eye movement and [(alpha + theta) / beta] performance optimal arousal is immediate but discontinuous; The type of eye movement and alpha sample entropy show different spatial patterns of landscapes have different effective lengths. In conclusion,(1) Landscape(Fully open with triangular shape) provides superior arousal effect;(2)The greening unit length threshold corresponding to the optimal arousal level of drivers is 666 m; (3)The alpha sample entropy of less than 0.234 can be identified as the threshold of effect greening length

1. Introduction

1.1. Background

Monotony means that road line types and landscapes remain unchanged or changed predictably [1]. Many simulations and real driving studies have proved that drivers' alertness and arousal levels under monotonous environments decrease and fatigue degree increases [2–7]. The global accident analysis data show that fatigue accidents related to a monotonous environment have prominent characteristics in road environment: Most fatigue-related accidents typically occur on roads with speed limits of 72 to 105 km/h in non-urban areas 81% of these accidents occur on straight lines [8–11]. Prairie highway is a typical, monotonous environment. The driver's workload is defined as underload [12, 13]. T. Oron-Gilad *et al.* proved setting alertness maintaining tasks (AMTs) or interactive cognitive tasks (ICT) in underload working conditions is an effective way to interrupt the accumulation of monotony on time dimension, but this effect is a short time, beyond a certain time threshold will be ineffective. These tasks are provided by on-board equipment, which is less likely to be extended to every driver than greening [13, 14–21]. Besides, Cassarino *et al.* proved drivers are more sensitive to natural landscapes than human-made ones by simulation driving and cognitive experiments [22–25]. Furthermore, the theory of directional response and habituation proves that the accumulation of continuous stimulus in the greening landscape will decrease the driver's vigilance [26–28]. To sum up, this paper assumes that (1) The greening unit can be used as an arousal task to maintain drivers' vigilance level by increasing visual stimuli,different spatial patterns of landscapes have different effective ; (2) There is an optimal arousal level of drivers from the greening unit. At this level, the greening unit can arouse drivers' visual attention and make the drivers more vigilance; (3) There is an adequate length for the greening unit. If the greening unit beyond this length, it will no longer attract the visual attention of drivers.

1.2. Clarify Fatigue, Vigilance, and Arousal

As a kind of arousal task, greening affects drivers' physiological and psychological processes in three aspects of fatigue, vigilance, and arousal [2]. Different definitions of these concepts may lead to some confusion in the understanding of these phenomena. Therefore, their significance in this study should be clarified first.

Vigilance: The literature highlights two concepts: a physiological state of alertness and a cognitive process representing the ability to maintain sustained attention while observing signals for long periods. Thiffault *et al.* indicate driving in a monotonous road environment is a vigilance task [1, 3, 29, 30]. For decades, much of the exploration of vigilance in the field of traffic safety has been tied to studies of driving fatigue, which has concluded that the most apparent consequence of fatigue is reduced vigilance [31–33]. Fatigue: Oron-Gilad and Matthews divide driving fatigue into mental alertness and physical impairment of body orientation. Unlike vigilance, fatigue studies focus on endogenous factors that influence vigilance, such as lack of sleep, changes in circadian rhythms, and driving duration. However, vigilance is mainly affected by exogenous or task-inducing factors, which will lead to changes in drivers' arousal and driving performance [34]. Arousal: Pribram *et al.* define arousal as, under the stimulation of AMTs, drivers improve the excitability of the cerebral cortex and the automatic physiological regulation function of increasing vigilance through the brain stem network structure [35, 36]. The arousal level is the level at which this function is performed. Kenny concluded that the low arousal level caused by long time monotonous road driving is an essential factor for fatigue [37].

Thus, it is fruitful to consider the combination of fatigue, vigilance, and arousal, since the study of either concept involves the measurement of the other two. Fatigue and vigilance have a similar theoretical basis, both of which focus on using the time-on-task experimental principle to detect a series of physiological and psychological signals from a monotonous stimulus for a long time [2]. Arousal focuses more on the drivers' ability to stay vigilance under AMTs.

1.3. A measure of Fatigue and Vigilance

Lal *et al.* indicate the most reliable and repeatable measure of time-related fatigue in monotonous driving tasks is the use of electroencephalography (EEG) [38–40]. Eoh proves both Alpha and [(alpha + Theta) / Beta] in brainwaves can represent the variation of driving fatigue with time [41]. Since vigilance is an essential measure of fatigue, the same EEG indicators that characterize fatigue describe vigilance. Craig *et al.* proved in a monotonous driving environment that Alpha and Theta power increased with vigilance decline[38, 42, 43]. Lal *et al.* proved [(alpha + theta) / beta] is the most reliable index to measure the vigilance of driving in a monotonous environment. The increase of this index indicates a decrease of vigilance [44, 45]. Therefore [(alpha + theta) / beta] can measure fatigue and represent alertness level. Since fatigue has a strict time limit and occurs after 20min of driving, this paper only studies the greening unit's impact on drivers' vigilance [2].

1.4. Measurement of Arousal

Arousal level is an indicator of whether the greening stimulus is significant. It varies continuously with the arousal task duration, but there is no definite measurement standard [46]. Therefore, the measurement of arousal is the key to judge whether the greening stimulus is significant. The following theories provide measurement methods:

1.4.1. Habituation theory

Loeb *et al.* explain habituation as the central nervous system is prone to form habits in response to repeated stimuli. With the continuation of repeated stimuli, habituation is strengthened, and vigilance is reduced. Since arousal is defined as the ability to stay vigilance, it also decreases arousal [28]. This theory suggests that arousal levels can be measured in terms of vigilance using [(alpha + Theta) / beta].

1.4.2. The transformation between spontaneous eye movement and exogenous eye movement

Stern indicates eye movement is composed of two categories: one category caused by identifiable external stimuli (exogenous), and the other is spontaneous (endogenous) [47]. Sirevaag *et al.* found that the spontaneous eye movements at the beginning of the arousal task were caused by increased gaze duration and saccade duration and the decrease of blink duration due to the exogenous stimulus [47–50]. Findlay *et al.* indicate this phenomenon is closely related to drivers' cognitive processing of stimuli [51–53]. Pivik and Kaneko explain that spontaneous eye movement is related to the presentation of motivation and cognitive load. The constant visual stimulus will increase drivers' cognitive load, leading to decreased vigilance and arousal level [54]. Tanaka *et al.* found that spontaneous blinking tended to grow with vigilance reduction during the constant arousal task [52, 55–63]. To sum up, blink duration, fixation duration, and saccade duration can measure arousal levels from the visual perspective. Still, there is no standard to measure endogenous and exogenous eye movement behavior.

1.4.3. Hypothesis on "highway hypnosis"

Wertheim explains highway hypnosis as a decline in drivers' vigilance in predictable environments for a long period [64, 65]. Other researchers, including Wertheim, believe that the type of eye movement could be a key factor in explaining highway hypnosis [27, 66]. The oculomotor system would receive two information types: retinal (external) and extra-retinal (internal) [67–70]. Retinal (external) controlling mainly ruled by retinal feedback, and extra-retinal (internal) controlling mainly ruled by extra-retinal feedback. Retinal feedback is used to deal with external visual information coming from the road environment. On the contrary, Extra-retinal feedback is used to deal with extra-retinal information to control eye movements. The extra-retinal signals include information from the mental activities and internal motor programmers [71–73]. While driving, the main visual feedback type is Retinal feedback [74–76]. The two types of feedback are in a state of equilibrium when one strengthens, and the other weakens [75]

Wertheim explained that when drivers are in a state of "highway hypnosis", the dependence on extra-retinal feedback is strengthened, but the dependence on retinal feedback is weakened. This is due to the monotony road environment, where the visual scene on the retina is highly predictable, drivers can accomplish the driving task by paying less attention to the road environment. As a result, a part of retinal feedback is replaced by extra-retinal feedback. Thus, driving is undertaken based on data derived from very few external visual signals. Furthermore, Wertheim observed that these two eye movement patterns correspond to the two ways of “controlled” attention and “automatic attention” that from brain cognition [65].

Wertheim used a psychophysiological measurement to distinguish eye movement control types that can be influenced by the visual system’s activity: EEG alpha activity (8–12 Hz). This activity is usually measured on the visual centers of the brain (occipital-parietal region). According to Wertheim, when the attentive component of oculomotor control predominates, the occipital alpha activity is either softened or blocked, this being a sign of mental vigilance. In contrast, when the intensive component is predominant, an increase is found in the occipital alpha activity, indicating low mental vigilance [74]. In his study, the occipital alpha activity was found to a greater extent in the high predictability condition (intensive control) than in the low predictability one (attentive management) [77].

Ray indicates alpha activity is present in mental relaxation states, physiological inactivity, surveillance loss and is either absent or blocked during visual attention [78]. Bender *et al.* demonstrated that alpha activity is associated with eye movement [79–81]. Therefore, this paper assumes a significant correlation between eye movement and Alpha in the simulation experiment. If the hypothesis is correct, the arousal level was measured by alpha activity united with [(alpha + Theta) / beta]. The sufficient length of the green unit was determined by alpha activity.

1.4.4. Objects

The road safety problem of young novices is a global problem. Novices tend to have narrower road areas than experienced drivers, and they are less efficient at predicting and responding to dangers, especially when the risks are not apparent [82–86]. Young novices under 25 are more susceptible to disturbances from environmental and cognitive loads, with males particularly prominent [87]. More specifically, Foy proved that experienced drivers among young drivers (driving more than 10,000 miles) have a higher ability to manage mental load than novices (driving less than 5000 miles) and that this ability is not related to age [88]. Studies from the UK and Greece show that traffic accidents in monotonous road environments mainly involve drivers aged 20–25 [89, 90]. Therefore, this study conducted a simulated driving experiment for male novice drivers aged 20–25 years.

1.5. Aims

(1) Investing the correlation between alpha and eye movement, if the correlation is significant, A combination of Alpha and [(alpha + Theta) / Beta] was used to measure the driver’s arousal level under the greening unit. Thus, the optimal spatial patterns of landscape and the length of the green unit corresponding to the optimal awakening level can be found.

(2) The sufficient length of the different landscape is different. The sample entropy representing Alpha’s complexity is selected as the Discriminating Threshold of the adequate size based on the Receiver

Operating Characteristic Curve (ROC) Analysis.

2. Methods

2.1. Experimental Platform

The human-machine transportation environment experimental platform of Inner Mongolia Agricultural University has a French Renault 6-DOF real-car simulation driving experiment system, as shown in Fig. 1. This system includes hardware and software. The hardware part mainly consists of a BYD’s real car cockpit, a curved screen subtending 300° horizontally, and three projectors with the frequency of 50 Hz project the virtual environment on the curved screen the resolution of 3072 × 768 pixels. The software part is mainly consisting of the SCANeR DT comprehensive driving simulation package. This simulation package can present the green landscape scene designed before on the curved screen through the APIs software of the windows system [91].

2.2. Experimental Equipment

MP150 multi-channel physiological recorder (maximum sampling rate 400 kHz, including EEG100C EEG amplifier) produced by American BIOPAC is used to obtain EEG data. A computer installed with Acknowledge 4.1 data analysis software is used to analyze and save EEG data. The MP150 was placed in the first officer position; the laptop is placed on a laboratory bench outside the car. The MPl50 system transmits data to the computer over Ethernet. The MPl50 system provides an Ag-AgCl electrode for the acquisition of EEG signals. The electroencephalogram (EEG) was connected to the corresponding electroencephalogram (EEG) via an electrode plate (Agcl as an induction element). Wertheim proved that alpha activity measured on the brain’s visual centers (occipital–parietal region) is significantly correlated with the type of eye movement [77]. Cerezuela proved α (8–13 Hz), β (14–30 Hz), θ (4–7 Hz) activity collected by an occipital–parietal derivation in position O2-P4 (bipolar fitting) (as per electrode fitting in the 10–20 International System) could reflect drivers’ vigilance [92]. Therefore this paper selects position O2-P4 (bipolar fitting) as EEG activity extraction potential. Adjust the sampling frequency to 250 Hz based on the kurtosis and probability criteria and set the bandpass filter frequency to 1 Hz (high-pass filter) to 30 Hz (low-pass filter) [93].

Eye movement is closely related to the stimulation of the exterior landscape and internal information processing mechanism. Eye movement data includes fixation, saccade,blink, and pupil diameter [94]. The iView HED eye tracker developed by the German company SMI was used to obtain eye movement data. The iView HED eye tracker consists of eyepieces that track the movement of the driver’s left eye and objectives that record driving videos and are fixed to the driver’s head by a hat. The other computer’s monitoring and storage of eye movement data are connected to the eye tracker located on the laboratory bench.

2.3. Subjects

In the experiment, the number of subjects will directly affect the reliability of experimental research results. EEG and eye movement of drivers are typically distributed (sig. > 0.05). The sample size formula [formula (1)] of the random sampling method can be used to calculate the required sample size [95]. According to the eye movement and EEG measured early by the research group, take alpha power as an example. The standard deviation is 3.49×10^{-11},permissible error is 1.75×10^{-11}. As a result, n is 15. The sample size is 11,12,19,16,18 and 17 by beta, Theta, fixation duration, saccade duration, blink duration, and pupil diameter. Therefore, 28 male novices (driving less than 5000 miles) between the ages of 20–25 (mean = 22.64, S.D. = 1.82) were selected as experimental subjects. Statement on ethics approval and consent was set in Declarations.

$$n \geq \frac{Z^2 SD^2}{d^2} \qquad \text{formula (1)}$$

n-sample size

Z-Z-statistic when the confidence level is 95%, Z = 1.96

SD-The population standard deviation of each test indicator of driving characteristics

the d-Allowable error of each test index

2.4. Experiment Scene Design

2.4.1. Greening elements

The greening unit is composed of green features. To ensure that the landscape can be used for visual stimulation in four seasons, two evergreen shrubs are selected as green plants: *Sabina procumbens* (Endl.) *Iwata et Kusaka* and *S.chinensis* (L.) Ant. (*Juniperuschinensis* L.).

2.4.2. The location of the greening location

This experiment's secondary road simulation complies with the People’s Republic of China's specifications in 2018. Two-way two-lane motor traffic, the lane width is 3.5 m, the shoulder width is 1m, and the greening bandwidth is 5 m [96–97]. The distance between shrubs and road shoulders was determined as 3 m [98, 99].

2.4.3. Greening unit simulation scene

The experimental scene is designed as four kinds in Table 1 and Fig. 2. The simulation scene was drawn using CAD 2009, Photoshop 2018, and 3D-MAX software [100]. The connection between the drawing location and each module of the simulation driving system was completed through SCANeR DT comprehensive driving simulation package.

Table 1
Four types of virtual landscapes designed

	Greening unit	The shape of greening element	enclosure degree/height(m)
Scene1(S1)	no	no	Fully open/no
Scene2(S2)	*S.chinensis*(L.)*Ant.* *(Juniperuschinensis* L.*)*	linear	Closed/1.5
Scene3(S3)	*S.chinensis*(L.)*Ant.* *(Juniperuschinensis* L.*)*	Triangular	Closed/1.5
Scene4(S4)	*Sabinaprocumbens* (Endl.) Iwata et Kusaka	Triangular	Fully open/0.5

2.4.4. Road design

The four scenes have the same parameters except for different greening elements. Thus, the scene's line style is a 1000 m adaptation section + 14.67 km greening section + 1000 m end section, lasting for 13 min. There is free traffic flow.

2.5. Experimental Process

The driver will be informed of the test time in advance. Accident statistics show that between 16:00 and 18:00 within 24 h is the daytime peak associated with reduced vigilance [8]. Every subject is arranged to arrive at the laboratory at 15:00 to complete the preparation work and start the experiment at 16:00. Subjects were asked to keep their heads as stable as possible and drive in the prescribed lane and keep the speed at 80 km/h. The test is divided into standard test and formal test, divided into two days. To familiarize the participants with the driving simulation system in advance and eliminate the simulated disease's interference in the experiment, a driving practice of 30 min was set up. Drivers 2 and 23 were unable to participate in formal experiments due to simulated conditions. The other subjects came back a day later for the standard test.

In a formal test, the driver was required to complete the experiments of four greening scenes S1, S2, S3, and S4 with a speed limit of 80 km/h, and the four scenes were randomly played. Thiffault has demonstrated that continuous driving on monotonous roads for more than 20 min can cause fatigue-like injuries [2]. To avoid this damage, the driver must relax and rest in the car for 10 min after completing one scene before starting the next scene's mission.

2.6. Data Preprocessing and Statistical Analysis

2.6.1. Data preprocessing

For every driver, eye movement (saccade duration, fixation duration, blink duration, and pupil diameter) are calculated every 30s, then the four eye movement indexes of 26 drivers were averaged. For every driver, Alpha, beta, and Theta's absolute power are calculated every 30 s. The EEG power of each driver was normalized by the following formula (formula 2) to obtain the relative power.

$$P(relative) = \frac{P(absolute) - min}{max - min} \qquad \text{formula (2)}$$

P(absolute)-the absolute power value of each waveform per driver

Min-the absolute minimum power of each wave for each driver

The max-the maximum absolute power of each wave for each drive

Then the relative power of the three waves of 26 drivers was averaged. There are two indicators related to eye movement type and vigilance:

- Alpha (frequency band (8–12 Hz)) relative power: Wertheim and Gamma indicate alpha power can be considered an indicator of controlling type for eye movement. Extra-retinal (internal) controlling with higher alpha power, Retinal (external) controlling with lower alpha power.
- [(alpha + theta) / beta] relative energy parameter: A large number of experiments showed that the higher the index, the lower the level of vigilance.

2.6.2. The verification of the correlation between alpha power and eye movement

Due to eye movement complexity, it is impossible to distinguish eye movement type by eye movement from present studies. The advantage of the hypothesis on ‘highway hypnosis’ is that alpha power can distinguish between external and internal eye movements to determine drivers' arousal level under the greening unit. Therefore, verifying the correlation between alpha wave and eye movement is the premise of this study. IBM SPSS 22.0 was used to analyze the correlation of Alpha relative power, fixation duration, saccade duration, blink duration, and pupil diameter in each scene. The results are shown in Table 2. It can be seen that relative alpha power is significantly correlated with average fixation duration and pupil diameter. The relative alpha power and [(alpha + Theta) / beta] of the four scenarios are plotted on boxplots 3 and 4. The median value, upper and lower 1 / 4 digit of relative alpha power, all showed S1 was more massive than other greening units, indicating that the proportion of external eye movement in greening landscape was significantly higher than that in blank control. The mean, median, and upper 1 / 4 digit of [(alpha + Theta) / beta] also showed S1 was more massive than other greening units, indicating that greening units' vigilance was significantly higher than that of the control group. However, only the lower 1 / 4 digit of S4 appears higher than S1, so each landscape’s optimal arousal level is defined as relative alpha power and [(alpha + Theta) / beta] less than their lower 1/4 digit.

Table 2
The correlation of Alpha relative power, fixation duration, saccade duration, blink duration, and pupil diameter in each scene

			Eye movement			
			Saccade duration	Blink duration	Fixation duration	Pupil diameter
Alpha relative power	S1					
	Alpha	Pearson	0.091	0.459*	0.457*	0.515*
	S2					
	Alpha	Pearson	-0.499*	0.454*	-0.578*	0.560*
	S3					
	Alpha	Pearson	-0.116	0.161	0.444*	-0.544*
	S4					
	Alpha	Pearson	-0.656**	-0.524*	0.729**	0.851*

** significant correlation at the 0.01 level (bilateral)

* significant correlation at the 0.05 level (bilateral)

3. Results

3.1. The Greening Length Corresponding to the Optimal Arousal Degree

The difference between Alpha and its lower 1 / 4 digit in each scene and [(Alpha + Theta) / beta] and its next 1 / 4 digit in each scenario are calculated separately. Both difference values are less than zero, indicating that the driver is at the optimal arousal level. In Origin 9.0, the two differences in each scene's time-varying pattern are obtained, as shown in the Figs. 4a-4d.

The arousal level only exists within the 30 s from the beginning of S2, S3, and S4. The conclusion that S1 is 90 s – 210 s and 570 s – 600 s and does not accumulate in time shows that the optimal arousal level occurs when the subject just recognizes the short landscape time.

3.2. Determination of the Effective Length of the Greening Unit

K-means Clustering algorithm was employed to conduct a clustering analysis of relative alpha power collected from four scenes in the Spyder module under Anaconda3 (64-bit), and the results are shown in

Fig. 5. The relative Alpha power threshold for eye movement type was 0.3, relative alpha power greater than 0.3 was internal eye movement, and Alpha relative power less than 0.3 was external eye movement.

The Alpha of S2, S3, and S4 was subtracted by 0.3, respectively, and the result was shown in Fig. 6 (a). Sample Entropy (SampEn) is an evaluation index that measures a time series' complexity by estimating the probability of generating a new pattern in a signal. The greater the likelihood of a new way, the greater the complexity of the sequence. The smaller the sample entropy's value, the higher the sequence self-similarity, and the lower the converse. Based on this, the relative alpha power's sample entropy is selected to determine the maximum duration of external eye movement control after the landscape appears. Sample entropy requires the number of time series $N \geq 3$, so the analysis starts from 90 s. The calculation process is completed in the Spyder module under Anaconda3 (64-bit). The calculation result is shown in Fig. 6 (b).

Alpha relative power reflects the type of eye movement, and sample entropy demonstrates the complexity of eye movement type changes. S2 and S1 showed a small sample entropy before 360 s. It indicates that the complex level of alternate control of internal and external eye movement types is different from S1 to S2 only appears before 90 s in S2. Also, S2 showed external eye movement control in the 30 s and 60 s, so the effect stimulation duration of S2 was 60 s. The sample entropy of S3 and S4 is significantly higher than that of S1, indicating that the complexity of the alternations of drivers' internal and external eye movement types in these two landscapes is much higher than that of S1. The intensity of S3's internal and external eye movement alternations decreases gradually over time S3, continuous internal eye movement control appeared after 150 s, so S3 has an effective stimulus duration of 150 s. The sample entropy of S4 is generally higher than the other four landscapes. It indicates that the intensity of internal and external eye movement control alternations is the highest under S4. However, there was a mutation at 120 s, meaning that the driver still maintains the external eye movement control of the previous 90 s. Only 330 s showed internal eye movement control, at which time the sample entropy showed a significant increase. This indicates that the intensity of the alternations of the driver's internal and external eye movement control increases, external eye movement control increased significantly to resist internal eye movement control. Therefore, the effective length of the S4 is 600 s.

ROC (receiver operating characteristic curve) is used to determine the sample entropy threshold of the Alpha. This process is completed in SPSS 20.0. The ROC curve area's AUC value is 0.92, which indicates that the judgment has higher accuracy. The ROC curve is shown in Fig. 7. According to the Jordan index, the optimal threshold of alpha sample entropy is 0.234. At this time, 90.9% of valid greening unit lengths are correctly judged, and only 16% of invalid greening unit lengths are misjudged as the right landscapes.

4. Discussion

This study's results consistently support the central hypothesis: the greening unit can play the role of arousal task within its threshold. What was also prominent in the works was: (1) fixation duration and pupil diameter are significantly correlated with relative alpha power, Alpha can be used as a standard to distinguish between internal and external eye movement; (2)Landscape(Fully open and triangular shape) provides superior arousal effect;(3) the optimal arousal threshold for the greening unit is 666 m; (4) the effective length of the different greening unit is extra, the alpha sample entropy of less than 0.234 can be identified as the threshold of effect greening length.

According to Wertheim, the stimulus movement's high predictability produces a rising dependence on the oculomotor control of extra-retinal feedback. Consequently, the intensive oculomotor activity's greater predominance is that the retinal information is not sufficiently used as feedback on the performance. Thus, driving is undertaken based on information derived from very few external visual signals. Besides, alpha activity is higher for external eye movement control and lower for internal eye movement control [77].This paper discovers that relative Alpha power extracted from position O2-P4 is associated with eye movement Significantly. This result verifies Wertheim's hypothesis on “highway hypnosis”. However, in the correlation analysis (Table 1), Alpha is correlated with fixation duration, but the positive and negative correlation is not uniform. Sirevaag *et al.* indicate that visual stimulation increases the fixation duration [47–50], which means that relative alpha power is negatively correlated with fixation duration. This contradiction can be explained as follows: there are two ways in which fixation reflects drivers cognize of the landscape - When the driver is stimulated by the green unit, the driver can track the green elements through fixation to increase the fixation duration. The oculomotor system's main feedback signal comes from the greening unit's retinal information so that external eye movements dominate. Alpha is negatively correlated with fixation duration; When the greening unit stimulates the driver, the driver can process the landscape information through fixation behavior to increase the fixation duration,extra-retinal signals would probably collect the information coming from the mental representations and internal motor process, internal eye movement dominates, Alpha is positively correlated with fixation duration. Similarly, blink duration, saccade duration, and pupil diameter also show different correlations with Alpha. Therefore, it is impossible to judge the driver's eye movement type by using eye movement alone. Alpha should be selected to distinguish eye movement types, which is the innovation of this article. Figure 3 indicates the greening landscape as an arousal task shows more obvious external eye movement dominance than the on-greening landscape and shows higher arousal levels than the on-greening landscape. The hypothesis on “highway hypnosis” can be explained in another way. Due to the landscape's tracking or information processing by drivers' eye movement in the same highly predictable road environment, the three greening units' experimental group still shows more external eye movement control and higher alertness than the control group without landscape. Therefore, the eye movement mechanism of the hypothesis on “highway hypnosis” is supplemented from the perspective of short time: Within 10 minutes of the simulated environment, the addition of a green landscape can increase external eye movement control and driver vigilance, although the green landscape is set up in a highly predictable manner. It is in accord with a conclusion Alertness maintaining tasks (AMTs), and interactive cognitive task (ICT) can increase driver vigilance developed by Oron-Gilad and Gershon [13, 21]. It supports the hypothesis that the greening unit is an arousal task. The scenery proposed by Jia indicates that the landscape should stay in the driver's field of vision for at least 5 s so that the driver can see it clearly [101]. Wang proposes that to prevent the vigilance drop caused by a monotonous landscape, the length of a single landscape should not exceed 5000 m at the speed of 80 km/h [102]. In this paper, the three greening unit's effect lengths are 1333 m, 3333 m, and 13,333 m, respectively, partly support Wang's conclusion. However, Fig. 3d shows that when driving under the landscape of *Sabina procumbens* (Endl.) Iwata et Kusaka, the drivers' vigilance does not significantly decrease after 5000 m, indicating that the length is insufficient to judge the effect threshold of greening units. This paper proposes the alpha sample entropy threshold of 0.234, which can judge different landscape types' effect length, avoiding generalization. Oron-Gilad and Gershon indicate alertness maintaining tasks (AMTs) and interactive cognitive tasks (ICT) have an immediate but localized influence on arousal [13, 21]. This view is supported by the optimal time threshold and the effect alpha sample entropy threshold. Therefore, the following suggestions are put forward for the formulation of the grassland highway greening standard: If the cost limit is considered, the greening length is set to 1333 m. When there is no cost limit, the lengths of different greening units are determined according to the sample entropy threshold alpha higher than 0.234. In this paper, the thresholds of the greening unit were obtained under the simulated environment with free traffic flow and young male novice subjects. Under the actual situation, each prairie highway has its unique traffic flow and owner situation, so it is necessary to study the greening threshold according to the traffic flow and owner situation of different prairie highway.

5. Conclusions

Greening unit can serve as an arousal task to withstand the monotony.EEG and eye movement from landscape's effect on drivers testify the confirmation.Different spatial patterns of landscapes have different arousal effect on drivers.There are optimal wake length and effective wake length for greening units:

(1)The optimal arousal length for different spatial patterns of greening units is 666m;

(2)The effective arousal lengths for different spatial patterns of greening units are different.The effective length of close and linear landscape is 1333 m, the effective length of close and triangular landscape is 3333 m, the effective length of fully open and triangular landscape is 13,333 m.Therefore fully open and triangular landscape has the best arousal for drivers.

(3)In order to provide the judgment threshold of effective length for the greening units of different spatial patterns in the future,alpha Sample Entropy combined with ROC curve can be used.The alpha sample entropy of less than 0.234 can be identified as the threshold of effect greening length

This study provide a reference to resist the bad effects of monotony on drivers through landscape intervention.Fully open and triangular greening units should be controlled in 13333m.Thus the driver has a high level of alertness,retinal (external) controlling is the main component，it is easy to deal with unpredictable events and ensure traffic safety.

Declarations

Availability of data and materials

The datasets used and/or analysed during the current study are available from the corresponding author on reasonable request.

Conflicts of interest

We declare that we have no conflicts of interest.

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Author Contributions

Y.L.Z. analyzed the data and wrote the manuscript. Y.L.Z. and S.L.Z. performed the experiments, participated in data analysis, S.L.Z. conceived and designed the whole project and funding support. All authors read and approved the final manuscript.

Statements

We confirm that all methods were carried out in accordance with the provisions of the Chinese Academy of Sciences on human-machine engineering experiments and strictly abide by the relevant provisions of the Chinese Traffic Law. All experimental protocols were approved by Inner Mongolia Agricultural University committee. We confirm that informed consent was obtained from all subjects.

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Figures

Figure 1

BYD car cockpit display

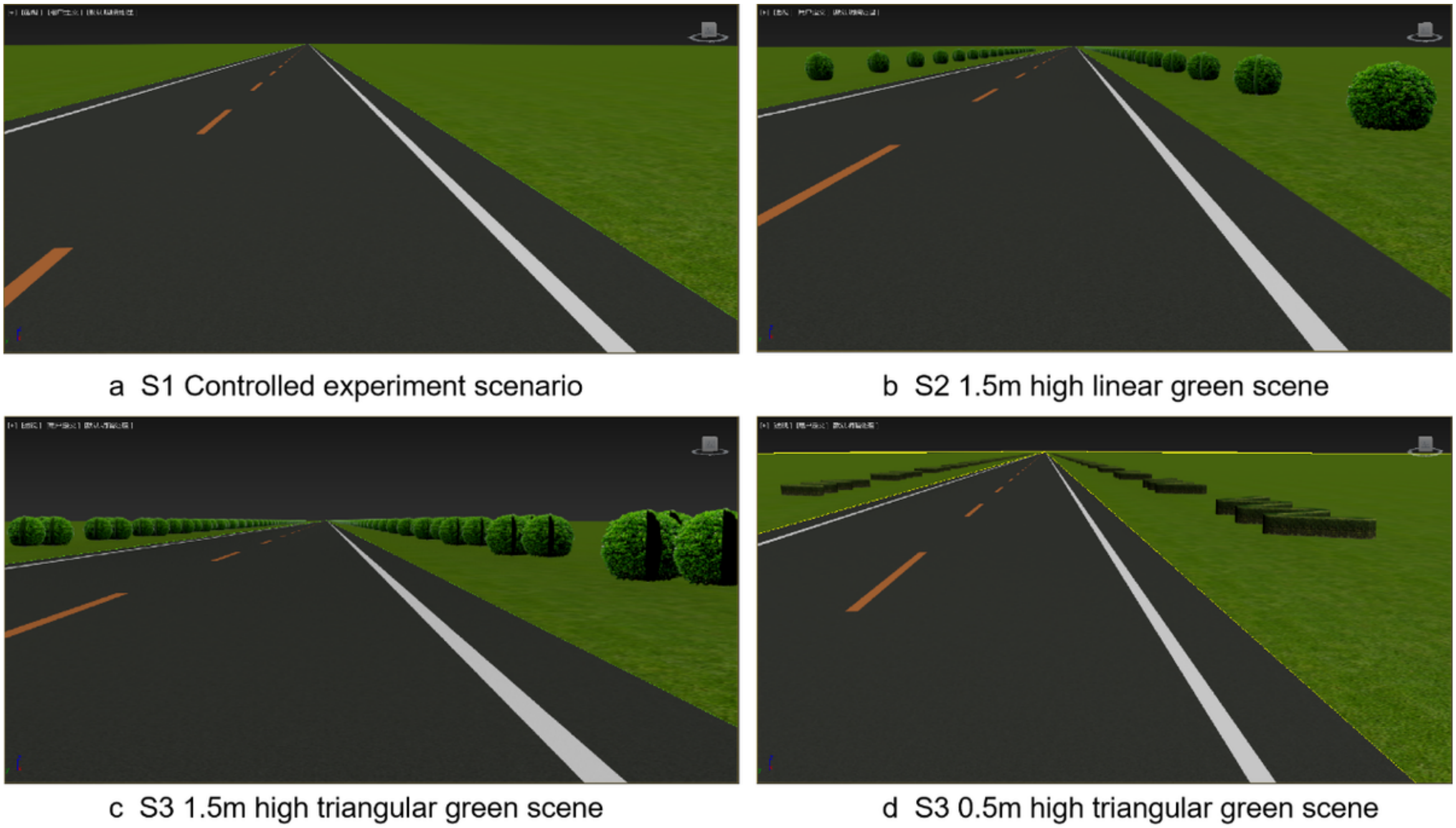

Figure 2

Four types of virtual landscapes designed using 3D-MAX

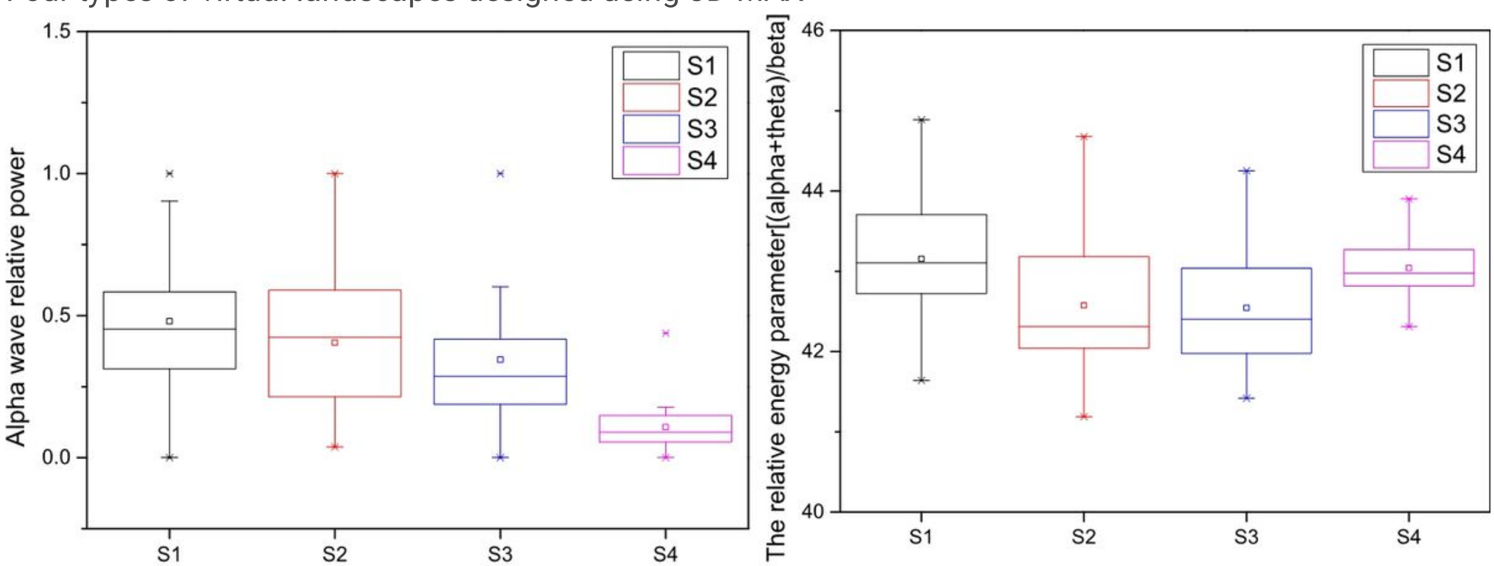

Figure 3

(a) Alpha relative power of the 4 scenarios, (b) The relative energy parameter [(alpha + theta) / beta] of 4 scenes

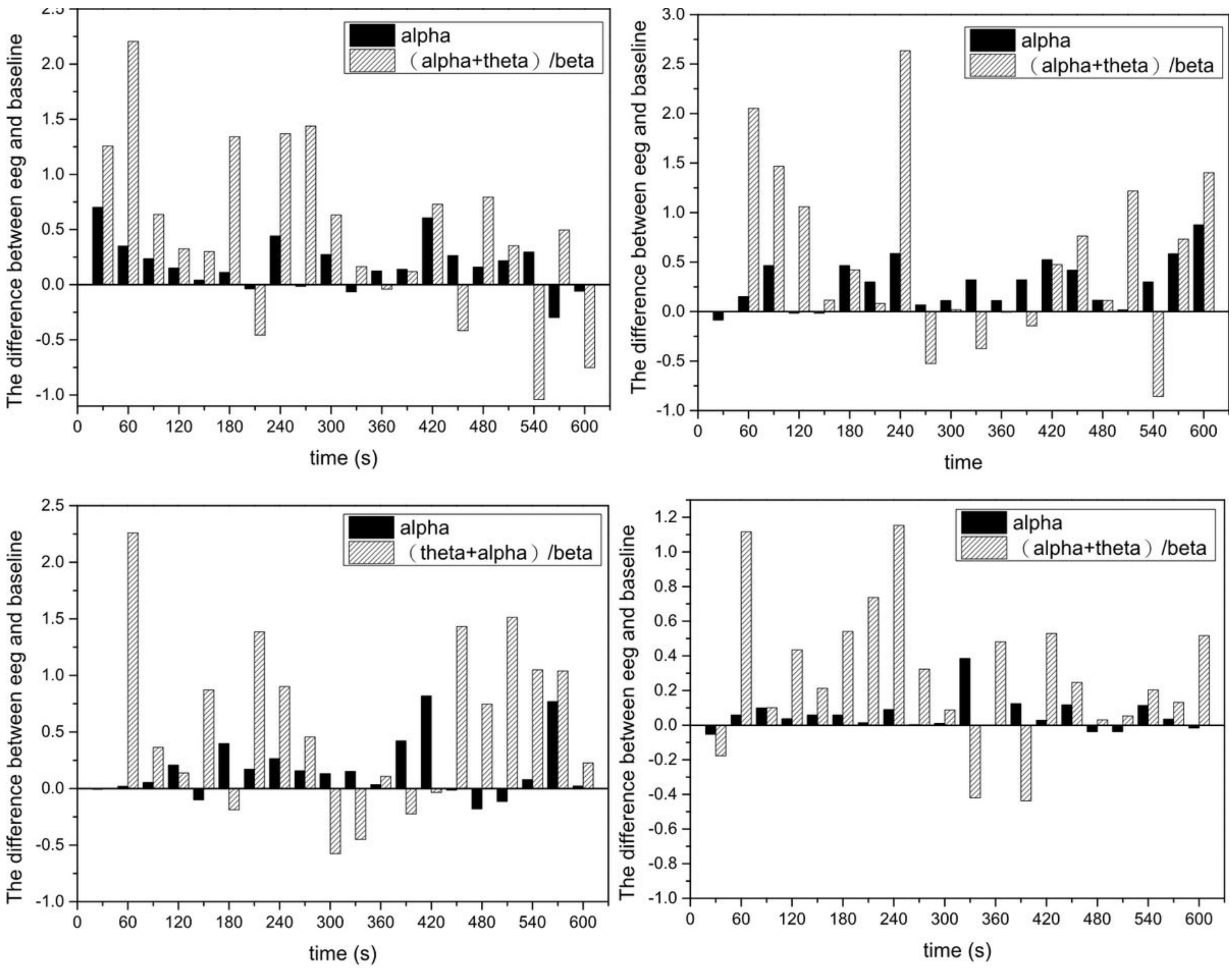

Figure 4

(a) Alertness and alpha power change with time of S1, (b) Alertness and alpha power change with time of Scene 2, (c) Alertness and alpha power change with time of S3, (d) Alertness and alpha power change with time of S4 (Test frequency: 30 s)

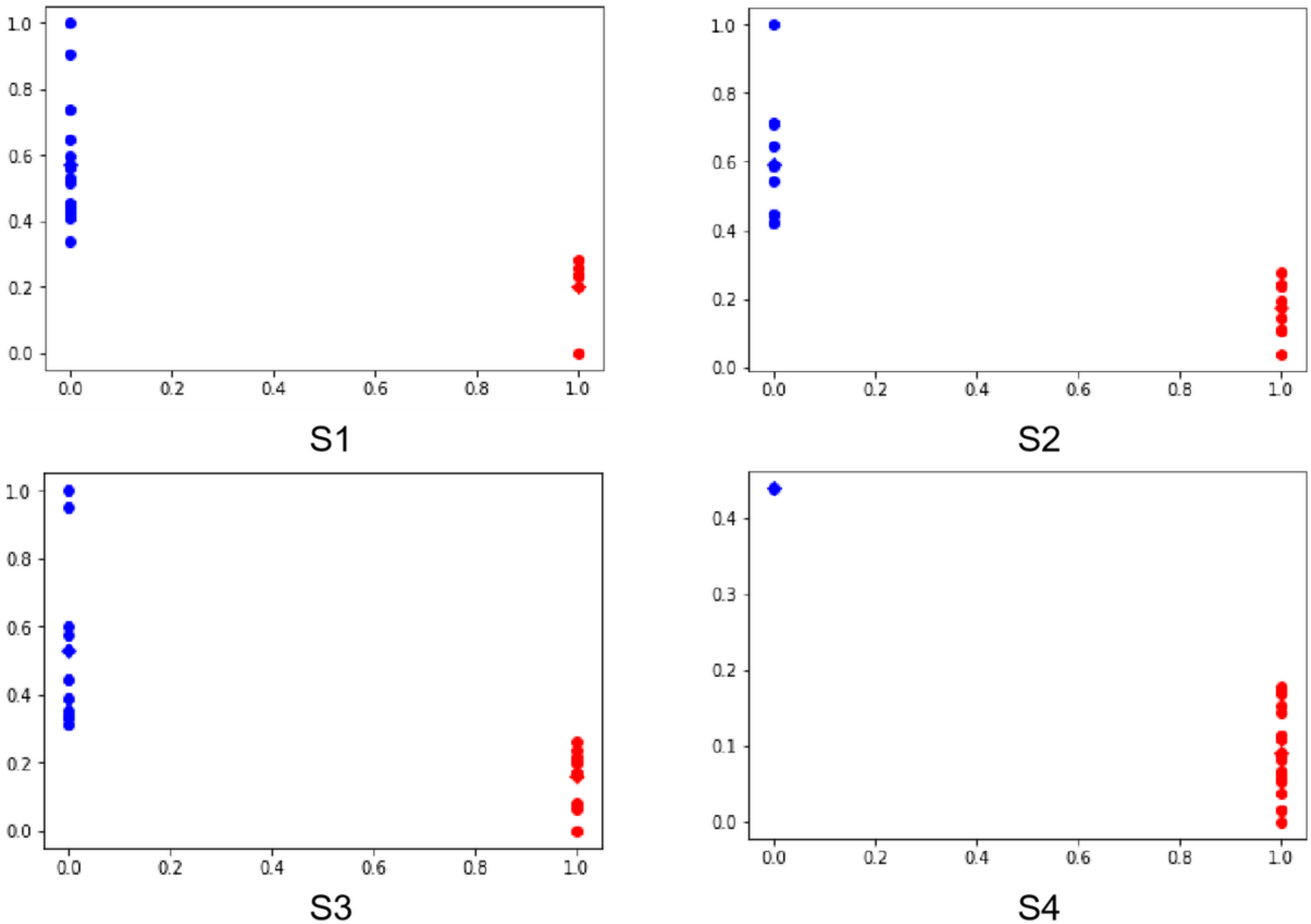

Figure 5

The result of k-means Classification on Alpha

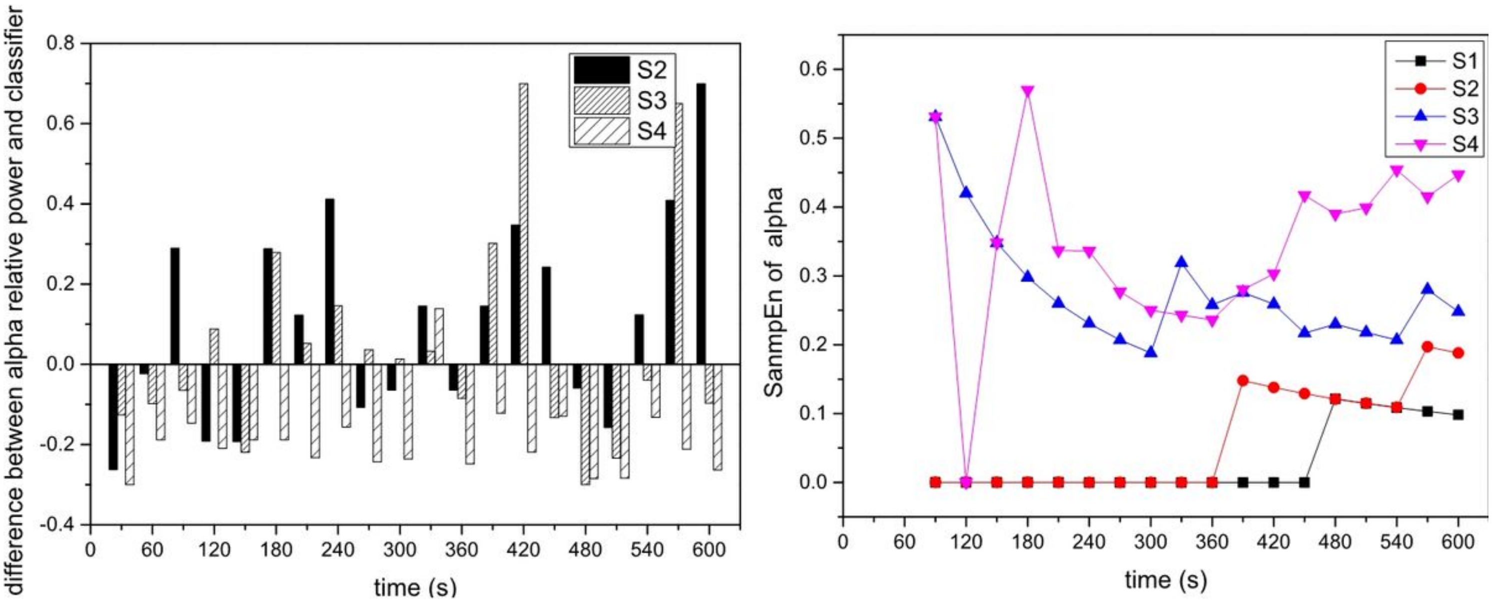

Figure 6

The maximum duration of external eye movement control after the landscape appears (a) the type of eye movement on time of 3 greening units (b) the change law of alpha SampEn over time (Sample frequency: 30 s)

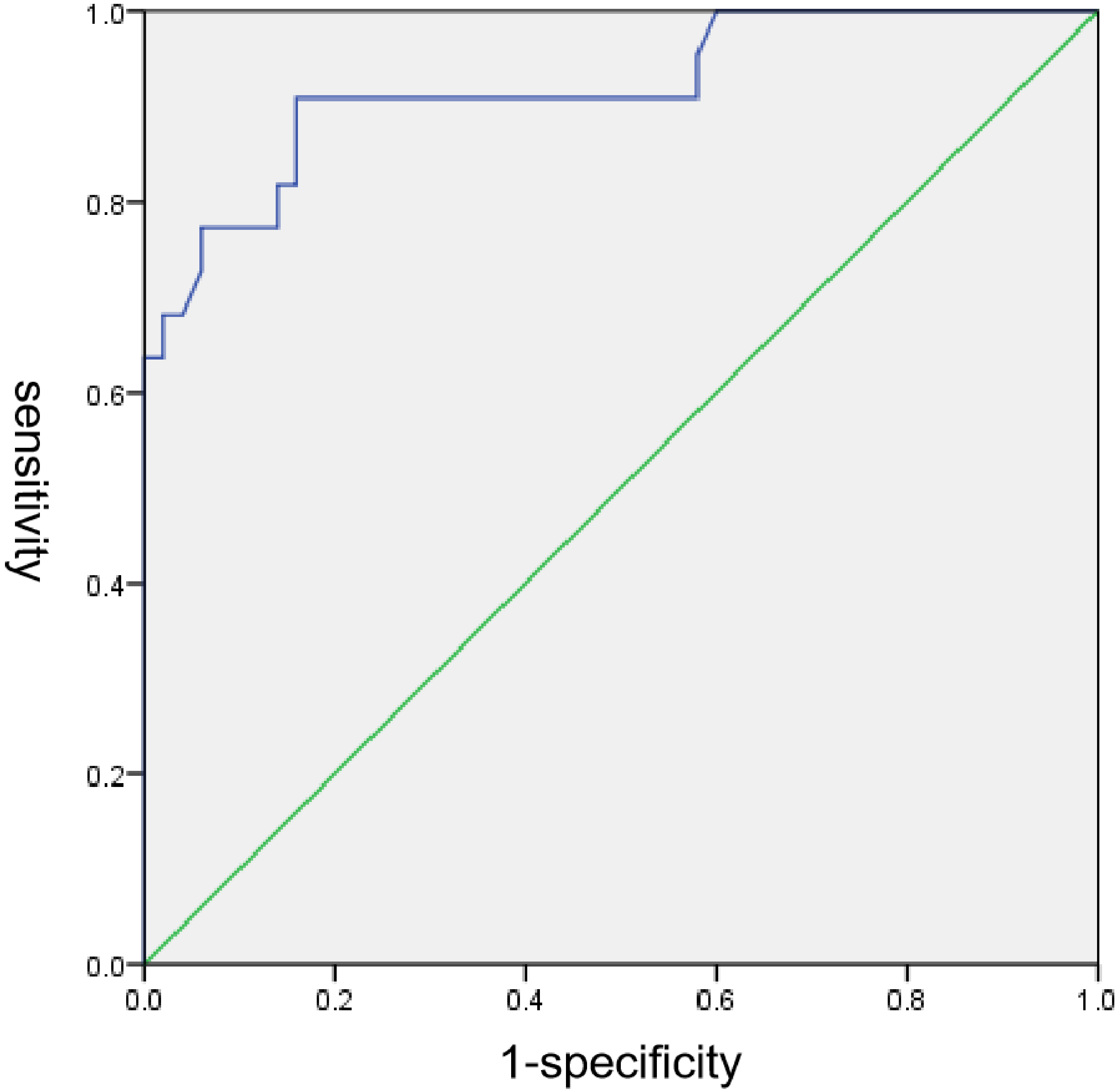

Figure 7

ROC of alpha sample entropy