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Article

Effects of the angle between objects of gaze and a visual target when driving a train[1)]

Kazushige WADA* and Makiko HATAOKA*

Train drivers must look ahead and react to many kinds of signals or signs when driving a train. We investigated whether they could perceive a visual signal when driving a train in actual setting while paying attention to the ordinary signal. In this experiment, train drivers (N = 41) were asked to blow a whistle as quickly as possible, when they see a target light about 610-720 meters ahead. The target light was set to be seen at 0, 1.8, 3.3 degrees away from an ordinary signal on the rail track. Each driver responded for just one target. There were no missed target errors. However, RTs (Reaction times) analysis indicated that RTs for targets separated by 1.8 and 3.3 from the central vision was significantly longer than those at 0. We concluded that when driving a train, it is hard for drivers to respond to a target that was separated from a focused object and discussed applicability of this result to driving environment and driver's education.

key words: train driving, visual attention, view field, eccentricity, actual setting of driving train

INTRODUCTION

Train drivers are required to look forward when driving trains. A train runs on railway tracks and various objects, such as signals, signs, and stations, appear in the direction of travel. Safe driving is achieved by giving full attention to each of these objects and recognizing them correctly and taking appropriate actions. However, sometimes an unexpected incident might occur while driving, such as an obstacle that appears suddenly, or a flashing signal indicating a problem at a railway crossing. Drivers are required to respond appropriately to these sudden incidents by accurately perceive them to maintain safe driving. In other words, train drivers need to immediately identify sudden incidents while attending to the usual signals and signs. Therefore, visual information processing is considered to play an essential role in train operations.

Field of vision while driving

People observe objects using their central vision, such that they perceive the object with high accuracy using the central area of the retina. The field of central vision ranges by a visual angle of 2 degrees. Object recognition beyond this range is conducted by using the peripheral vision, in which the accuracy decreases as it gets farther from the central visual field. Therefore, it is predicted that the response would deteriorate when a visual target appears away from the point of gaze (e.g., Carrasco, Evert, Chang, & Katz, 1995; Carrasco, & Frieder, 1996; Carrasco, & Yeshurun, 1998).

Many studies have been conducted on the visual field of car. Crundall, Underwood, and Chapman (1999) conducted an experiment in which they showed a video clip of the driver's visual scene when driving a car to the participants, place holders were presented in the four corners with individual eccentricities from the center of the screen. When the eccentricity exceeded 7°, the hit rate decreased, and the reaction time was delayed. In this experiment, the processing demand was also manipulated based on the level of hazard that could be perceived from the video. When the processing demand was higher, the reaction time was delayed. Miura (2002) used a real car, pasted miniature light bulbs on the windshield

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* Safety Research Institute, West Japan Railway Company, 1-2-12 Matsuzaki-cho, Abeno-ku, Osaka, 545-0053, Japan
e-mail: kazushige-wada02@westjr.co.jp

with certain eccentricities, and responses to the miniature light bulbs that were flashed randomly were examined. The results indicated that when the degree of traffic congestion increased, the eccentricity to which participants could respond decreased. The above results suggest correlations between processing demand and the field of vision. Williams (1982; 1985) also indicated a tunnel vision, such that when the processing demand increases, the visual field becomes narrower.

Although visual attention is also important when driving trains, only a few experimental studies have been conducted on the visual field of train drivers. In train driving, the route has been determined in advance, which is different from driving a car, and a driver cannot arbitrarily change the route or choose where to turn. Therefore, train drivers can allocate more attention to the forward direction than car drivers. Therefore, when visual targets that disturb train drivers, such as emergency signals or flying objects, appear in front of trains, the driver's response might not be delayed even when the visual targets are far from the gaze point to some extent.

On the other hand, close attention is paid to objects that appear while driving a train even during regular operations. Especially, signals notify the safety-conditions of the train tracks, and it is indispensable for drivers to obey signals to maintain safety because train drivers are responsible for their passengers, and safe driving is their first priority. As a result, train drivers tend to pay much attention to objects and instruments related to safety, such as signals, and when they are looking at safety-related instruments or objects, their visual fields might become excessively narrow.

As described above, the detection of visual targets while driving trains has different characteristics from car driving. Therefore, empirical research is required for train driving. In this experiment, we examined the effects of eccentricities from the gaze point on the detection of visual targets in operation of an actual in-service train.

METHODS

Purpose

Our purpose was to examine the effects of eccentricities from the gaze point on the detection of visual targets that appear while watching a different object when driving the train during an actual train operation setting (in service). Through this experiment, we expected to examine attention condition to the gaze point under a workload and the pressure of transporting passengers.

Participants

In-service train drivers (N = 41, 39 male and 2 females, mean age = 34.5, SD = 5.5) participated in the experiment. The experimental conditions consisting of three types of target eccentricities were developed; 0°, 1.8°, and 3.3°. Participants were randomly allocated to each condition (between-subjects design). Twelve participants were assigned to 0°, 13 to the 1.8°, and 16 participants to the 3.3° conditions.

Dates and location

In this study, the section where the target might appear was set as approximately 20 km that included five stations so that the appearance of the target might be similar to a sudden incident, and drivers would not be able to predict the point at which the target would appear. The experiment was conducted on Aug 4-6, 2015, from 10:00 to 17:00, on a part of the JR Sanyo main line in Okayama and Hiroshima prefecture in fine weather.

Gaze point and visual target

The experiment was conducted in an actual train operation setting. It was necessary that the gaze point was a real object, and the targets were objects that would be easily identified without a sense of incongruity when they appeared on train tracks. Therefore, signals were regarded as the object of visual attention. Drivers carefully attend to signals, which engage their visual attention most effectively, among other objects of attention for safety.

Firstly, in this experiment, a block signal that appeared while driving the train was the gaze point. Block signals are placed in each block. The block is a section made by dividing the route between stations into parts, such that only one train might occupy a block at any given time. Block signals indicate whether there is another train in the next block, i.e., whether the train can enter the block. By following the signal, trains are able to maintain a distinct separation and assure their safety. To ensure safety, train drivers must not miss block signals, and therefore, the

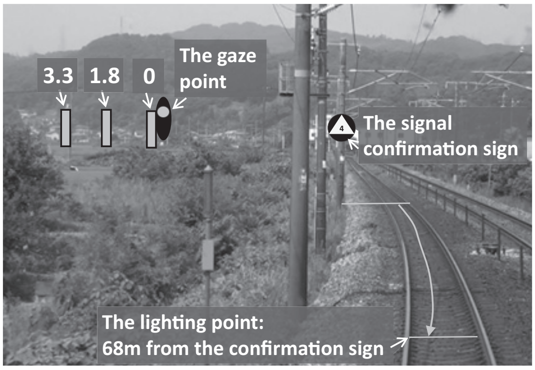

Figure 1 Layout of target signals and the gaze point from the driver's cab.

drivers' visual attention is strongly focused on watching these signals.

Secondly, a light was used as the visual target. However, if the same light as the block signal was used as the target, the drivers might regard the target as the real signal. On the other hand, placing an object that is not normally found on the railway tracks might attract the drivers' attention excessively and also prevent the driver from responding, which would also influence the safe operation of the train. Moreover, a red signal which is used to notify danger, or a stop, would hinder the experiment and train operation.

Therefore, in this experiment, a device imitating an obstruction warning indicator by using a green light was developed. An obstruction warning indicator is a signal that usually emits a red light when problems occur at railway crossings, and has a different shape from a blocking signal that is currently used. As a result, there was only a limited possibility of mistaking these two signals and causing misunderstandings. Moreover, by using a green light instead of a red light, drivers were able to recognize that it is not a risk or a stop sign. The obstruction warning indicators is one of major signs that notifies sudden incidents. By confirming responses to a target that is similar to the obstruction warning indicator, responses similar to the responses to sudden incidents that might occur in actual driving settings would be made. Based on the above reasoning, the green light was considered appropriate as the experimental stimulus.

The visibility distance was set to be identical to real obstruction warning indicators (over 800 m). If the target light is too bright compared to obstruction warning indicators, drivers might perceive it to be abnormal. Therefore, the visibility of the signal was made as similar as possible to the real signal to examine responses to sudden incidents in actual settings. The degree of luminescence was decided based on the evaluations by participants with driving experience to ensure an identical degree of visibility.

Setting of visual targets

Three types of visual target eccentricities were prepared; within the central vision, within the useful field of view but outside the central and broader vision. The target within the central vision can be detected when drivers are looking ahead. The useful field of view is close to the central vision, although it is included in the peripheral visual field. The useful field of view is the range of the visual field that contributes to perception, which has a visual angle of 4°-20° (Miura, 2007). Considering that participants were driving a train, the angle was set as under 4° (the minimum angle, one side 2°). Moreover, a more extensive eccentricity condition was prepared because the detectable range of the target might be wider. These three conditions were set up using a curve. As a result, the following three types of eccentricities were prepared; 0°, 1.8°, and 3.3°, all on the left side of the gaze point (Figure 1, 2). The targets were set up using telegraph poles. Therefore, the three angles were defined in accordance with the positions of the telegraph poles. The target was not seen when the angle exceeded 3.3°, because of obstructions. Therefore, 3.3° was set as the maximum angle.

There were no height differences in this section. It was confirmed that there were no obstructions between the target and the point where the target started to flash. When the target started flashing, the distance between the train and the target was approximately 610-720 m (Figure 2, Table 1).

Participants were instructed that the experiment would be conducted in the 20 km-long section that included the five stations (A, B, C, D, and E). The targets were always presented between B and C, whereas there were four sections in the experimental section.

The signal confirmation sign was used as the refer-

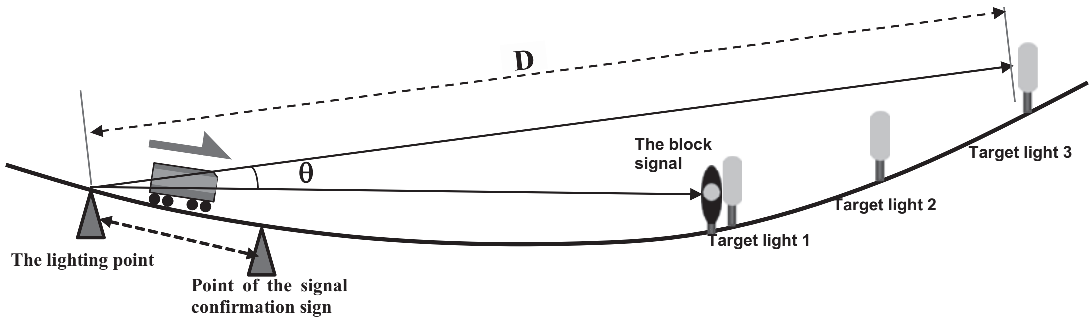

Figure 2 Layout of target signals and the point of starting to emit light.

Table 1 Angle and distances of each condition

Target light	Visual angle (θ)	Distance (D)
1	0°	610 m
2	1.8°	671 m
3	3.3°	718 m

ence point for deciding the point at which the targets started to flash. The signal confirmation sign is a sign for instructing drivers to confirm the signal (go, be cautious, or stop). This sign is almost put up to a telegraph pole, drivers usually confirm an index of signal by calling or pointing when the train pass the sign. When they found the signal (usually about 100 m before the signal confirmation sign), they continue to monitor it until they reached the confirmation sign. During this period, drivers kept watching the signal. Therefore, the point at which the targets started to flash was set within 100 m before the sign so that the target would start to flash when drivers were watching the gaze point. In this experiment, trains were observed, stimuli were presented, and responses were measured from the side of the train track. Therefore, landmarks were necessary to confirm the passing train from the side of the track. A telegraph pole stood 68 m before the signal confirmation sign, which was useful for checking the passing train. When the front part of the train passed the pole, a cue for emitting light was sent by the staff. That is, this pole was regarded as the lighting point (Figure 3). The eccentricities of the targets were the angles when looking at the gaze point from the point of flashing.

Apparatus and materials

Figure 4 shows the size and shape of the target light. The width of the light-emitting part was 80 mm, and the height was 400 mm. The light was set on a pole with a height of 2300 mm rom rail track levels. Flashing rate was 8.3 Hz.

The vehicles used in the experiment were 115, 117, and 213 series trains. Participants used the whistle to indicate making a reaction, and experimenters judged that the response was made by the whistle. Participants could blow a whistle by stepping the foot pedal. The experiment was conducted on a train with passengers. Devices, including foot pedal (for whistle), power handles, and brakes, among others, were inspected in advance, and no abnormalities were confirmed. Measurements were made using two video cameras (SONY HDR-CX680). The recording mode was MP4 (resolution 1280 × 720), with a frame rate was 30p. A transceiver (ICOM IC-DPR6) was used for transmitting signs, among others.

Tasks

Participants were instructed to immediately blow a whistle when they found the target of green light flashing at a specified spot when driving the train. The target light started flashing at the moment when the train reached the lighting point. Participants were also instructed that the target would be placed at some point along the railroad track between A Station and E Station (distance = 19.3 km, driving time = about 20 minutes). However, the exact place where the target would be encountered was not specified in advance.

Procedures

Figure 4 shows the experimental procedures. All the participants were instructed about the experimental procedures 1-6 days before the experiment. The

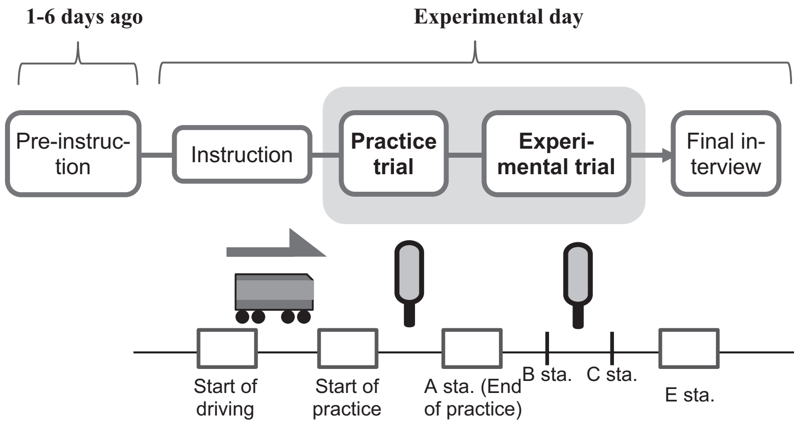

Figure 3 Experimental procedures

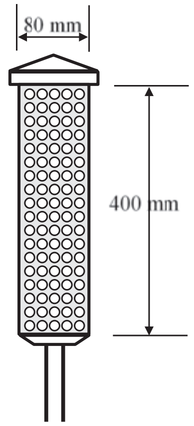

Figure 4 The green target light used in the experiment

instructions stated that a green light would appear when they would be driving the train between A station and E station. When they noticed the light, they have to blow a whistle immediately. A picture of the green light was shown to them and they were requested not to tell the place where they observed the target to other participants after the experiment. After instruction, the participants informed consent to take part in the experiment was obtained.

On the day of the experiment, we arranged experimental staffs at the starting station of train driving (staff A), the practice section (staff B), the lighting point (staff C), the video recording point (staff D), the setting point of the target (staff E), and the end station of train driving (staff F), as shown in Figure 5. Participants were again explained the procedure by staff A before they started to drive. When the train entered the practice trial area, the target started flashing on the left side of the railroad track. The practice trial was conducted in a straight section of the railway-line with good visibility. After confirming the response to the target in the practice trial (staff B), the train entered the experimental section of the trial.

When the train reached the lighting point, the staff C gave the other staff a cue using a transceiver, and the staff D immediately turned on the target light. Participants blow the whistle as soon as watching the flashing light. The target kept flashing until the driver blew the whistle or passed the target (all the drivers responded before passing the target). After the train reached the final station and halted, the drivers were asked about immediacy of response by staff F, “Did you blow the whistle immediately when you noticed the green light?” The drivers responded using a five-point scale ranging between 1 (*Responded at once*) to 5 (*Considerably delayed*).

The experiment was conducted for three days. The conditions were changed between the morning and the afternoon. As shown in Table 2, the experimental conditions were designed such that the number of trials in each condition was equal as much as possible.

This experiment was conducted using in-service car in actual settings. All experimental staff played their roles out of trains.

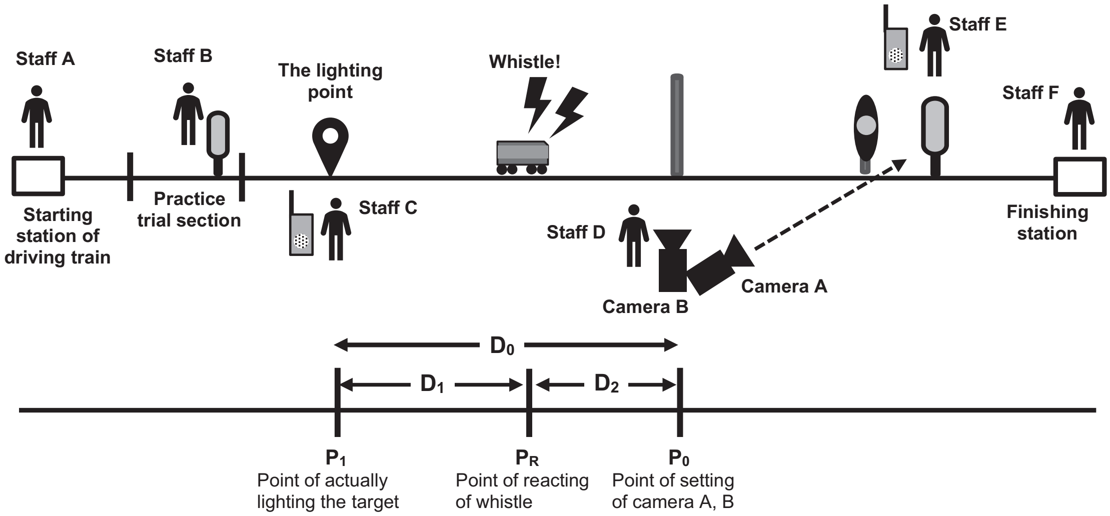

Figure 5 Layout of experimental staffs, apparatus and each point of measurement

Table 2 Assignment of each condition (number of sample)

	Days		
	1st	2nd	3rd
Morning	3.3° (6)	0° (5)	1.8° (4)
Afternoon	1.8° (9)	3.3° (10)	0° (7)

Measurements

Two video cameras were used for making the measurements (Figure 5). These two cameras were set at almost the same point (P_0) so that the two videos can be synchronized. Camera A with a microphone recorded the flashing target as well the whistle. Camera B also recorded the whistle to be synchronized with Camera A and the scene of a train passing the specific landmark in front of the camera for calculating the speed of the train. The railroad track was gently curved from where the target was flashing (P_1) to the point where the target was set up. Therefore, it was a coasting section without acceleration, and it was considered that the speed at the point where the target started flashing was kept maintained to the point where the driver made a response.

The reaction time and reaction point were calculated based on the videos taken from Cameras A and B using the following procedure. First, the time from the target starting to flash to the whistle blow was analyzed using Camera A, which was regarded as the assumed reaction time (RT_0). Moreover, the time from the front of the train passing the landmark to the end of the train passing the landmark was measured using Camera B, and the speed of the train was calculated (V m/s). The length of the train was 20 m a car. Time was calculated using the frame rate (30p) of the camera.

Next, two videos were synchronized using the whistle recorded by the two cameras and the time from the target starting to flash to the train passing the landmark was measured (T_1). By using T_1 and V, the distance (D_0) from P_1 to P_0 was calculated using the formula below (Although the point where the target started flashing was theoretically defined, in reality, the flashing was started manually by a cue from a staff member, which might have caused some errors. Therefore, the accurate position was calculated through the analysis).

$D_0 = V \times T_1$ (1)

$D_0 = D_1 + D_2$ (2)

D_1 = distance from P_1 to P_R (reaction point)

D_2 = distance from P_R to P_0

RT_0 includes the traveling time from P_1 to P_R and the sound propagation from P_R to the camera. RT_0 is expressed as follows by regarding the speed of sound as 350 m/s,

$RT_0 = D_1/V + D_2/350$ (3)

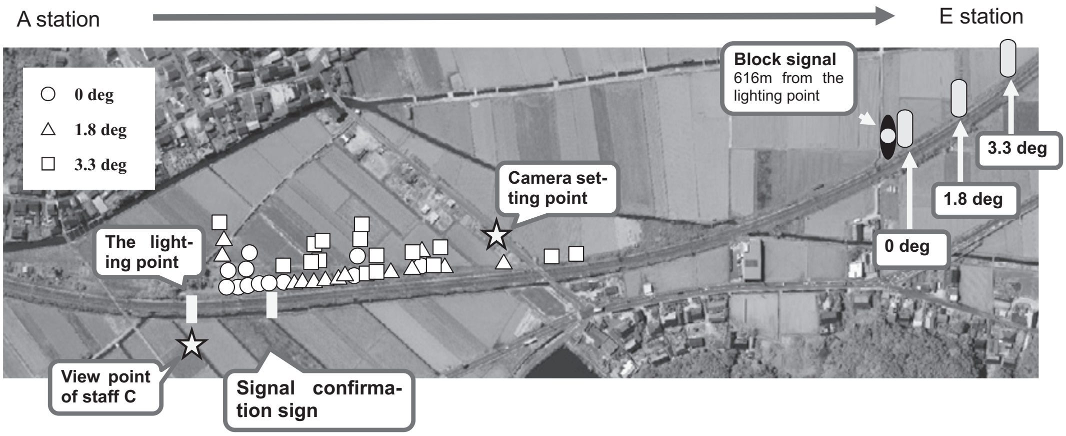

Figure 6 Bird's-eye view of the reaction distribution and stimulus points

Based on (2) and (3), the accurate reaction time (RT_1) from the start of flashing to the reaction point (P_R) was calculated.

$RT_1 = D_1/V$ (4)

($D_1/V = RT_0 - D_2/350$)

The reaction point was plotted on the map after it was identified. By measuring the distance on the map, the angle between the gaze point when the response was made, and the target was calculated by measuring each direct distance between the reaction point and the gaze point, between the reaction point and the target, and between the gaze point and the target by using the second cosine theorem. The calculated reaction times and angles were used for analysis. Both Cameras A and B were fixed at the same point for three days.

RESULTS

Reaction points from a bird view

The calculated points where the whistle was blown were plotted on a map of the experimental site (Figure 6), which indicated that the range of reaction points extended as the angle increased. The number of participants that made a response before the signal confirmation sign, at which point they were expected to pay the most attention to the gaze point, was 8 (75%) at 0°, 2 (15.4%) at 1.8°, and 1 (6.3%) at 3.3°. A chi-square test was conducted on these ratios, which indicated a significant difference ($\chi^2(2) = 14.02$, $p < .001$). Multiple comparisons using Ryan's method were conducted, which indicated that the number of reactions made at 0° was significantly larger than to 1.8° and 3.3° (0° vs. 1.8°, $p = .015$; 0° vs. 3.3°, $p = .002$). There was no significant difference between 1.8° and 3.3° ($p = .57$).

Reaction performance

Error rate There were no participants that did not respond between the target starting to flash and reaching the target, indicating that the error rate was 0%.

Reaction time The time from the target starting flashing to a driver blowing the whistle was regarded as RT, and the values were logarithmically converted and compared among the conditions (Figure 7). A one-way analysis of variance (ANOVA) was conducted, which indicated a significant main effect of factor ($F(2, 38) = 6.07$, $p = .005$, $\eta_p^2 = .24$). Bonferroni's multiple comparisons indicated a significant delay in RT at 3.3°, compared to 0° ($p = .004$) and a further delay in RT at 1.8°, compared to 0° ($p = .06$). No significant differences were shown between 1.8° and 3.3° ($p = 1.00$).

Moreover, the speed of the train, age, and experience of the driver was compared among the conditions as indices affecting the RT. Each one-way ANOVA indicated no significant main effect of the factor (Table 3, speed; $F(2, 38) = 0.28$, $p = .76$, $\eta_p^2 = .01$; experience; $F(2, 38) = 0.75$, $p = .48$, $\eta_p^2 = .04$; age; $F(2, 38) = 1.52$, $p = .23$, $\eta_p^2 = .07$). The experiment was conducted outdoors. Therefore, the effect of sunlight was analyzed before and after lunchtime (13:00-14:00) (Table 4). A two-way ANOVA; eccentricity (0°, 1.8°, 3.3°) × before/afternoon indicated a significant main effect of the eccentricity ($F(2, 35) = 5.12$, $p = .01$, $\eta_p^2 = .23$). On the other hand, there were no significant main effect of before/afternoon ($F(1, 35) = 2.72$, $p = .11$, $\eta_p^2 = .07$) and interactions ($F(2, 35) = 0.28$, $p = .76$, $\eta_p^2 = .22$).

Degree of eccentricity at the reaction point The visual angle between the gaze point at the reaction point and the target was calculated, and a one-way ANOVA was conducted (Table 3), which indicated a significant main effect of the factor ($F(2, 38) = 1037.09$, $p < .001$, $\eta_p^2 = .98$). Bonferroni multiple comparisons indicated that there were significant differences between all three conditions (0° vs. 1.8°, 0° vs. 3.3°, 1.8° vs. 3.3°; $ps < .001$).

Immediacy of response The percentage of participants that answered 4 or 5 was 0%, suggesting there was no delay in responding to the target. Moreover, the rating score was reversed and analyzed by a one-way ANOVA (4.67 vs. 4.77 vs. 4.88). There was no significant main effect of the factor ($F(2, 38) = 0.65$, $p = .53$, $\eta_p^2 = .03$)

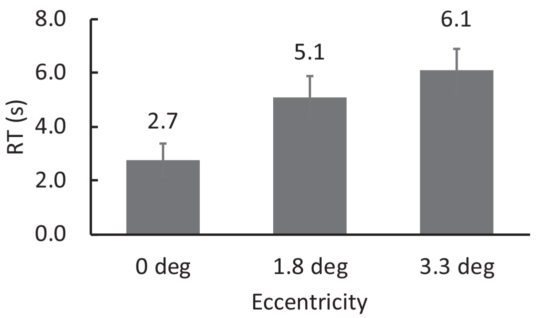

Figure 7 Reaction time under each condition (error bars represent standard errors)

DISUCUSSION

We experimentally investigated whether a driver could correctly perceive a target if a visual target appears while watching an object while driving a train and whether the perception was affected by the position of the target were examined in an actual train operation setting. The results indicated that the drivers did not miss the target, although they were not informed of the position of the target in advance. However, RT was affected by the eccentricity of the target from the object of the gaze. When the eccentricity increased, RT increased. There was neither difference in RT based on the speed or the drivers' age or experience nor interaction between eccentricity and sunlight. Therefore, the above results were considered to have resulted from eccentricity.

It has been indicated that when a visual target appeared while driving a car, the driver might be able to respond to it when the angle between the object of the gaze and the target is smaller than 3.3°, suggesting eccentricity might not affect the accuracy of perception. However, the RT differed. RT at 1.8° and 3.3° were delayed compared to 0°, suggesting that although participants could cope with an eccentricity exceeding the central vision when the target started flashing, they could cope with larger eccentricities with time. This issue is discussed below.

Table 4 Means and SD of RT in each condition

		Eccentricity		
		0°	1.8°	3.3°
Morning	*M*	2.79	3.41	4.70
	SD	2.61	1.40	2.56
Afternoon	*M*	2.72	5.83	6.92
	SD	1.57	2.80	3.22

Table 3 Means and SD of Speed, age, driver experience, and eccentricities of reaction points in each condition

	0° (*n* = 12)		1.8° (*n* = 13)		3.3° (*n*= 16)	
	M	*SD*	*M*	*SD*	*M*	*SD*
Speed (km/h)	90.3	4.0	89.5	3.9	90.5	3.1
Age (years)	33.7	9.9	42.0	13.5	36.3	11.8
Driver experience (years)	8.6	10.7	13.6	11.4	9.4	9.8
Eccentricities of reaction points (°)	0.0	0.0	2.3	0.2	3.9	0.3

The eccentricity changed depending on the position. Participants might find and react after eccentricities of 1.8° and 3.3° conditions were within central visual field, 1°. However, when analyzing the eccentricity at the reaction point, eccentricities of 1.8° and 3.3° were larger than 0°, suggesting that participants did not make a response after the eccentricity was included in the central vision. The reaction was rather made in the larger eccentricity than 1.8° or 3.3°. It is possible that responses made just after the flashing started and responses at places further away from the point where flashing started were made using different strategies.

This idea was supported by the significant difference indicated by the analysis of the reaction ratio around the signal confirmation sign. Compared to 0°, participants made a response more often after passing the confirmation sign at 1.8° and 3.3°. In other words, perception for dealing with larger eccentricities that exceed the central vision might be conducted after passing the confirmation sign. The confirmation of signals is an important task for train drivers, which is indispensable for driving safety. Therefore, drivers' attention to signals increases, and perception in the central vision is prioritized at the point where they are required to check a signal. On the other hand, drivers' attention to other objects might increase, and they might try to explore a range of fields after passing the confirmation point, and drivers are released from the need to attend to the signal strongly. As a result, their useful field of view might expand at least to around 4°, or the central vision might shift in the curve direction.

The above findings indicated that when driving a train, it is difficult to respond to a target appearing outside of the central vision while closely attending to an object. On the other hand, it becomes possible to perceive things outside of the central vision after being released from focusing on the object. Therefore, participants did not miss the target of perception.

Possible application of experimental results

The results of this experiment suggest that the visual field narrows while watching the gaze point. The present study was conducted in the actual in-service situation, using the target setting that the appearance position was unexpected. Therefore, the following applications of the results of this study are suggested for sudden incidents. Firstly, critical signals or signs that appear out of the central vision might be missed in sections where drivers must focus attention on the block signal. Therefore, especially, signals that need to be detected when they are emitted, even though they usually not emitted, such as obstruction warning indicators, should be placed in an area where they can be easily detected.

Secondly, regarding drivers' education, there is a possibility that drivers might miss things that appear out of the central vision, although usually things that appear in the direction of travel are easily perceived when driving a train. In the present experiment, on average, 2.1-3.5 second delays were observed. When a train is running at 90 km/h, which is identical to the speed in this experiment, a 3-second delay will increase the stopping position by 75 m. Although the distance of visibility of signals is over 600-800 m, it includes the braking distance, whereas the distance required for identifying an object is not considered carefully. The risk of collision is increased by overrunning the stopping position by 75 m. Based on the data obtained from this experiment, drivers are able to recognize the risk. Moreover, such phenomena tend to occur when watching important items, such as signals. Therefore, places that need careful attention are easily identified, and necessary measures can be taken in advance, such as trying to expand the visual field by accurately confirming essential factors.

It was indicated that target detection decreases when watching an object while driving a train. This result might be applied to improving the driving environment and drivers' education. There are only a few studies on visual attention when driving a train (e.g., Dunn, & Williamson, 2012 ; Luke, Brook-Cater, Parkes, Grimes, & Mills, 2006). It is suggested that studies that are applicable to actual train operation settings should be conducted in the future.

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