Can Visual Information Reduce Anxiety During Autonomous Driving? Analysis and Reduction of Anxiety Based on Eye Movements in Passengers of Autonomous Personal Mobility Vehicles

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Keywords: Autonomous Transportation, Personal Mobility Vehicles, Anxiety, Cognition, Eye Movements, Visual Information.

Abstract: It is important to consider reducing passenger anxiety when promoting autonomous transportation services of personal mobility vehicles (PMVs). This research aims to identify when anxiety occurs based on the eye movements and subjective assessment of autonomous vehicle passengers and to reduce that anxiety by presenting visual information. Temporal changes in passenger's anxiety while passing through a group of pedestrians were investigated by an experiment using a driving simulator. By analyzing the passenger's eye movements and subjective assessment, it was suggested that anxiety occurs with changes in the positional relationship with surrounding pedestrians and the sudden change in behavior of the PMV. Moreover, the results suggested that anxiety can be reduced by the presentation of visual information with the effect of visual guidance that diverts passenger's attention from anxiogenic pedestrians and provides content that conveys PMV's intention of its behavior. Additional experiments revealed that the visual information presented in this study significantly reduced passenger anxiety during the autonomous transportation of PMVs.

1 INTRODUCTION

In the midst of global aging, securing means of transportation for older people, whose physical and cognitive functions tend to decline, has become a global issue. This is important for maintaining the frequency of going out and ensuring their quality of life. Personal Mobility Vehicles (PMVs), like electric wheelchairs, are one of the means of transportation, and the number of users is increasing year by year in Japan, where aging is a major social problem. Since many of the PMV users are older people, it is necessary to consider mobility assistance to compensate for the deterioration of their cognitive and physical functions. Assistance using autonomous navigation is one way to realize this support that does not depend on the cognitive and physical ability of the passenger. Although there are many studies on the reliability and safety of autonomous navigation, it is also important to avoid passengers from feeling anxious while it moves automatically through pedestrians. Autonomous PMV passengers may experience various types of anxiety. For example, given that the PMV drives through pedestrians, there is a possibility that the passenger may feel anxious about collisions due to the positional relationship with surrounding pedestrians. This anxiety is thought to be similar to the anxiety that occurs when pedestrians approach each other. Interactions between traffic participants in pedestrian spaces have been extensively studied. Hall (1966) has revealed the existence of a space called Personal Space (PS), where pedestrians feel uncomfortable with the intrusion of others. PS is an egg-shaped space that scales according to the velocity vector of the individuals. The idea of PS has been extended to the interaction between pedestrians and robots (Shiomi et al., 2014). Helbing and Molnar (1995) suggested that the movement path of a group of pedestrians can be represented by a dynamic model called Social Force Model (SFM), which is based on the repulsive force

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Harada, R., Yoshitake, H. and Shino, M.
Can Visual Information Reduce Anxiety During Autonomous Driving? Analysis and Reduction of Anxiety Based on Eye Movements in Passengers of Autonomous Personal Mobility Vehicles.
DOI: 10.5220/0011802800003417
In *Proceedings of the 18th International Joint Conference on Computer Vision, Imaging and Computer Graphics Theory and Applications (VISIGRAPP 2023) - Volume 2: HUCAPP*, pages 318-325
ISBN: 978-989-758-634-7; ISSN: 2184-4321

between pedestrians and the attractive force from the target point, which is built from a concept similar to PS. Previous research also suggests that passengers of PMV also shows negative reaction to surrounding pedestrians approaching them (Isono et al., 2022). Moreover, anxiety caused by autonomous navigation is also assumed. Watanabe et al. (2015) suggested that passengers feel discomfort not knowing the future behavior of the PMV and its intentions. They succeed in reducing this discomfort by presenting visual information about the PMV's intention. However, only a simple passing scenario with one pedestrian was examined, and it is not clear what the passenger received from the presented visual information and why it led to the reduction of discomfort. Therefore, this study aims to clarify the trigger of anxiety and reduce them by displaying visual information, as was the case in previous studies that reduced discomfort. Experiments were conducted using a driving simulator to repeatedly reproduce the scene passing through a group of pedestrians according to the route calculated by an autonomous navigation strategy. The anxiety of the participants was analyzed based on eye movements and their subjective assessments.

This paper is structured as follows. Section 2 describes the triggers of anxiety and how visual information reduces them. It also shows several types of visual information considered in this study. Section 3 describes the method of the experiment, followed by Section 4 showing the results. Section 5 describes the additional experiment conducted to evaluate the effectiveness of the proposed visual information. Lastly, Section 6 summarizes the findings of this study.

2 VISUAL INFORMATION REDUCING ANXIETY

This section describes the triggers of passenger's anxiety and how visual information reduces them. Among the various possible factors of anxiety, two types of triggers were extracted based on previous research, some of which were mentioned in the previous section. With the aim of reducing anxiety, three types of visual information were proposed.

2.1 Triggers of Anxiety

Roseman (2001) suggests that cognitive appraisal plays an important role in the arousal of emotions such as anxiety. This model describes that human selects the stimuli from the environment using their perception filter and interpret whether the stimuli have a negative effect on them. This process is called the primary appraisal. When they interpret the stimuli as negative, they estimate the amount of resources they need to be able to cope with the situation related to that stimuli. This is called the secondly appraisal. Once they estimate the required resources occupy an excessive proportion of the attentional resource, they find the stimuli as their stress (Lazarus and Folkman, 1984). Roseman suggests that negative emotions such as anxiety arouse from stimuli that individuals apprise as inconsistent with their motives, which is often due to an uncontrollable circumstance caused by others. Roseman also points out that the predictability of the stimuli is one of the key factors of cognitive appraisal.

In the case of autonomous PMV passengers, there are two main stakeholders who might give them stimuli that they apprise as inconsistent with their motives: the surrounding pedestrians and the autonomous PMV. As for the surrounding pedestrians, proximity that evokes the danger of collision is one of the stimuli which leads to passenger's anxiety (Isono et al., 2022). On the other hand, sudden changes in PMV's behavior, such as velocity and angular velocity, are stimuli that are hard to predict and can result in the arousal of negative emotions (Watanabe et al., 2015).

2.2 Visual Information

In the model of cognitive appraisal, it is explained that once individuals feel some stress, they try to overcome it by changing those stimuli with their actions. However, since an autonomous PMV operates independently of the passenger's intentions, it basically cannot be affected by them. Therefore, in order to fill this gap in intention, it is important to communicate the PMV's intentions to the passenger in advance. In this study, visual information was examined as a means of this communication. Visual information may improve the predictability of the stimuli given by the PMV and reduce the anxiety of the passengers. There is also an expectation that the perception filter will exclude anxiety-causing stimuli from nearby pedestrians through the effect of visual guidance toward the presented information.

There are three types of parameters that determine the behavior of a PMV: position, velocity, and posture angle. In this study, three types of visual information were examined as a means of presenting these parameters to passengers. Figure 1 describes these three types of visual information and which parameters they represent. In general, information presentation is said to be processed differently depending on the presentation timing and from the perspective of iconic memory. Thus, we prepared conditions for presenting information 1 second ahead and 3 seconds ahead for each type (Kitajima and Toyota, 2013).

(a) PATH **(b)** PS **(c)** FOLLOW

Figure 1: Visual information examined in this study. (a) PATH type describes future position information as a line on the ground. (b) PS type describes future velocity information as an egg-shaped space scaling according to its vector, which imitates PS. (c) FOLLOW type describes the future posture angle along with its position as a leading vehicle.

3 METHODS

This section describes the method of an experiment that aims to clarify the trigger of anxiety and how passengers react to them. We also investigated how visual information changes those anxiety and reactions. In order to clarify the timing of passenger anxiety and its factors, subjective assessment and eye movements were measured. The experiment was conducted with the approval of the Ethics Committee of The University of Tokyo.

3.1 Conditions

One hundred fifty pedestrians were randomly placed in a 10 m width aisle at an interval of 0.1 person/m^2. Half of the people walked in the same direction as the PMV, and the other half walked in the opposite direction. Pedestrians moved at about 1.1 m/s based on an SFM mentioned in Section 1. The PMV drove through this group of pedestrians at 0.7 m/s based on an autonomous navigation strategy called the Dynamic Windows Approach (Fox et al., 1997). Participants experienced the same scene with seven different visual information conditions listed in Table 1.

3.2 Experimental Procedure

Three males (A–C) with an average age of 26.3 years old (SD = 4.2) participated in this experiment. After obtaining informed consent, participants were equipped with an eye tracking device (Tobii Pro Glasses 2, Tobii AB) and given a button that they were instructed to press when they felt anxious while watching a 30-second driving scene on the driving simulator (Figure 2). On the screen with a field of view of 180 degrees, a PMV that drives through a group of pedestrians using autonomous navigation was projected from a first-person perspective. After each scene, participants were asked why they pressed the button and the factors which caused their anxiety. Since the driving scene was fixed in the experiment, we prepared a dummy scene to prevent the influence of familiarity and let the participants experience it between the experiment target conditions. There was a 1-minute interval between each scene experience.

Table 1: Experimental conditions.

ID	Visual Info.	Presenting Info.
None	n/a	n/a
Pa01	PATH	1 sec. ahead
Pa03	PATH	3 sec. ahead
PS01	PS	1 sec. ahead
PS03	PS	3 sec. ahead
Fo01	FOLLOW	1 sec.
Fo03	FOLLOW	3 sec.

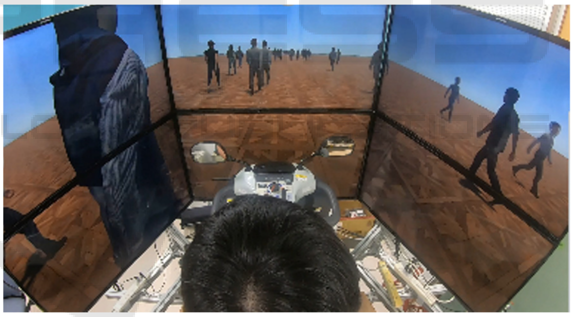

Figure 2: Driving simulator used in the experiment.

3.3 Analysis of Eye Movements

In this study, by analyzing visual behavior, we expect to clarify why passengers feel anxious and how they visually recognize the surrounding objects when the anxiety occurs. If the passenger feels anxious about the proximity of surrounding pedestrians, it is conceivable for them to keep watching the target pedestrian. On the other hand, when the vehicle suddenly changes its behavior, it is reasonable that the passenger tries to obtain information by looking at various places. Janelle (1999) discovered that saccades increase when drivers feel anxious in an auto racing simulator. Therefore, if the intention of the PMV can be conveyed to the passenger through the visual information, it is more likely that the frequency of this saccade decreases as the rate of attention to the visual information increases and the evaluation of anxiety decreases. Moreover, increasing attention to visual information might also decrease the anxiety against pedestrians as the possibility of seeing the target, which triggers anxiety, decreases.

To test this hypothesis, a metric that quantifies saccade frequency is in need. Krejtz et al. (2014) proposed two indices for gaze transition using the concept of Shannon's entropy (Ciuperca and Girardin, 2005). This metric is used in the eye movement analysis of car drivers (Dillen et al., 2020). These entropies are calculated based on the stationary rate and the transition rate of the Area of Interest (AOI), which is an area where fixation points are dense (Salvucci and Goldberg, 2000). Stationary entropy H_s is defined as equation (1), where i represents one AOI, n is the total number of AOIs, and π_i is the stationary probability distribution of AOI within a certain period of time. When passengers distribute their visual attention more equally between AOIs, this stationary entropy will show a higher value. The other entropy is called transition entropy which is defined as equation (2), where p_{ij} is the probability of the subject's fixation transiting from AOI i to AOI j. A higher value of transition entropy means that there are more saccades between the AOIs.

$$\mathrm{H}_s = -\sum_{i=1}^{n} \pi_i \ln \pi_i \tag{1}$$

$$\mathrm{H}_t = -\sum_{i=1}^{n} \pi_i \sum_{j=1}^{n} p_{ij} \ln p_{ij}, \mathrm{i} \neq \mathrm{j} \tag{2}$$

4 RESULTS

This section describes the result of the experiment. First, factors of anxiety were classified using a subjective assessment of the condition without visual information presentation. Then, eye movements during that duration of anxiety were analyzed. Changes in eye movements and anxiety evaluation on visual information presented conditions were also analyzed.

4.1 Factors of Anxiety

Figure 3 shows when the participants felt anxiety during the scene without any information presentation. Participant B, who felt particularly anxious, commented that he felt anxious about the proximity of a pedestrian in S1 and that he was anxious about not being able to understand the behavior of PMV in S2. Participant C commented the same way in S2. Anxiety in S3 was excluded because it was associated with changes that occurred when the scene finished playing in the simulator. Therefore, factors that cause anxiety in this scene can be broadly classified into two sections, S1 and S2. S2 is a scene in which the vehicle makes a large left turn after meandering to avoid pedestrians.

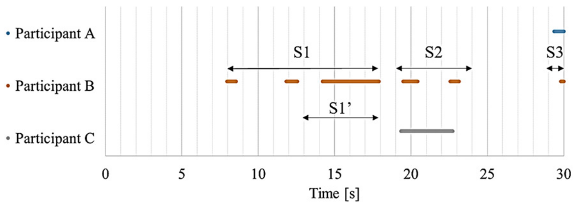

Figure 3: Occurrence of anxiety in the condition without presentation of visual information.

4.2 Eye Movement Analysis

4.2.1 Analysis Conditions

The video recorded by the eye tracking device was 25 fps which means there are 40 ms intervals between the frames. The minimum fixation duration was set to 80 ms, referring to the previous research (Krejtz et al., 2014). The analysis time was set to 5 seconds in line with S2. From S1, S1' was extracted, which is a 5-second section that participant B felt more anxious (Figure 3). From S1' and S2, five areas were set as AOIs shown in Figure 4. All fixations in the two sections were classified into these five AOIs.

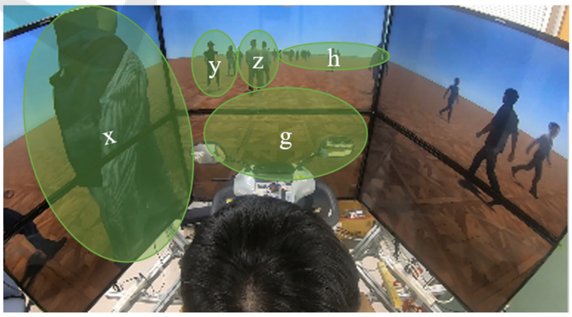

Figure 4: AOIs in S1' and S2. (x) AOI-x Pedestrian X, which is the pedestrian participant B was anxious about. (y) AOI-y Pedestrian Y. (z) AOI-z A group of pedestrians Z. (g) AOI-g Ground, including visual information. (h) AOI-h Horizon.

4.2.2 Analysis of S1'

S1' is where the proximity of pedestrian X causes anxiety. The results of eye movement analysis in the condition without visual information are shown in Figure 5. Participant B, who claimed that the proximity of pedestrian X was anxious, had a longer fixation against AOI-x. Leading to a decrease of stationary entropy H_s. Participant B also showed a low value in the transition entropy H_t, which means that once he saw pedestrian X, which made him anxious, he tended to keep looking at it.

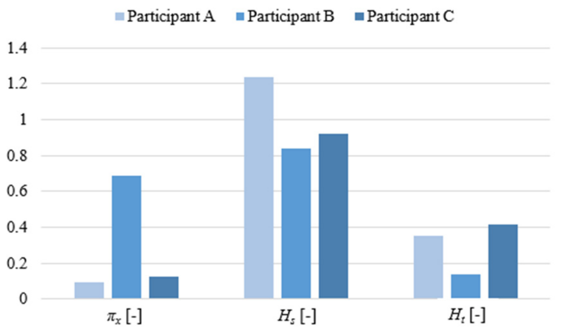

Figure 5: Eye movement of S1' in the condition without visual information (ID: None). π_x is the stationary probability distribution of AOI-x.

Figures 6 and 7 show the result of the changes in anxiety and eye movements of participant B under different visual information conditions. In the condition with visual information, the amount of time during which the participants felt anxious was shorter than in the condition without visual information (None), and the rate of fixation on X (π_x), which was the target of anxiety, decreased while the rate of fixation on the ground (π_g), including information presentation, increased. This result suggests that visual information attracts passenger attention which has the effect of diverting the passenger's attention from the object that makes them feel anxious. Especially FOLLOW type has a strong effect of visual guidance given that both entropy is lower than others. Comments reveal that high anxiety in PS03 was due to the difficulty in interpreting visual information.

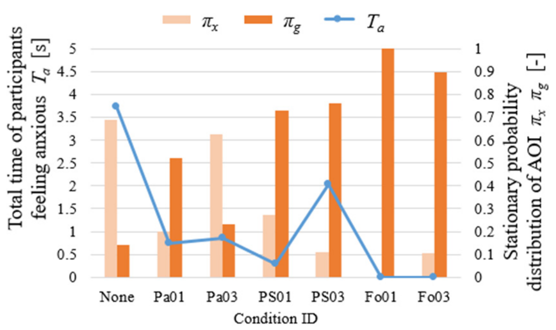

Figure 6: Anxiety and eye movement of S1' in different conditions (Participant B).

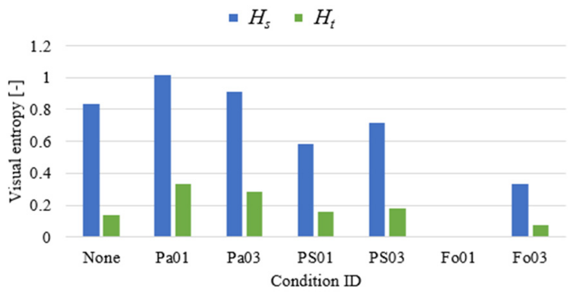

Figure 7: Visual entropy of S1' in different conditions (Participant B).

4.2.3 Analysis of S2

S2 is where the difficulty in understanding PMV's behavior causes anxiety. Participant C felt more anxious than A and B in S2. Thus, the effect of visual information on participant C is analyzed.

Figures 8 and 9 show the result of the changes in anxiety and eye movements of participant C. In the conditions in which visual information was shown, T_a decreased while π_g increased, leading to a decrease in both entropies. Thus, it can be said that when passengers feel anxious about PMV's behavior, they tend to seek information from their surroundings, increasing their saccades, and the content of visual information contributes to reducing this anxiety by providing clues of PMV's intention of its behavior.

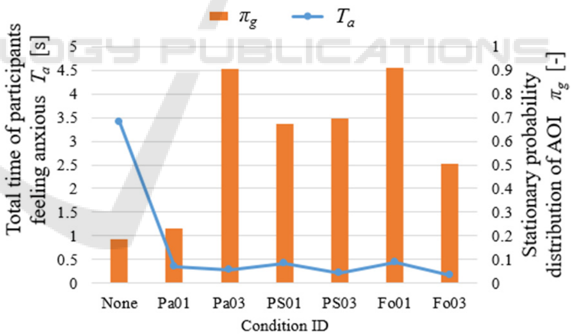

Figure 8: Anxiety and eye movement of S2 in different conditions (Participant C).

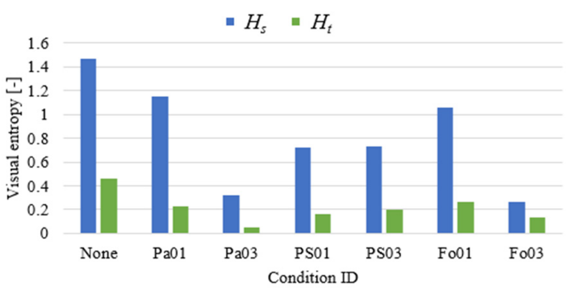

Figure 9: Visual entropy of S2 in different conditions (Participant C).

5 EVALUATION OF VISUAL INFORMATION

Results in the previous section suggested two effects of visual information, which reduce anxiety; visual guidance that diverts the passenger's attention from the object, which might cause anxiety, and providing content that conveys PMV's intention of its behavior. However, this tendency did not consider the influence of individual differences, and it only focused on specific sections (S1' and S2). Thus, an additional experiment was conducted to evaluate whether it contributes to reducing anxiety throughout the scene for a larger number of participants. Nine males and females with an average age of 23.0 years old (SD = 1.1) participated in this experiment.

Methods of this experiment mostly conform with the former, except that participants rated their anxiety after each condition on a 7-point Likert scale, with -3 to -1 feeling relaxed, 0 feeling neutral, and 1 to 3 feeling anxious.

Figure 10 shows the subjective assessment scores for anxiety under each conditions. Visual information of PATH and FOLLOW significantly reduced anxiety, while PS did not. This result might be due to the difficulty of interpreting PS, as mentioned in Section 4.2.2. Combined with the results in Section 4, it can be said that visual information which displays a path or a leading vehicle has the effect of visual guidance and intention communication, which significantly reduces anxiety throughout the scene.

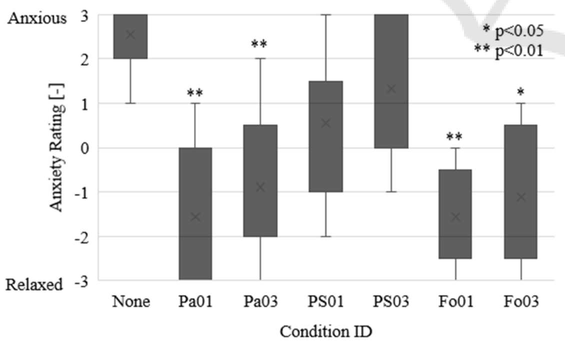

Figure 10: Subjective assessment scores for anxiety under different conditions. The asterisk indicates a significant difference from the None condition, which did not display visual information.

It was also examined whether the findings on visual behaviour obtained in section 4 would be applicable to a large group of people. First, the characteristics of visual behaviour in None condition were analysed, and then it was clarified how the behaviour changed when information was presented.

Figure 11 and 12 shows the visual entropy in condition None which did not provide any visual information. Participants were classified into two groups according to their rated anxiety values. Those who rated their anxiety as 3 points were in the high anxiety group, and those who rated their anxiety as 1 or 2 points were in the low anxiety group. Results show that there was no difference in stationary entropy, while transition entropy increased in the high anxiety group. This indicates that when passengers feel anxious, they engage in exploratory visual behaviour to obtain information that reduces anxiety.

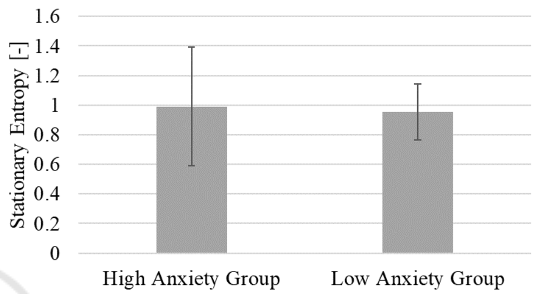

Figure 11: Difference of stationary entropy between the perception of anxiety among participants in condition None.

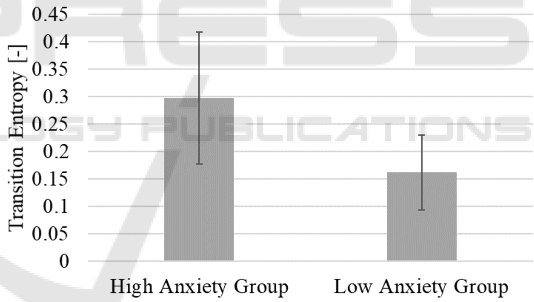

Figure 12: Difference of transition entropy between the perception of anxiety among participants in condition None.

Figure 13 describes the transition entropy in different visual information conditions. Result shows that visual information has the effect to decrease transition entropy. This suggests that passengers no longer engaged in exploratory visual behaviour because they found that visual information provided content that could alleviate their anxiety, which is likely to be the PMV's intention of its behaviour.

Moreover, this experiment also suggested that visual information was effective in reducing the anxiety associated with approaching pedestrians by visual guidance. Figure 14 describes the stationary probability distribution of AOI in different visual information conditions. Result shows that visual information increases the stationary probability distribution of AOI-g while decreases AOI-x which includes the pedestrian that provokes anxiety. This effect was more pronounced in the visual condition which significantly reduced anxiety (Fig.10).

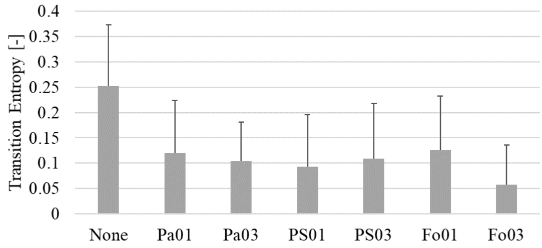

Figure 13: Transition entropy in different visual information conditions.

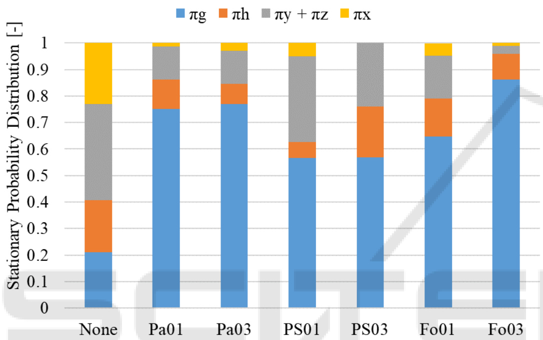

Figure 14: Stationary probability distribution of AOI in different visual information conditions.

6 CONCLUSIONS

In this study, the relationship between anxiety and eye movements of autonomous PMV passengers was investigated in an experiment using a driving simulator. As a result, the following human characteristics were obtained:

- In the experimental scene in this study, there were two types of anxiogenic factors: proximity of pedestrians and sudden change in behavior of the PMV.
- People who feel anxious about the proximity of pedestrians tend to fixate on the pedestrian for a longer period of time and find it difficult to change their fixation on other objects.
- People who feel anxious about the sudden change in behavior of the PMV tend to increase saccades and explore surrounding information.

In addition, the effect of visual information on anxiety and the reason for it were investigated. The followings are the findings obtained in this study:

- By the effect of visual guidance of the visual information, it was able to divert attention from the pedestrian which gives them anxiety and make the passenger feel relatively relaxed.
- Visual information had the effect of conveying the PMV's intentions for future behavior, which reduced passenger's anxiety when the PMV makes abrupt movements.

From this research, it is suggested that when humans feel anxiety, they search for the cause of anxiety, and when they identify it, they try to obtain information by paying attention to the object which gives them clues for future situation.

However, the scene of the experiment was limited in this study. Thus, further investigations in more diverse scenes are needed, such as a scene with a sudden change in velocity, gaining a deeper understanding of the relationship between passenger anxiety and eye movements. Furthermore, considering the actual implementation of information presentation in society, it will be necessary to examine information projection methods such as using MR glasses and conduct experiments in real environments.

ACKNOWLEDGEMENTS

This paper is based on results obtained from a project, JPNP18014, commissioned by the New Energy and Industrial Technology Development Organization (NEDO).

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