Gaze and Coordination in Collision Avoidance between Personal Mobilities

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***Abstract*—In collision avoidance between pedestrians, they smoothly avoid collisions. In Personal Mobility (PM) collision avoidance, eye movement information, which is not often used in pedestrian collision avoidance, may be a powerful source of information. This is because information from body movements is limited in the case of PMs. This study shows the relationship between gaze and the opponent's coordination behavior in collision avoidance between PMs. Only the Follower who passed later through the collision point gazed at the opponent more when they adjusted their own behavior more. This study extends the findings on collision avoidance behavior between pedestrians and provides insight into collision avoidance behavior between PMs.**

Keywords - collision avoidance; gaze; coordination.

I. INTRODUCTION

We avoid collisions with others as we walk through crowded places, such as supermarkets, hospitals, and airports. Collision avoidance between pedestrians is achieved smoothly by using a common strategy among pedestrians to determine their roles of going first or going second [1]. In this paper, the role of the person who passes through the collision point first is defined as the Leader, and the role of the person who passes through the collision point later is defined as the Follower.

On the other hand, recently, due to the development of Personal Mobility (PM), there has been an increase of shared spaces where different types of mobility other than pedestrians are present [2]. Some reports suggest that the safety in such shared spaces is better than in conventional segregated spaces [3]. Specifically, it has been reported that driver attention to pedestrians improves [3], vehicle speeds decrease, traffic congestion decreases, and accident rates decrease [4].

In a shared space, the interaction partners are not only pedestrians but also various mobilities including PMs. Therefore, the need for knowledge on collision avoidance behavior via PMs is expected to increase in the future. The purpose of this study is to investigate the factors that influence collision avoidance behavior via PMs.

Studies of collision avoidance among pedestrians have shown that pedestrians acquire roles and adjust their behavior accordingly [5][6]. Coordination behavior in collision avoidance uses information that varies with the crossing situation, such as the crossing angle and its rate of change, and the estimated time to collision [1][5]–[7]. For example, pedestrians adjust their walking speed and walking path according to the crossing angle and available space [1]. In addition, it has been reported that when avoiding a collision in a face-to-face situation, pedestrians make avoidance decisions based on the direction of the oncoming person's feet [7]. On the other hand, there has also been progress in examining factors that do not contribute to collision avoidance between pedestrians. For example, it has been shown that gaze at the other person does not affect coordination behavior in collision avoidance between pedestrians [8]. In other words, in collision avoidance between pedestrians, coordination behavior is based on information, such as location, speed, and body movements, such as body orientation and foot direction.

In the case of collision avoidance between PMs, the information available for coordination behavior is more limited compared to the case of a pedestrian partner. Specifically, while coordination behavior with a pedestrian partner uses information on body motions, such as body and foot orientation [7][8], in the case of a PM partner, body motion information

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is limited because there is no up-and-down motion of the legs in both the seated and standing positions. Therefore, the available body motion information is limited to the direction of the head and eye movements. In other words, in the case of collision avoidance between PM passengers, unlike in the case of pedestrians, gaze may be a valuable source of information for coordination behavior.

In fact, it has been shown that gaze plays an important role in traffic negotiation situations with a partner whose behavior cannot be estimated from body motion. For example, in traffic negotiations between cars and pedestrians, it is known that a pedestrian's direct gaze at the oncoming lane elicits more concessive behavior from the car [9][10]. However, the relationship between gaze and coordination behavior in collision avoidance between PMs has not been clarified.

In this study, we examine the relationship between gaze and coordination behavior in collision avoidance between PMs. In examining the relationship between gaze and coordination behavior, it is necessary to examine the influence of gaze depending on the role. There is a difference in the required coordination behavior between the Leader and the Follower. The Follower adjusts speed and path more than the Leader in collision avoidance situations [5][6]. Similarly, the relationship between gaze and coordination behavior may differ depending on these roles.

Therefore, this study examines the relationship between gaze and coordination behavior in collision avoidance between PMs, considering this role. Specifically, we examine the following three points. First, we examine the difference in gaze between the Leader and the Follower. Then, we confirm whether there is a difference in coordination behavior depending on the roles of the Leader and the Follower. Finally, by examining the correlation between gaze and coordination behavior of the Leader and Follower, we examine whether there is a role-dependent difference in the relationship between gaze and coordination behavior in collision avoidance between PMs.

II. Method

A. Participants

Twenty participants (N_{female} = 17, N_{male} = 3, M_{age} = 41.95, SD_{age} = 14.95) were recruited through a recruitment agency. 4 participants participated in the experiment per day.

B. Apparatus

Eye movement and position data during collision avoidance were measured. Eye movements were measured with Tobii Glasses 2 manufactured by Tobii Technology Co. The pose and velocity information was obtained using the 2D-LiDAR-based localization system (presented in [11]). The vehicle used was a WHILL Model C manufactured by WHILL Inc. (Figure 1).

C. Tasks

The task was to board a PM and cross paths with other participants only by operating acceleration and deceleration.

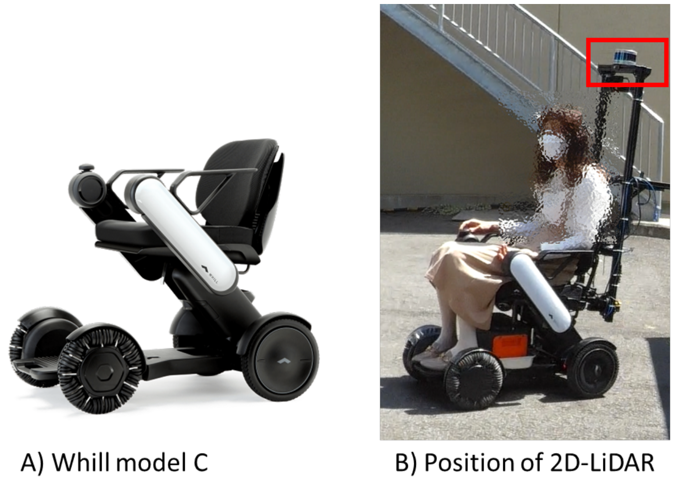

Figure 1. PM (A) and 2D-LiDAR position (B).

The paths were designed to intersect at the center of the paths, which were 10 m straight from each other (Figure 2). A straight line, such as A→G in Figure 2 means path in one trial. Three angles of intersection (60, 90, and 120 degrees) were provided. The two participants switched sides so that the direction from which the other person came was not fixed to either the left or right. One set of 24 trials, two rounds of 3 (crossing angle) × 2 (reciprocation) × 2 (direction of the other person), was used. For example, in the case of a pair of participants x and y, the x participant moves a set of paths (A→G→A) × 2→(B→H→B) × 2→(C→I→C) × 2, while the y participant moves a set of paths (L→F→L) × 2→(K→E→K) × 2→(J→D→J) × 2. Subsequently, x and y exchanged sets of paths.

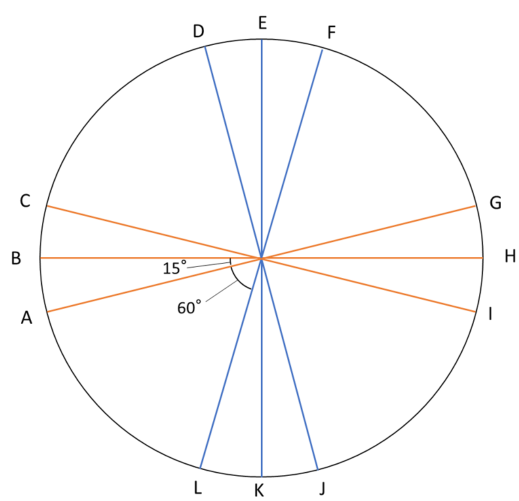

Figure 2. The path design in tasks.

D. Procedure

First, informed consent was conducted. After the task explanation, participants practiced 12 trials to familiarize themselves with the operation of the PM. They then participated in the main task. In this task, all combinations of two out of four participants participated in a set. That is, the total number of sets was six, and each participant participated in three sets of the experiment. The time he/she did not participate was considered a rest period.

III. Results

A. Difference in the gaze toward the opponent between Follower and Leader

We analyzed the video recorded by the eye tracker. Gaze toward the opponent was defined as the overlap of the coordinates of the gaze position and the position of the opponent in the video. The amount of gaze in each trial was calculated by dividing the number of logs in which each participant gazed by the total number of logs recorded every 100 hz (Table I). To examine differences in the amount of gaze by role, a paired t-test comparing the amount of gaze was conducted, and significantly more gaze was observed for the Follower (t(535) = -28.55, $p < .001$).

TABLE I
Mean (SD) of amount of gaze and operation

	Leader	Follower
Gaze	.014(.023)	.083(.053)
Operation	3.97(1.58)	4.30(1.54)

To examine the nature of gaze for each role, we plotted the time from the beginning of the trial on the horizontal axis and the number of trials in which gaze was performed at that point on the vertical axis (Figure 3). The results showed that the Follower continued to gaze until the middle of the trial, while the Leader rarely gazed after gazing at the beginning of the trial. In other words, the Follower gazed more, and continued to gaze until the middle of the trial, when coordination behavior was required.

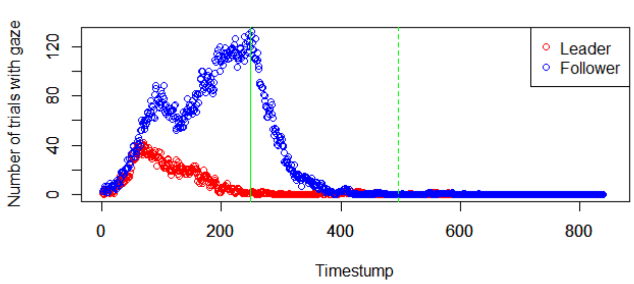

Figure 3. Timing of the gaze toward the opponent. The green dotted line indicates the average end time of a trial, and the green solid line indicates half of that time.

B. Difference in the coordination behavior between Follower and Leader

Differences in coordination behavior by role were examined. In this study, the coordination behavior in collision avoidance was limited to acceleration/deceleration. In other words, the more acceleration/deceleration during the trial, the more it contributed to the coordination behavior. However, acceleration/deceleration after passing through the intersection is not a coordination behavior for collision avoidance.

Therefore, the amount of operation to reach the intersection of the paths of the Follower and Leader was calculated. Specifically, we calculated the amount by which the speed of the Leader and Follower changed (Table I). This value represents the amount of speed change per unit of time. That is, the value is larger when there is a sudden acceleration or deceleration. The point of intersection is the point of intersection between the start and goal of the two vehicles, and the value is used until the vehicle enters a 1m circle centered at the point of intersection.

The operation volumes of the Follower and Leader were then compared using a paired t-test. The analysis showed that the Follower had more operations than the Leader (t(535) = -3.81, $p < .001$).

C. Relationship between gaze toward the opponent and coordination behavior.

To examine the relationship between the gaze and coordination behavior for each collision avoidance role, Pearson's product-moment correlations were calculated for each value (Table II). The results showed that, regardless of the role, gaze was significantly correlated with the amount of operation of the opponent. On the other hand, the Leader's gaze was not significantly correlated with the amount of their own operations, while the Follower's gaze was significantly correlated with the amount of their own operations.

TABLE II
Correlation between gaze toward opponent and operation by role ($* : p < .05$, $*** : p < .001$)

	Leader's Operation	Follower's Operation
Leader's Gaze	.08	.09*
Follower's Gaze	.10*	.14***

IV. Discussion

The purpose of this study was to examine the relationship between gaze toward the opponent and coordination behavior in collision avoidance between PMs. The results of the experiment are summarized with a focus on the difference between the roles of the Leader and the Follower.

The Follower had more gaze toward the opponent and more coordination behavior (amount of manipulation) than the Leader. This is consistent with the findings of previous studies in pedestrians that coordination behavior is mainly performed by the Follower [5][6]. Our findings provide empirical evidence that the Follower performs more gaze toward the partner, as well as coordination behavior.

The important point is that the relationship between gaze and coordination behavior was different between the Leader and Follower. First, there was no role-dependent difference in the fact that gaze toward the opponent was positively

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correlated with the opponent's coordination behavior. This suggests that regardless of the role, gaze toward the opponent has a role in promoting the opponent's coordination behavior. This point was not observed in the case of collision avoidance between pedestrians. This mean that gaze toward the opponent is a powerful source for coordination behavior in situations where information is limited, such as in PMs.

On the other hand, the Follower's gaze was related to the amount of their own operations, but the Leader's gaze was not related to the amount of their own operations. This result can be interpreted that only the Follower gazed more when they coordinated behavior with their opponent. This interpretation is supported by the fact that the Follower's gaze was mainly focused on the opponent before reaching the point of intersection where coordination behavior was performed, and that the Follower, who performed more coordination behavior than the Leader, gazed more than the Leader. These results suggest that the gaze toward the opponent is performed for different purposes depending on the role of collision avoidance. Specifically, the Leader's gaze is intended to encourage the opponent to coordinate behavior, while the Follower's gaze may be intended to coordinate their own behavior in addition to encouraging the opponent to coordinate behavior.

V. CONCLUSION AND FUTURE WORK

The purpose of this study was to examine the relationship between gaze toward the opponent and coordination behavior in collision avoidance between PMs. This study extends the knowledge of pedestrian-to-pedestrian collision avoidance behavior and provides insight into PM-to-PM collision avoidance behavior by the following contributions. First, we extended the knowledge that Follower coordinates behavior in pedestrian-pedestrian collision avoidance to the case of PMs. Second, we provided evidence that gaze is involved in coordination behavior in collision avoidance between PMs, unlike in collision avoidance between pedestrians. Finally, we showed that the relationship between gaze and coordination behavior differs depending on the role in collision avoidance, and that only the Follower gazes towards the opponent to coordinate their own behavior. Future work should extend the discussion to the functions of gaze to smoothness and role determination in collision avoidance.

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