A Study on the Behavior of Pedestrians when Confirming Approach of Right/Left-Turning Vehicle while Crossing a Crosswalk

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Abstract: In this study, head-turning behavior is analyzed to determine the most appropriate location for pedestrians to confirm the approach of a vehicle while crossing a crosswalk. It was found that the head-turning frequency increases towards the entry of the crosswalk and the conflict point. Moreover, the analysis of different attributes indicated that the head-turning frequency at nighttime or by elderly people tended to be low, and that head-turning was performed more at the conflict point. These results suggest that there is a need to provide information about approaching vehicles. When a vehicle approached the subjects from behind, the head-turning frequency was low, implying the need for information for pedestrians. According to the above results, there are several important locations where pedestrians should confirm the approach of a vehicle to ensure their safety.

Keywords: Traffic Safety, Pedestrian, Head-turning behavior, Crosswalk

1. INTRODUCTION

Traffic fatalities have been decreasing year by year in Japan. However, accidents involving pedestrians account for more than half of all fatal accidents in Japan, the only OECD nation for which this is true. It is important to install effective traffic safety measures for pedestrians. Almost half of all pedestrian accidents occur at crosswalks. Although road administrators have installed many traffic safety measures, such as traffic signals and road traffic signs, there is a need to install additional effective traffic safety measures to ensure pedestrian safety at signalized intersections. In Japan, where drivers drive on the left, accidents caused by right-turning vehicles in daytime mostly involve pedestrians who are crossing the road from the opposite direction of a vehicle, and such accidents at night mostly involve pedestrians who are crossing the road from the same direction of a vehicle. When the visual conditions for driving are poor, accidents involving pedestrians crossing from the right of a vehicle account for a high proportion of accidents between right-turning vehicles and pedestrians (Hagita (2011)). Traffic safety measures for the case of right-turning vehicles are thus expected to contribute to decreasing the number of fatalities among vulnerable road users.

Much of the research on pedestrian accidents has focused on decreasing the number of accidents between pedestrians and right-turning vehicles at signalized intersections (Milazzo II, J.S. et al (1998), Leden, L. (2002), Hagiwara (2009) and (2011)). Hamaoka et al. (2007)

investigated the effect of the stopping position of right-turning vehicles on the recognition of pedestrians approaching from the right at night. This study found that drivers of right-turning vehicles could more easily recognize pedestrians approaching from the right when the vehicle stopped further from the intersection center before starting the right turn. Other studies addressed the visibility of crossing pedestrians to drivers of right-turning vehicles at night (Hagiwara (2010)). Such researches mainly aimed to establish traffic safety measures for the drivers of right-turning vehicles, and these measures are intended to improve the road and driving environment. However this approach that considers the countermeasure from drivers' viewpoint is important, considering the countermeasure from the pedestrians' viewpoint is also important to establish a better traffic environment. Of course, pedestrians have a right-of-way in crossing a crosswalk. By considering the current situation that many pedestrians were involved in a traffic accident at a crosswalk, installing the countermeasures for pedestrians would be important to avoid occurring pedestrian accident. If traffic safety measures for pedestrians, such as safer crossings were clarified, the safety of the intersections would increase as a result of the synergistic effect of traffic safety measures for both pedestrians and drivers. It is important to investigate pedestrian accidents at intersections from the viewpoint of pedestrians. However, there is few research that focuses to the pedestrian (Hamaoka et al. (2012)). In this study, we analyzed the behavior of pedestrians when confirming the approach of right/left-turning vehicles, with the aim of clarifying the most appropriate location for pedestrians to confirm the approach of vehicles when crossing a crosswalk. Therefore, the behavior of drivers by the pedestrian behavior was not considered in this study.

2. METHOD

2.1 Outline of the Experiment

The experiment was conducted at the Tomakomai Winter Test Track of the Civil Engineering Research Institute for Cold Region, Public Works Research Institute, in Tomakomai City, Japan (Table 1). The test track was selected mainly for its ability to enable the safe testing of the behavior of pedestrians at a crosswalk under conditions that closely reproduce those of an actual roadway. Figure 1 shows the T-intersection used in the experiment. The experiment was carried out from August 21 to 26 and from September 11 to 16, 2011, and involved 44 subjects: 19 young subjects (8 female and 11 male), and 25 elderly subjects (10 female and 15 male). By utilizing a large number of subjects, we could analyze the behavior of pedestrians from various viewpoints.

Table 1. Outline of the experiment

Date	21-26 August, 11-16 September, 2011
Place	Tomakomai Winter Test Track
# of Subjects	44
Number of the experiment for one subject	18 (including 2 practice runs)
Attributes of the experiment	Start position of subjects (R, L) Approaching vehicle (right, left, none) Age (young, elderly) Gender (female, male) Time (daytime, nighttime) Hearing sense (wearing headphones or not)

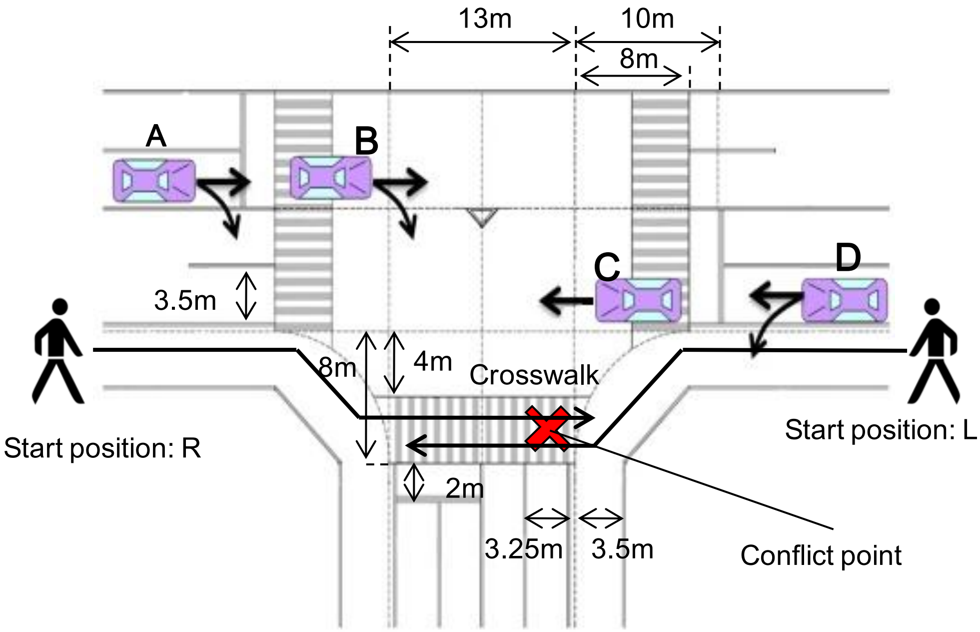


Figure 1. Experimental intersection

2.2 Start Positions and Experimental Procedure

Experiments on subjects crossing a crosswalk and encountering vehicles were conducted at the test track to determine in detail how people check for vehicles at crosswalk. In the experiment, subjects started to cross the crosswalk from one of the two start positions shown in Figure 1 (R and L) while a vehicle made one of four possible maneuvers, (i.e., Vehicle A turns right, Vehicle B turns right, Vehicle D turns left, all vehicles proceed without turning), which were unknown to the subjects in advance. The starting times of the vehicles and subjects were arranged so as to produce a conflict point on the crosswalk (i.e., the vehicle would hit the pedestrian if neither changed speed).

Each subjects crossed the road 18 times, the first two times as practice to familiarize themselves with the experiment. Each subjects subsequently crossed the road 16 times under different experimental settings (start positions of the subjects, with/without wearing headphones, and so forth). The start positions of the subjects and the maneuvers of the vehicles (which vehicle approaches the crosswalk) were varied randomly to avoid serial correlation.

2.3 Measurement of the Checking Behavior of the Pedestrian by Wearable Motion Recording System

In the experiment, to determine the head-turning behavior of the subjects, each subject wore the baseball cap shown in Figure 2. When engaging in checking behavior, the subject scans for approaching vehicles by turning his/her head on the horizontal plane in the possible directions of vehicles. To examine this checking behavior, we recorded the horizontal head movements of the subjects during each trial run. Previously, the only way to measure head movements during walking was by using a compact video camera mounted on a baseball cap. In this experiment, however, we used a small wireless six-axis gyro sensor (39.0 mm (W) x 44.0 mm (H) x 12.0 mm (D), 20 g) recently developed by Advanced Telecommunications Research Institute International. The gyro sensor system was mounted on a baseball cap and used to measure the horizontal head movements of the subjects. A compact video camera was also mounted on the baseball cap. The gyro sensor system measured data sampled at 50 Hz, which was sent to a Personal Digital Assistant (72.0 mm (W) x 115.0 mm (H) x 17.8 mm (D), 170 g) via Bluetooth communication. The Personal Digital Assistant received and stored the GPS location data at a frequency of 1 Hz.

(A) GPS logger (B) CCD camera and sensor (C) sensor

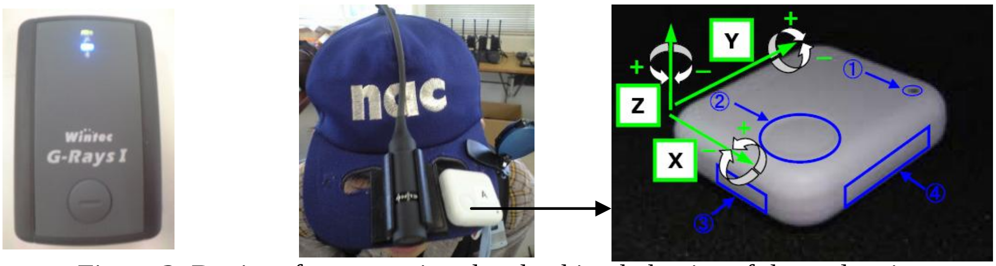


Figure 2. Devices for measuring the checking behavior of the pedestrian

3. ANALYZING METHOD AND RESULTS OF THE CHARACTERISTICS OF HEAD-TURNING BEHAVIOR

When a pedestrian crosses a crosswalk and finds that a right/left-turning vehicle is approaching, he/she turns his/her head to look at the approaching vehicle. Thus, head-turning can be analyzed to determine the behavior of crossing pedestrians. In this section, the head-turning behavior of the subjects is focused on to analyze the characteristics of crossing pedestrians. The head-turning angle of the subjects is analyzed for many conditions, including the two start positions (R and L), with or without wearing headphones, daytime or nighttime, and so forth. Also, analysis of their attributes, such as whether they are elderly or young and female or male, is also carried out to determine the relationship between the head-turning behavior and these attributes.

3.1 Calculation Method of Head-Turning Angle

The head-turning angle is calculated by utilizing the six-axis gyro sensor. The horizontal angular acceleration of the gyro sensor is used to calculate the head-turning angle. In this sensor, angular acceleration was recorded every 0.02 seconds (50 Hz). Moreover, a positive value indicates counterclockwise rotation and a negative value indicates the clockwise rotation. Therefore, the summation of consecutive positive values gives the head-turning angle to the left, and the summation of consecutive negative values gives the head-turning angle for the right. This sensor is extremely precise in measuring angular acceleration, because the resolution of angular acceleration measurement of this sensor is 0.01 deg./s2. Thus, this sensor can measure the head-turning angle even for small movements. Therefore, it is necessary to distinguish between head-turning behavior to look for an approaching vehicle and other head-turning behavior. In this study, the threshold value for the former was set to 7 degree. This angle was obtained from the situation that the subject confirms the approach of vehicle from the opposite side of the road. If the head-turning angle exceeds 7 degree, it is considered that the subject has turned his/her head to confirm the approach of a vehicle.

3.2 Data Utilized for Analysis

In this analysis, selected data is utilized under the situation that subjects turned their heads to confirm the approach of a vehicle. To analyze the location characteristics of the behavior of subjects in head-turning, it is important for subjects to enter the crosswalk, because the location at which the approach of a vehicle is confirmed by the subjects as they cross the crosswalk is indicated by their pushing a button. Therefore, conditions required for the utilization of data are follows: 1) a vehicle approaches a subject by performing a right turn or left turn, 2) the subject enters the crosswalk, 3) the subject pushes the button to show that he/she has confirmed the approach of the vehicle. As a result, the number of trials in which the data was utilized was 287 out of a total of 792, because 219 trials in which all vehicles proceeded in a straight line without turning, 114 trials in which subjects did not enter the crosswalk because they stopped before entering the crosswalk; and 172 trials in which they subjects did not push the button because they did not see an approaching vehicle were eliminated.

3.3 Analysis of Head-Turning Angle

In this section, the location where subjects turned their heads is analyzed using the results of trials involving different maneuvers of the vehicles (right turn/left turn), the start positions of the subjects (R/L), gender (female/male), and so forth. In analyzing the location of head-turning, the location where subjects pushed the button was categorized in terms of the number of half widths of a lane, referred to as a block. The width of a lane in this simulated intersection is 3.25 m, therefore the width of a block is 1.65 m. At the intersection, there are two lanes in each direction (Figure 1); therefore, the crosswalk has a width of eight blocks. The numbers of blocks is also used to categorize the location on the sidewalk where the subject walks toward the crosswalk. These blocks were numbered to match the location where the subjects enter the crosswalk from the edge of the crosswalk and approach the conflict point. The locations where the subject enters the crosswalk is +1 and the number increases towards the conflict point. Therefore, the block number increases from +1 to +8 for the case that the start position of the subject is R, and the block number increases from +1 to +2 for the case that the start position is L because of the different locations of the conflict point for each case. Because the head-turning behavior near the start position might be unrelated to searching for approaching vehicles from the viewpoint of traffic safety at the crosswalk, the block numbers used in the analysis are –10 to +8 and –10 to +2 when the start position is R and L, respectively.

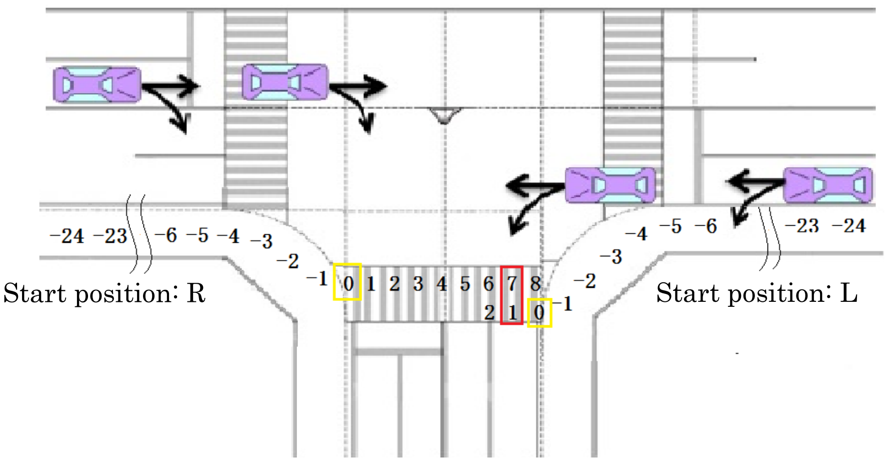


Figure 3. Concept to define block numbers for each start positions

3.4 Analysis of the Average Head-turning Angle

We first focus on the head-turning angle to clarify the behavior of the subjects. It may be important to determine the head-turning angle in each block, because it may indicate the difficulty in noticing an approaching vehicle. Figure 4 shows the average head-turning angle in each block when subject makes head turn for the two start positions (R and L). The figure shows that block -4 has the largest head-turning angle for start position R. By comparing the mean head-turning angle for both start positions, the head-turning angle of start position L is larger at the entry of the crosswalk. This is considered to be because the distance to the conflict point from the sidewalk for start position L is less than that for start position R, resulting in the subjects having greater consciousness of approaching vehicles.

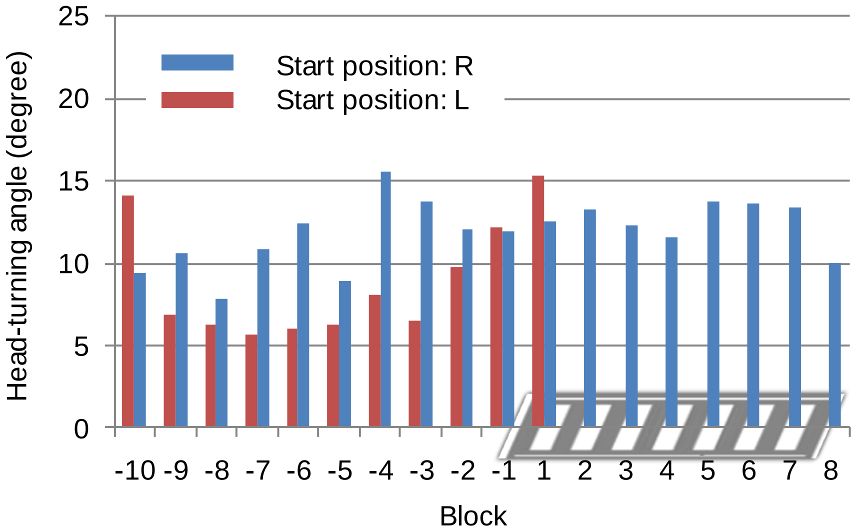


Figure 4. Head-turning angle by the start position

3.5 Analysis of the Head-turning Frequency

Next, the head-turning frequency is focused on to determine the characteristics of confirmation, because the head-turning frequency may indicate the importance of head-turning from the viewpoint of the subject. Figure 5 shows the relative head-turning frequency in each block for the two positions. Here the head-turning frequency is divided by the total number of instances of head-turning in the trials, enabling the easy comparison of results for different attributes with different total frequencies. This figure shows that the head-turning frequency increases towards the entry of the crosswalk for both start positions, indicating that pedestrians consider it important to check for approaching vehicles at this point. An interesting result is that the head-turning frequency for start position R decreases after entering the crosswalk then increases towards the conflict point. By comparing the results from the different start positions of the experiment, it was found that the head-turning frequency is higher for start position L than for start position R at the entry of the crosswalk. This is considered to be because the distance between the conflict point and the entry of the crosswalk for start position L is shorter than that for start position R. Therefore, the subjects do not have enough time to confirm the approach of a vehicle, which many result in then checking for an approaching vehicle a large number of times. From the above results, it is confirmed that there is a clear difference in the distribution of the head-turning frequency for the two start positions.

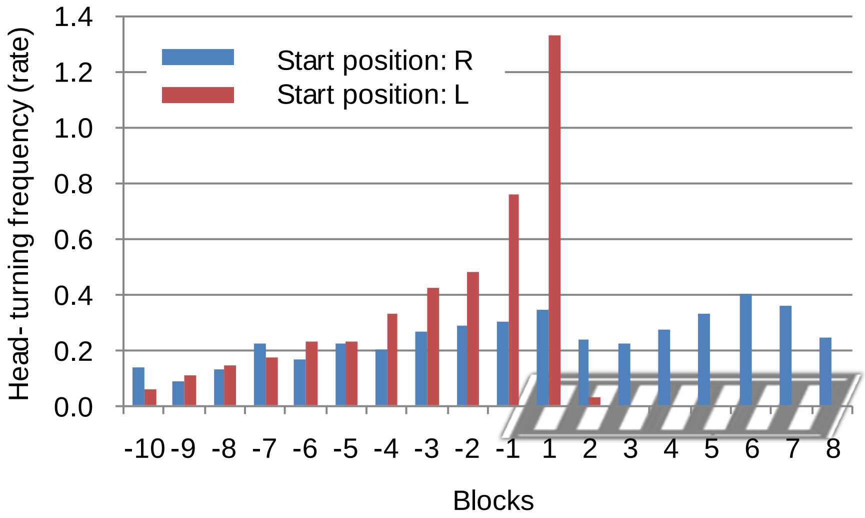


Figure 5. Head-turning frequency by the start position

3.6 Analysis of the Head-turning Frequency for Start Position R

In the previous section, it was clearly shown that the head-turning behavior of the subjects differs with the start position. To more clearly understand the differences in the head-turning behavior of the subjects in detail, several attributes are focused on. Figure 6 shows the head-turning frequency for the cases of right-turning and left-turning vehicles for start position R. This figure shows that the distribution of the head-turning frequency for both cases is almost the same. In the case of an approaching right-turning vehicle, the head-turning frequency increases from the start position to the entry of the crosswalk, and when entering the crosswalk, the head-turning frequency decreases. After that, the head-turning frequency increases again and is highest near the conflict point. However, in the case of an approaching left-turning vehicle, the head-turning frequency does not have the same distribution as that in the case of an approaching right-turning vehicle. Increase transition could be shown, however the highest head-turning frequency was at the conflict point.

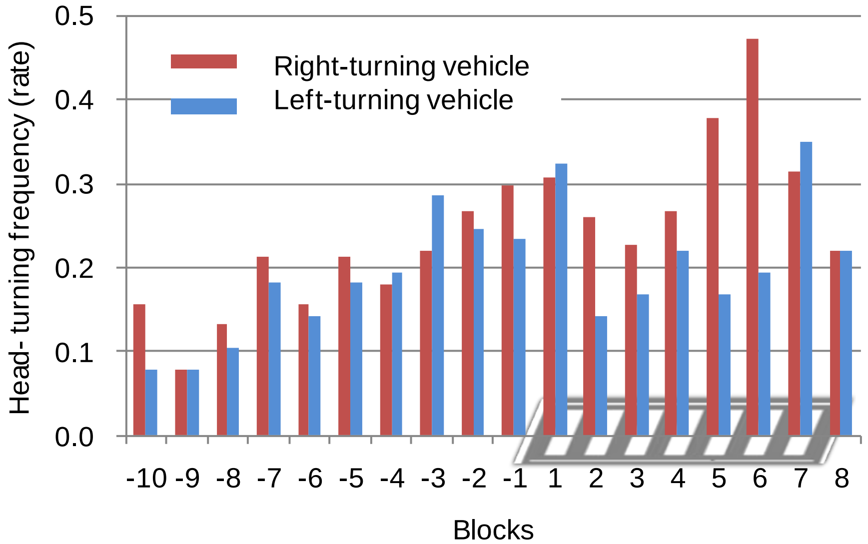


Figure 6. Head-turning frequency in the case of start position R

By conducting the same analysis for the other attributes, the following findings were obtained.

Female/Male:

The head-turning frequency of females is highest near the conflict point, where as the head-turning frequency of males is highest just in front of the conflict point. The head-turning frequency at the entry of the crosswalk is higher for males than for females.

Young/Elderly People:

Before entering the crosswalk, the head-turning frequency of young people is higher than that of elderly people. At the block just in front of the conflict point, the head-turning frequency of elderly people is higher than that of young people, whereas at the conflict point, the head-turning frequency of young people is higher. Furthermore, the head-turning frequency of elderly people is lower than that of young people after entering the crosswalk.

Daytime/Nighttime:

The head-turning frequency at nighttime is lower than that during daytime just in front of the entry of the crosswalk and after entering the crosswalk.

With/Without Wearing Headphones:

The head-turning frequency is similar in both cases. In the case of wearing headphones, the head-turning frequency decreases at the entry of the crosswalk and then increases towards the conflict point. The head-turning frequency at the conflict point is higher in the case that no headphones are worn.

3.7 Analysis of the Head-turning Frequency for Start Position L

In the same way, we analyzed the head-turning frequency for start position L for the cases of right-turning and left-turning vehicles. Figure 7 shows the head-turning frequency for both cases. This figure shows that the location where the increase in the head-turning frequency occurs is closer to the crosswalk in the case of an approaching left-turning vehicle. After the subjects pass block -5, the head-turning frequency to check for an approaching right-turning vehicle become high.

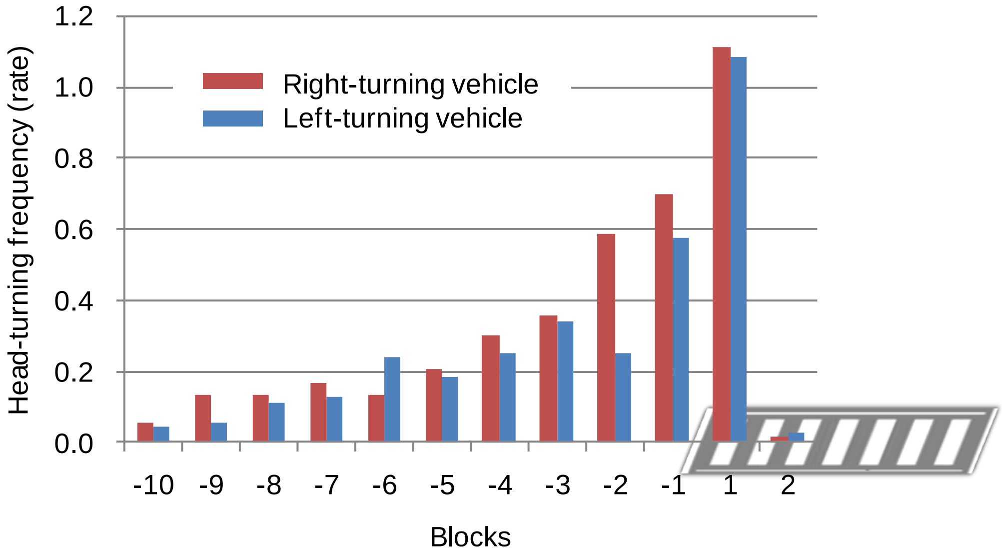


Figure 7. Head-turning frequency in the case of start position L

By conducting the same analysis for the other attributes, the following findings were obtained.

Female/Male:

The location of highest head-turning frequency is at the conflict point for both genders. The head-turning frequency is higher at the conflict point for males than for females. The head-turning frequency of males is higher far from the crosswalk than that for females.

Young/Elderly People:

The head-turning frequency shows a similar transition for both ages, however, the head-turning frequency of young people is higher at the conflict point.

Daytime/Nighttime:

The head-turning frequency shows a similar transition for both times, however, the head-turning frequency at nighttime is higher at the conflict point.

With/Without Wearing Headphones:

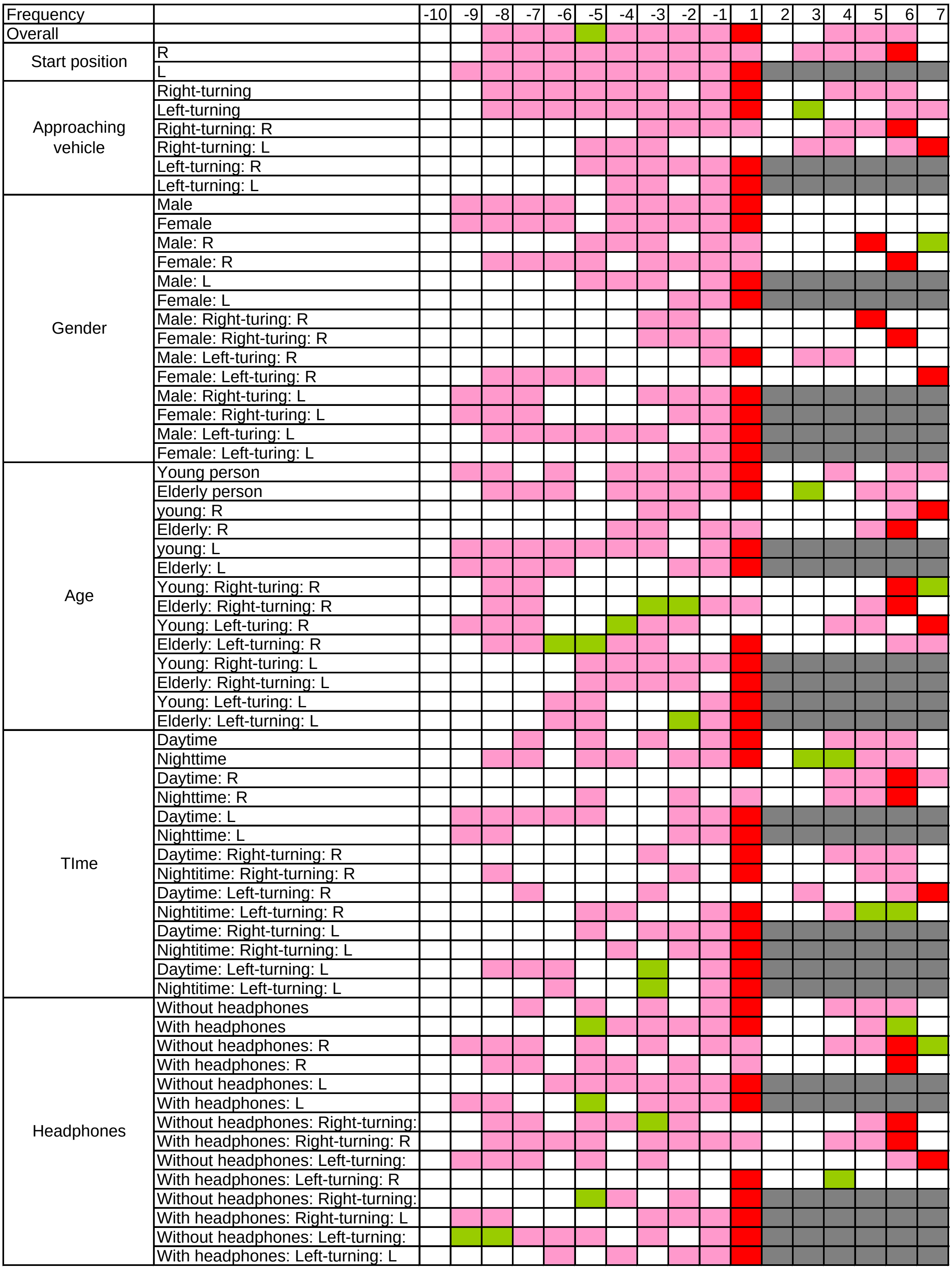
The head-turning frequency of the subjects without headphones is high in every block including the conflict point.

3.8 Results of the Analysis of Head-turning Frequency for Various Attributes

From the obtained characteristics of the head-turning frequency described above, the findings are summarized as follows: the head-turning frequency differs with the type of approach of the vehicle. When an approaching vehicle is behind the subjects, confirmation of the presence of this vehicle tends to be delayed. When a vehicle approaches from the opposite side, the subjects observed it quickly before arriving at the crosswalk. The results of this analysis are summarized in Figure 8. This figure shows the highest blocks of head-turning (red) for each situation by conducting the same analysis shown in sections 3.5 to 3.7.

From this figure, it is easy to compare the characteristics for different attributes. By comparing the behaviors of young and elderly people, it was found that elderly people have a lower head-turning frequency, especially at nighttime. Also, elderly people tend to increase their frequency of head-turning later than young people. Therefore, it can be considered that elderly people might have lower ability in noticing approaching vehicles. To summarize, the number of times that elderly people check for an approaching vehicle tends to be small. Moreover, elderly people might have difficulty in confirming the approach of a vehicle or be late in confirming the approach, resulting in them being at greater risk when crossing a crosswalk. This indicates a need to assist elderly people in crossing crosswalks.

The analysis of whether the wearing of headphones affected subject behavior did not clearly shown a difference in the head-turning frequency. It may be considered that listening to music through headphones could reduce the amount of information obtained about approaching vehicles. This suggests the importance of providing a better experimental environment so as to simulate the actual situation. Classical music was used in the experiment. However, if the subjects did not like classic music, they may not have listened to the music attentively, resulting in no decrease in interest in the surrounding environment. This might be an important issue in establishing more realistic experimental conditions.



Note: Red/Pink/Green area shows the highest/increasing trend/even trend of head-turning

Figure 8. Results of the analysis of head-turning frequency by various attributes

4. ANALYSIS OF APPROPRIATE HEAD-TURNING BEHAVIOR

A questionnaire was given to the subjects after each trial. Therefore, each subject had to answer the questions 18 times. The questions were about the actions taken before becoming aware of the approaching vehicle and the impression of the subject after he/she confirmed the approach of a vehicle. Because these question is easy to answer, answering time was less than 1 minute in each trial. In this analysis, both questions are used to distinguish whether or not his/her confirmation was accurate. By comparing the observed head-turning behavior with the results of the questionnaire, we aimed to establish the most appropriate location to confirm the approach of a vehicle.

To analyze the awareness of the subjects of an approaching vehicle, data corresponding to the case that subjects entered the crosswalk and pushed the button are used. There were 12 cases in which invalid data were given in the questionnaire and 42 cases which subjects did not pay attention to an approaching vehicle. Therefore, 275 data were used for this analysis.

4.1 Summary of Results of Questionnaire

First, the awareness of an approaching vehicle was analyzed. Figure 9(a) shows the answers to the question "Did you pay attention to the approaching vehicle before you are aware of its existence?". The figure showed that almost 80% of subjects were looking for an approaching vehicle.

Then, the impressions of the subjects are analyzed from the viewpoint of their perceived likelihood of collision with the approaching vehicle. Figure 9(b) shows the answers to the question "Did you think that the approaching vehicle would collide with you?", and Figure 9(c) shows reasons why subjects did not feel danger. Figure 9(b) shows that many subjects felt danger because of the approaching vehicle. Therefore, this result indicates that we established a suitable environment for the experiment with a realistic setting. However, Figure 9(c) shows that some subjects felt that the approaching vehicle would stop in front of the crosswalk, indicating that the experiment could have been designed to be more realistic. From the answer of subjects that there was sufficient distance from the approaching vehicle in Figure 9(c), it can be concluded that they were correct in feeling no danger because they had intentionally maintained a certain distance from the approaching vehicle.

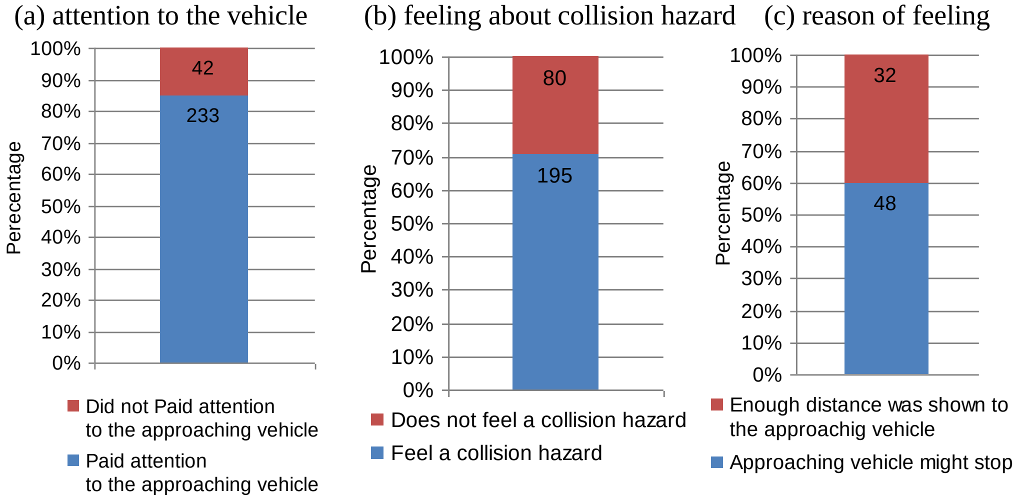


Figure 9. Result of the questionnaire

4.2 Comparison between Appropriate and Average Head-Turning Behavior

To clarify the location where subjects with appropriate head-turning turned their heads, it is necessary to compare the locations of head-turning in the case of both appropriate and average head-turning. To this end, the characteristics of appropriate head-turning should first be identified. In this study, by utilizing the results of the questionnaire, the case that subjects felt safe because they had maintained a certain distance from the approaching vehicle is considered to correspond to appropriate head-turning behavior. In analyzing the appropriate locations where subjects had turned their heads to find and confirm the approaching vehicle, it is considered that a higher head-turning frequency indicates a location where the approach of a vehicle was confirmed and a large head-turning angle indicated a location where subjects were looking for an approaching vehicle.

Figure 10 shows a comparison of head-turning behavior between the cases of appropriate and average head-turning behavior when the start position of the subjects is R and a right-turning vehicle is approaching. The figure shows that subjects with appropriate behavior had a higher head-turning frequency at the entry of the crosswalk and at the conflict point. Moreover, the head-turning frequency in the middle of the crosswalk was high. This head-turning behavior is considered to correspond to subjects looking for an approaching vehicle regardless of whether or not a vehicle was actually approaching.

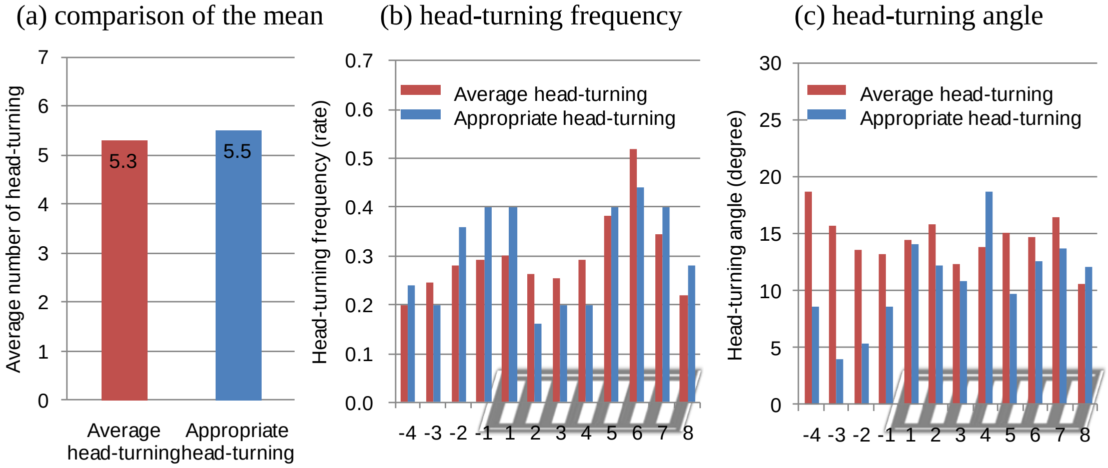


Figure 10. Comparison of the head-turning behavior between average and appropriate

In the case of elderly people, appropriate head-turning behavior was performed just in front of the entry of the crosswalk and at the conflict point. Moreover, the head-turning angle of the subjects with appropriate head-turning behavior is large. Also, the head-turning frequency of subjects wearing headphones with appropriate head-turning behavior is high. Moreover, subjects with appropriate head-turning behavior turned their heads very often just in front of the entry of the crosswalk and at the conflict point with a large angle just after entering the crosswalk and near the middle of the crosswalk.

Various other conditions the start position was R and a left-turning vehicle was approaching, the start position was L and a right-turning vehicle was approaching, and the start position was L and a left-turning vehicle was approaching, were analyzed to identify the locations where subjects with appropriate head-turning behavior confirmed the approach of a vehicle. The results indicate that appropriate head-turning behavior is mainly performed near the entry of the crosswalk. In three cases, elderly people (having difficulty in crossing), nighttime (restricted visibility), and wearing headphones (restricted hearing), these were clear differences between the appropriate head-turning behavior and average head-turning behavior.

Figure 11 shows a summary of the above results in terms of the location of appropriate head-turning behavior of pedestrians for confirmation that they can cross without feeling danger. X mark in this figure shows the conflict point, and yellow-colored-area shows the most appropriate point to make head-turning. These results are shown by the start position of pedestrian, turning direction of approaching vehicle and attributes of pedestrians. Generally, a location of appropriate head-turning behavior is just in front of the crosswalk. The middle of the crosswalk is also an important location for checking the approach of a vehicle when the start position is R and a right-turning vehicle is approaching.

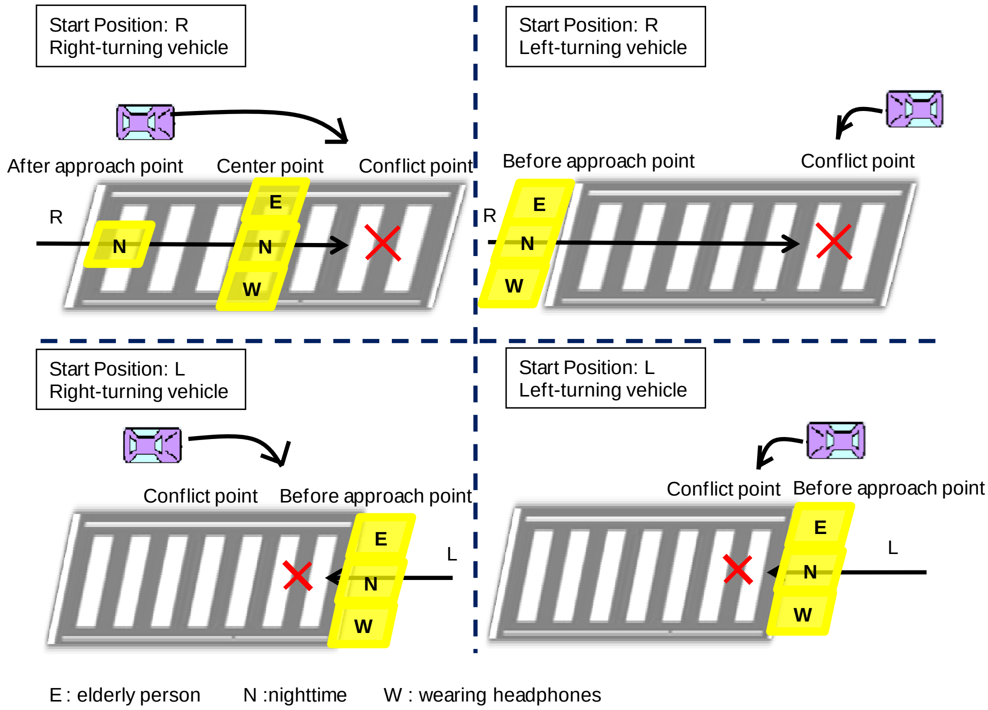


Figure 11. Location of appropriate head-turning behavior

5. CONCLUSIONS

In this study, head-turning behavior is analyzed to determine the most appropriate location for the pedestrians to confirm the approach of a vehicle when crossing a crosswalk. It was found that the head-turning frequency increases towards the entry of the crosswalk and the conflict point. Moreover, the head-turning frequency at nighttime and of elderly people tends to be low, although head-turning was performed more at the conflict point. These results indicate that there is a need to provide information about approaching vehicles. When a vehicle approaches the subjects from behind, the head-turning frequency was low, also implying the need to provide information for pedestrians.

By the comparison of results for different experimental settings, it was found that the position where pedestrians started to enter the crosswalk is the most appropriate location to confirm the approach of a vehicle in three cases; elderly people (having difficulty in crossing), nighttime (restricted visibility), and wearing headphones (restricted hearing). Moreover, head-turning was frequently performed in the middle of the crosswalk when that start position was R and a right-turning vehicle was approaching, which may be an appropriate action to confirm the approach of a vehicle. From the above results, there are many critical locations where pedestrians crossing a road at a intersection should confirm the approach of a vehicle to ensure their safety. These results could contribute to establish the warning system to the walking pedestrian at the appropriate location for the safety crossing of the crosswalk, and this system might be acceptable for all pedestrians.

In this study, the attributes selected were age, gender, time of day, and the use of headphones. However, other factors might have a significant effect in this environment such as the walking speed, the setting of traffic signals and so forth. These attributes should be included in future studies. Moreover, the locations where subjects with appropriate head-turning behavior mainly turn their heads should be verified by conducting another experiment. These are the important issues should be analyzed in the future.

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