Head-turning and Visual Search Behaviors at Intersections with Permissive Signal Phasing: An Eye-Tracker Experiment

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Abstract

Permissive signal phasing is a common design in intersections in Taiwan where turning vehicles share the same green-time periods with pedestrians for occupying crosswalks. Despite that traffic laws and regulations give pedestrians rights of way on crosswalks, the accident risk inevitably rises, and pedestrians have to maintain alert during crossing the road. The present study aims to explore the visual search behaviors of pedestrians, including their head-turning and eye fixation behaviors while crossing an intersection with permissive signal phasing. A field experiment is developed by asking twenty young adults to walk on a designated path twice where the participants may encounter conflicting turning vehicles from different directions. Each participant receives a situational awareness test before the walking experiments, and an intervention is made between the first- and second-round experiments by informing the participants of a higher chance of encountering conflicting turning vehicles from back. The head-turning and visual search behaviors are collected with a mobile eye tracker; surrounding traffic conditions are recorded by research assistants following the participants. The analysis results showed that participants with a high level of situational awareness ability exhibited more head-turning but not necessarily more eye fixations. When walking through a crosswalk segment protected by a refuge island, the participants demonstrated a lower frequency of eye fixations, suggesting a lower attention burden because of refuge island. The behavioral change because of the intervention includes more head-turning and better performance of fixating eyes on turning vehicles. The study highlights the effectiveness of roadside safety education when the provided information is specific. Pedestrians mostly pay more attention before entering an intersection; yet, maintaining a certain level of situational awareness is preferred when walking across an intersection with permissive signal phasing.

Keywords: pedestrians; crosswalk; signalized intersection; eye fixation; multilevel model

1. Introduction

In Taiwan, many traffic signals at intersections have a permissive phase, meaning that turning vehicles share the same time period with pedestrians for occupying crosswalks. A permissive design is especially common in the central business district as a permissive design may increase the efficiency of intersections (Urbanik et al., 2015). Meanwhile, a permissive design is also known for its safety concerns. Although traffic laws and regulations give pedestrians rights of way, the accident risk of pedestrians inevitably rises in walking through signalized intersections with a permissive rather than a protected design (Hurwitz et al., 2013; Pratt et al., 2012). For example, under a permissive design left-turning vehicle drivers have to pay attention to the opposite through vehicle movements and look for acceptable gaps for both through vehicles and pedestrians; any inappropriate attention allocation or vehicle maneuvering could lead to traffic accidents.

Visual search has been considered as a reflection demonstrating attention allocation, which is also the primary way that pedestrians use to identify potential threats on the road. Previous studies have focused on the visual search behaviors in children pedestrians as visual search is highly related to cognitive development. For example, based on a sample of 60 children aged 4/5, 7/8, and 10/11 years and a random sample of 10 adults, Whitebread and Neilson (2000) identified four strategic approaches that differentiated how children and adults used visual clues on the road, which included the frequency and pattern of looking in the relevant different directions; the presence and sophistication of a last-minute checking procedure just before a decision to cross; the exhaustiveness of visual

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search strategies; and the speed of making a crossing decision. By comparing younger children (average age 6 years), older children (average age 9 years), and adults (20.6 years), Kovesdi and Barton (2013) indicated age and working memory both contributed to explaining the variance of visual search behaviors including reaction time, fixation count, saccade velocity, and visual efficiency detection performance. Another stream of pedestrian visual search studies lies in gender difference. Tom and Granie (2011) showed that before crossing, men pedestrians looked at vehicles more than women pedestrians did; during crossing the road, women pedestrians focused on other pedestrians more than men pedestrians did, particularly on signalized intersections. Their study also showed that men pedestrians first looked at vehicles and then at traffic lights; on the other hand, women pedestrians first looked at traffic lights and pedestrians, and then at moving vehicles. These visual search differences may partially explain why an observed relatively low compliance rate of traffic signals in men pedestrians.

Under a permissive signal timing design pedestrians still need to pay attention to surrounding vehicles during crossing; but where should pedestrians look to? During these six years, 490 pedestrian accidents occurred in Taipei. Vehicles collided with pedestrians mostly (42.4%) from the back of the pedestrians; head-on collisions accounted for approximately one-fifth. Notably, the collisions that vehicles and pedestrians were perpendicular to each other contributed to 30.8% of the total pedestrian collisions. As occurring at signalized intersections, these vehicle-to-pedestrian perpendicular collisions may result from running red lights by either the vehicle or the pedestrian. The statistics above highlight the importance to pedestrians for paying attention during crossing despite that the law gives pedestrians rights of way on a crosswalk.

Based on the background above, the study has two purposes. The first purpose is to explore pedestrian eye searching behaviors during crossing; in particular, we focus on signalized intersections with permissive signal phases. Seeing the high frequency of vehicle-pedestrian collisions that vehicles were running from the back of the pedestrians, the study designs an experiment that aims to raise the situational awareness of pedestrians for such potential threats. In particular, we tell the participants about the relatively high frequency of vehicle-pedestrian collisions that vehicles are coming from back of the pedestrians, and compare the participants' eye searching behaviors before and after knowing the safety fact.

2. Methodology

2.1 Eye tracker experiment

To understand how pedestrians allocate attention during crossing the road, the study conducts a field experiment that uses eye-trackers to detect pedestrians' head-turning behaviors and eye movements. The experiment consists of three steps including an interview for the participants' background information, followed by a pretest of their situational awareness ability, and finally a walking experiment in a selected field. The research team recruits 20 participants aged between 20 and 30 on the campus of National Yang Ming Chiao Tung University, Taiwan. We limit the participants to be young adults without any disability in walking and had an equal number of male and female participants. Each participant receives NT$600 in cash as a reward for the experiment. The experiment is approved by the Research Ethics Committee for Human Subject Protection, National Yang Ming Chiao Tung University (NYCU-REC-110-092E). The details of the experiment are described below.

2.1.1 Pretest of situational awareness ability

The study develops three question sets for measuring the situational awareness of the participants. The first question asks the participants to draw potential conflict points for a pedestrian crossing at an unsignalized four-leg intersection. The highest score is 10 if a participant identifies all the potential conflicts. For the second question set, we provide two snapshots of real-world crosswalks. We ask participants to identify objects that bring their attention and circle the objects that may affect crossing safety. We then ask whether an object circled by the research team would affect the crossing safety of the pedestrians. If the answer is yes, the participant needs to describe how the circled object would affect the crossing safety. If the answer is no, the participant is asked to describe why they think the safety would not be affected. For the third question set, we ask the participants to enroll in an online hazard perception test developed by the Cathay Century Insurance Company (https://carrisk.cathay-ins.com.tw/danger_test.asp). The test provides three videos from the first perspective of scooter drivers; participants click on the screen when they identify hazards on the video. A score is given for each click based on the timing of the click. The highest score that could be obtained is 20. The final score is the summation of the score of all three question sets, ranging between 0 and 50.

2.1.2 Pedestrian walking experiment

The goal of the pedestrian walking experiment is to explore the way that pedestrians pay attention during crossing an intersection where attention allocation is examined using an eye tracker. An intervention is also designed in the field experiment to examine the effect of providing pedestrians safety facts on changing their attention allocation. The study uses the Pupil Invisible of the Pupil Labs (https://pupil-labs.com/). Pupil lab's Eye tracking glasses work like a pair of glasses. It is a device with two cameras that captures participant's every eye's movement and one world camera attached to the frame of the glasses. The hardware and the Pupil Lab Mobile Bundle are flexible and carefully designed to be lightweight and unobtrusive. A mobile phone will be connected to the eye tracker and carried by the participants to record the detected eye movement and video data.
The experimental field was on Chunghwa Road, Taipei. Each participant started his or her experiment at the southeastern corner of the Zhonghua-Wuchang intersection (the bottom-left corner of Figure 1; also see Figure 2(a)). At the beginning of the experiment for each participant, the research team made a brief on the purpose and procedure of the field experiment, collected the background interview, and conducted the situational awareness test. Then the participant wore the eye tracker and walked on the sidewalk for a short distance to make sure the participant was comfortable with the eye tracker and the recorded data were fed into the mobile phone.
Each participant walked through a selected path twice. In the first round, the participant walked clockwise from the starting point (the bottom-left corner) to the turning point (the bottom-right corner) along the path indicated in Figure 1, including walking across the Zhonghua road with protection from a refuge island, turning left, walking straight across the Zhonghua-Wuchang and Zhonghua-Hankou intersections, turning right at Zhonghua-Kaifeng intersection (Figure 2(b)), walking across the Zhonghua road, and finally arriving at the turning point, i.e., the southeastern corner of the Zhonghua-Kaifeng intersection. Then, the participant followed the same path back to the starting point.
After the participant arrived at the starting point, the research team briefed the participant again, telling the participant that the most frequently occurring vehicle-pedestrian collision type at signalized intersections in Taipei was vehicles running from back at an odds ratio greater than two. Then, the participant went through the same path to the turning point and came back to the starting point. For each round of walking, a participant would encounter vehicles running from the right rear (RB) twice, from the left rear (LB) once, from the right front once (RF), and from the left front (LF) twice. The participant would also walk through three junctions without any conflicts of turning vehicles.

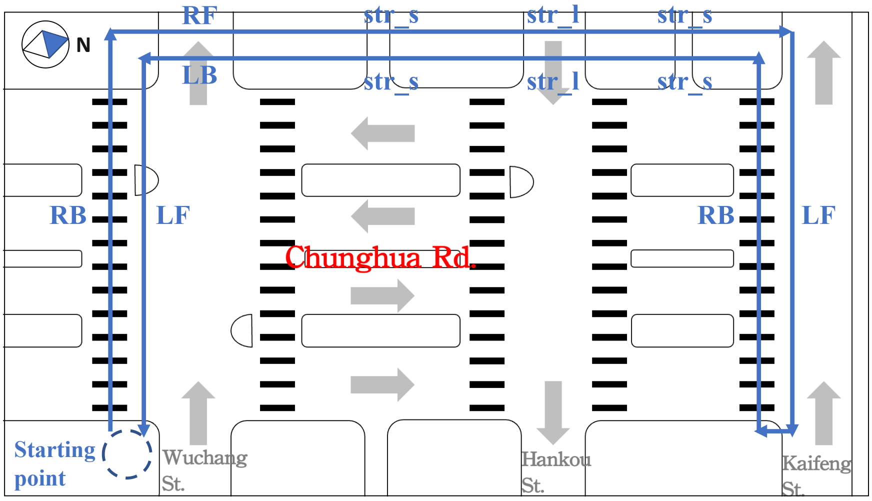


Figure 1 Experimental site: the blue path indicates the walking path selected by the research team

(a) Zhonghua-Wuchang intersection (b) Zhonghua-Kaifeng intersection

Figure 2 Snapshot of the three main intersections in the field experiment

2.2 Variable definitions

The study has two main outcome variables, head-turning, and eye fixation frequencies. Head-turning is counted once when a participant turns his or her head towards left or right and turns back to look to the front. This behavior can be observed by watching the recorded world video.

The study considers the following predictors when developing pedestrian behavior models:

(1) Exposure variables

It is crucial to include exposure variables in count models. The study considers two types of exposure variables: road exposure and traffic exposure. The road exposure variable indicates how long a participant walks across an intersection. This variable could be defined either from a spatial (the distance walked) or a temporal (the time walked) perspective. Considering different walking speeds among the participants, the study selected walking time as the pedestrian exposure variable. When pedestrians walk across an intersection under a permissive signal timing, turning vehicles would impose threats on them. Unlike traditional accident frequency modeling where total traffic flow is used as an exposure variable, the number of turning vehicles does not matter as turning vehicles are usually queued to wait for making turns. Therefore, the study defines traffic exposure as a binary variable indicating whether a certain type of turning vehicles was present during crossing the road. The vehicle types included cars, scooters, and large vehicles.

(2) Intervention

As mentioned previously, the study designed an intervention between the first and second rounds of the walking experiment. To examine the effect of the intervention on pedestrian behaviors, the intervention is coded as a binary variable into the models.

(3) Refuge island

In the experimental field, one segment of the crosswalk was protected by a refuge island. To examine the effect of refuge island, a binary variable is defined.

(4) Sociodemographic characteristics and situational awareness ability of the participants

As shown in the literature, age and gender are two sociodemographic characteristics that differentiate pedestrian behavior performance. Since the present study recruits young adults only, the age factor is ignored in the following analysis. On the other hand, the study includes gender as a binary predictor in the following analysis. The present study examines the participants' situational awareness before the experiment. As mentioned previously, the SA pretest is a score ranging between 0 and 50. We will use the total score as a continuous predictor in the following analysis.

2.3 Analysis method

The eye tracker experiment could provide two pedestrian behaviors: head-turning (left or right), and eye fixation frequencies. Since pedestrian behaviors are easily affected by road-specific factors such as traffic flows, and traffic control devices (e.g., a refuge island or not), the study defined the outcome variable as y_{ijk}, meaning the i^{th} behavior y of pedestrian j on road segment k. The outcome variables are count variables, count models such as Poisson or negative-binomial regression models would thus be appropriate. Since head-turning or eye fixation counts are usually large, it is also possible to use linear regression to approximate the count distributions. Moreover, as described in the previous section, the study recruited 20 participants; each participant walked twice ($i = 1, 2$) along the same path. In other words, the data collected were hierarchical with the pedestrian behaviors within each road segment and also within each individual; pedestrian behaviors on the same road segment are expected to be more similar to each other than those on a different segment, and behaviors conducted by the same individual were more similar to each other than among different individuals.

The relationship between the level-1 pedestrian behavior variable, the level 2 individual- and road segment-level variables are illustrated in Figure 3. The pedestrian behavior variable y_{ijk} is explained by both level-1 and level-2 variables. The level-1 explanatory variables are walking time, the exposure variable, the intervention variable (i.e., before or after the intervention), and the conflicting vehicle variables. The level-2 explanatory variables include gender (male or female) and situational awareness ability of the individual characteristics, and refuge island (with or without) of the road segment characteristics. As the data were hierarchically structured, so were the developed regression models.

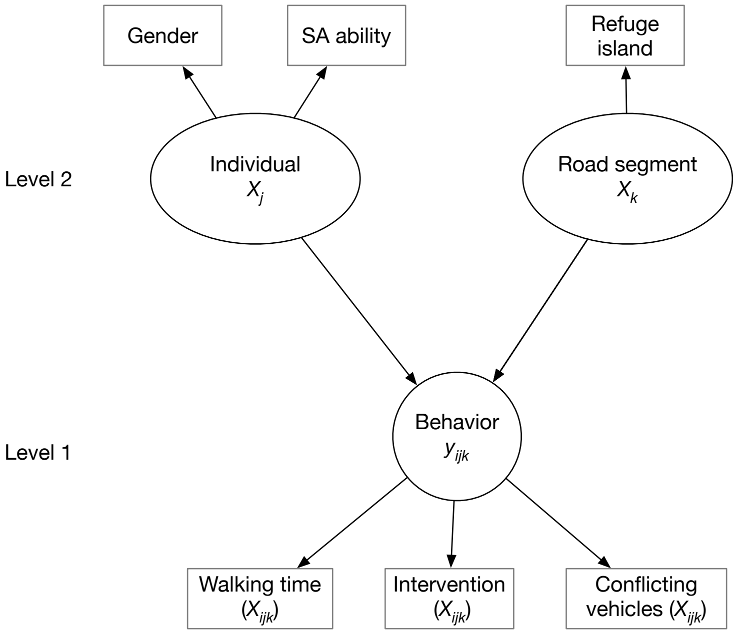


Figure 3 Modeling framework: the level-1 pedestrian behaviors (y_{ijk}), and level-2 individual (x_j) and road segment (x_k) characteristics

A multilevel Poisson regression model can be specified as follows:

$$y_{ijk} \sim \text{Poisson}(L_{ijk}) \quad (1)$$

A natural logarithm link is a natural choice for the mean of the Poisson distribution:

$$\ln L_{ijk} = \beta_0 + \beta_j + \beta_k + \sum_h \beta_h x_{hijk} + U_{0jk} \quad (2)$$

$$\beta_j \sim N\left(\sum_g \gamma_g x_j , \sigma_j^2\right) \quad (3)$$

$$\beta_k \sim N\left(\sum_q \gamma_q x_j , \sigma_k^2\right) \quad (4)$$

$$U_{0jk} \sim N(0, \sigma^2) \quad (5)$$

where U_{0jk} is the level-1 residual, distributed as a normal distribution (Eq(5)). The individual- and road segment-level variance are explained by their corresponding explanatory variables (Esq(3)&(4)). The study assumes normal distributions for both their residuals. The models were fit with the lme4 package (Bates et al., 2014) in the *R* environment (R Core Team, 2013).

3. Results

3.1 Participant characteristics

The participants were aged 21.6 on average with a standard deviation of 1.4 years. For the convenience of the following analysis, we dichotomize participants by the median value of the sum score; a sum score of three pretest question sets greater than 33.5 was labeled as participants with a high level of situational awareness, and the remaining was labeled as those having a low level of situational awareness.

3.2 Descriptive statistics of outcome variables

(1) Head-turning frequency

The average of the total head-turning frequency was 59.9 with a standard deviation of 34.5; it is clear that the head-turning frequency among participants was different. On average, the head-turning frequency after the intervention was greater than that before the intervention, a result consistent with our expectation. However, the difference was small (average: 3) and highly varied (standard deviation: 10.6). Moreover, half of the participants exhibited a higher head-turning frequency after than before the intervention, and the other half had an opposite result. Therefore, it is difficult to conclude any difference because of the intervention based on this simple difference. The following analysis will further incorporate individual characteristics, traffic flow conditions, and road design to evaluate the effect of the intervention on head-turning frequency.

The participants turned their heads more frequently when conflicting vehicles came from the back of the participants (i.e., same direction), as compared to when conflicting vehicles came from the front of the participants (i.e., opposite direction). This relative trend held no matter when conflict vehicles came from left- (LB=0.48 > LF=0.22) or right-hand side (RB=0.36 > RF=0.33) of the participants. This is consistent with our expectation that pedestrians feel more threats when vehicles come from their back than face-to-face; consequently, pedestrians paid more attention to vehicles coming from their back. The participants paid more attention to long than short segments when a perpendicular collision was the only possible vehicle-pedestrian collision type. This is also consistent with our expectation because it is easier for pedestrians to spot conflicting vehicles on crossing a narrow than a wide street; the speed of conflicting vehicles also tends to be slower on a narrow than a wide street.

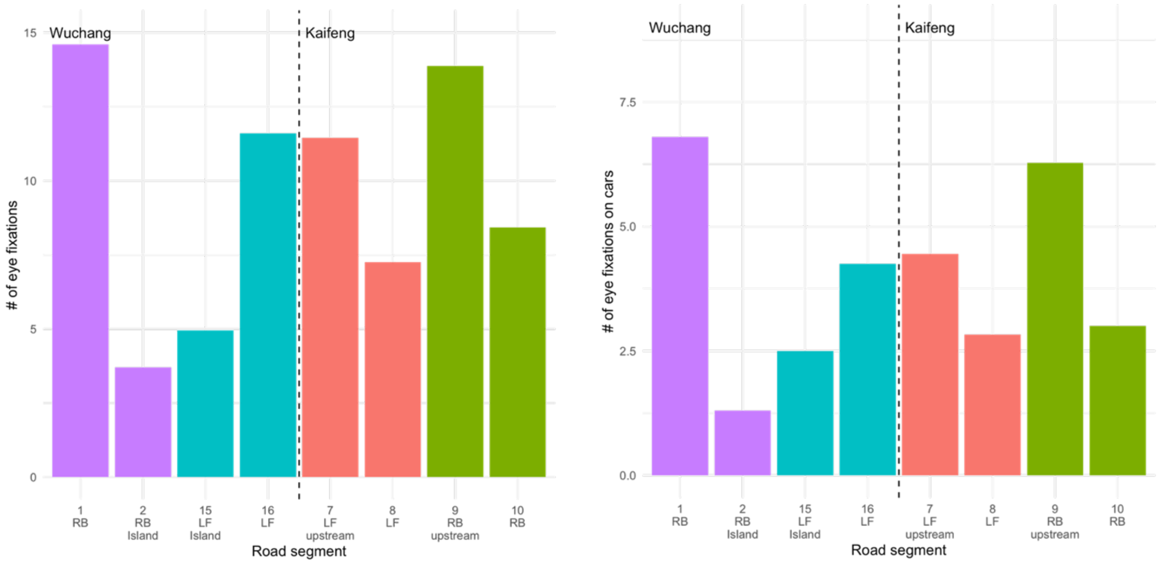
(2) *Eye fixation frequency*

The average eye fixation frequency was 331.7 with a standard deviation of 103.7. The eye fixation frequency was relatively similar among participants as compared to the head-turning frequency. More eye fixation frequency was also observed before than after the intervention, a result consistent with our expectation. However, again, the difference was trivial; the average difference was 3.8 with a standard deviation of 20.1. Among the 20 participants, 13 of them exhibited more eye fixations after the intervention, and the remaining seven showed more eye fixations before the intervention. The reason behind these differences will be explored in the analysis below.

Figure 4 illustrates the distribution of eye fixations while the participants were crossing the Zhonghua road. On the Zhonghua-Wuchang intersection, the pedestrians walked across a crosswalk partly protected by a refuge island. As can be seen from the left panel of Figure 4(a), the participants exhibited more eye fixations when walking on the crosswalk segment that was not protected by the refuge island as compared to the eye fixations when the participants walked on the crosswalk segment without the protection of the refuge island. The result is consistent with our expectations. A refuge island reduces the opportunity of potential conflicts; therefore, pedestrians could reduce their burden on paying attention to cars under the protection of a refuge island.

The study compared the frequency of eye fixations on the Zhonghua-Kaifeng intersection between the upstream and downstream segments. An upstream segment referred to the first-half segment of the crosswalk, and a downstream segment was the second-half segment of the crosswalk. As shown in the right panel of Figure 4(a), the participants exhibited more eye fixations on the upstream (first-half) than on the downstream (second-half) segments no matter when conflicting vehicles came from the left or right side of the pedestrians.

Figure 4(b) extracted the fixations on cars from all the fixations. The overall patterns were similar to those observed in the total fixations though slight differences could be observed.



(a) Sum of all types of fixations (b) Fixation on cars

Figure 4 Eye fixation frequency distribution by conflicting directions of vehicles

3.3 Regression modeling results

The study develops five models for each outcome variable, including a constant-only model, followed by adding the exposure variable (i.e., walking time), the intervention binary variable (before and after the intervention), the refuge island binary variable (with or without a refuge island), and the all model where the type of conflicting vehicle, the sociodemographic characteristics of the participants, and the situational awareness level (high or low) of the participants were further incorporated.

Table 1 summarizes the estimation results of the final multilevel models.

(1) Head-turning frequency (model M1)

The constant-only model showed that the individual- and road segment-level accounted for 28.2% and 17.4% of the total variance, respectively; the residual accounted for the remaining 54.4% of the total variance. By adding the exposure variable, walking time, the variance accounted for by the road segment level was reduced to 5.7%. Since the variance of the road segment level did not further reduce by adding any other road segment variables, exposure was crucial to head-turning frequency. The intervention variable exhibited a significant effect in both models M3 and M5. In other words, informing the participants about the safety fact made the participants pay more attention to surrounding traffic conditions. The refuge island variable and the sociodemographic characteristics of the participants did not show any significant relationship with head-turning frequency. But, the estimated coefficient of the situational awareness variable was significant. In other words, participants that were classified into a high-level of situational awareness based on three pretest question sets did exhibit more head-turning frequencies, a result consistent with our expectation.

Table 1 Multilevel linear regression results of head turning frequency

	Head turning	**Eye fixation**	**Eye fixation**	**Eye fixation**
		Total frequency	On turning vehicles	Efficiency
	(M1)	(M2)	(M3)	(M4)
Intercept	-1.404^{*}	0.735^{**}	-3.225^{***}	-0.038
	(0.704)	(0.250)	(0.786)	(0.087)
log(Walk Time (second))	0.857^{***}	0.443^{***}	0.630^{***}	0.032
	(0.193)	(0.068)	(0.146)	(0.025)
Intervention (after = 1)	0.196~	0.022	0.208^{**}	0.026^{*}
	(0.113)	(0.025)	(0.066)	(0.012)
Refuge island (yes = 1)	0.071	-0.596^{***}	-0.561^{***}	-0.022
	(0.251)	(0.083)	(0.166)	(0.029)
Conflicting vehicle (scooter = 1)	0.015	0.056~	0.429^{***}	0.095^{***}
	(0.146)	(0.033)	(0.051)	(0.016)
Conflicting vehicle (large vehicle = 1)	-0.258	-0.061	-0.162	0.015
	(0.273)	(0.061)	(0.113)	(0.029)
Gender (male = 1)	0.394	0.115	0.179	0.027
	(0.445)	(0.143)	(0.224)	(0.019)
Situational awareness (high = 1)	0.852~	0.056	0.139	0.025
	(0.445)	(0.143)	(0.224)	(0.019)
AIC	2358.123	3519.763	1720.577	-484.882
BIC	2407.200	3564.378	1765.192	-435.857
Log Likelihood	-1168.062	-1749.882	-850.289	253.441
Var: Individual (Intercept)	0.927	0.099	0.224	0.001
Var: Road segments (Intercept)	0.189	0.048	2.316	0.014
Var: Residual	2.029	na	na	0.023

*** $p < 0.001$, ** $p < 0.01$, * $p < 0.05$, ~ $p < 0.1$; na: not applicable

(2) Eye fixation frequency (model M2)

Before adding any variable but a constant, the road segment variance was 1.6 times larger than the individual variance. In other words, without any explanatory variables, the observed eye fixation variance could mostly be explained by road segment differences; the longer a road segment is, the more eye fixations are observed. Adding the walking time variable greatly reduced the variance of the road segment level; the variance of road segment was only one-fourth of the variance of individuals. The intervention variable did not show any significant effect either in the Intervention model or the full model. On the other hand, the refuge island variable did exert a significant effect on reducing eye fixations. In other words, installing a refuge island on the road may ease the burden of pedestrians by reducing eye fixations. As for the remaining variable, only the conflicting scooter variable demonstrated a significant effect. The positive estimate suggests that pedestrians would spend more eye fixations when conflicting vehicles were scooters rather than cars. The result might be sensible as scooters are relatively difficult to spot as their vehicle size is smaller and instant speed and lateral changes are larger than cars.

(3) Eye fixation on turning vehicles (model M3)

The variance ratio explained by the individual- and road segment-level intercepts changed only slightly among models; the individual-level intercepts accounted for 9% to 10% variance as compared to the total variance explained by the individual- and road segment-level intercepts. The exposure variable, walking time, was significant in all the models; the positive estimate suggests more eye fixations on turning vehicles along with the increase of walking time. The intervention was also significant in all the models that consisted of the variable; the positive estimate indicates that the participants had more eye fixations on turning vehicles after being informed about potential vehicle conflicts from the back. This is consistent with our expectations. Note that the intervention variable was not statistically significant for the total fixation outcome variable but significant for the fixation on turning vehicle variable. These results suggest that the specific information provided by the research team allowed the participants better spotted potential threats during crossing the road.

The refuge island variable exhibited a significantly negative effect, which indicates that the participants had fewer eye fixation on turning vehicles when walking on a road segment protected by a refuge island than on a road segment without being protected by a refuge island. This reduction may come from two effects. One is that a refuge island changes the way that turning vehicles approach the crosswalk, such as a larger contact angle between the vehicle and the crosswalk; therefore, pedestrians do not need to constantly pay attention to turning vehicles. The second reason may come from a subjective perception about the refuge island; pedestrians may feel relatively safe being protected by a refuge island and thus pay less attention to turning vehicles.

For the remaining variables, only the conflicting scooter variable was significant; the positive estimate indicates that the participants had more eye fixation on turning vehicles when the turning vehicles consisted of scooters. This result is consistent with the modeling result of total fixations. We may conclude that pedestrians consider scooters are more of a threat than are cars or large vehicles during crossing a signalized intersection.

(4) Efficiency of eye fixation on turning vehicles (model M4)

The dependent variable was the proportion of eye fixation on turning vehicles, i.e., the frequency of eye fixation on turning vehicles divided by the total frequency of eye fixation. Eye fixation efficiency was not significantly related to walking time. This is expected as the walking time for each road segment was small (average: 25.9 seconds, standard deviation: 20.16 seconds). The intervention variable showed a significant effect even after all the variables were included; the positive estimate suggests that informing pedestrians of safety facts could effectively enhance their eye fixation efficiency. For the remaining variable, only the scooter conflict variable was significant; the positive estimate suggests that pedestrians' eye fixation efficiency was relatively high when encountering traffic was scooters. That is, scooters grab more pedestrians' attention than do other vehicle types. In all the models, the individual- and road segment level intercepts accounted for approximately 2.5% and 36% of the total variance, respectively. The result suggests that over 60% of the variance was unexplained.

4. Discussions

Pedestrians have rights-of-way on a crosswalk; however, under a permissive signal phase design, vehicle-pedestrian collision risk is inevitably rising as both parties are allowed to occupy the crosswalk during a green phase. Paying attention while crossing is thus important to pedestrians. The study attempts for exploring pedestrians' attention allocation while crossing using eye trackers. Twenty participants were recruited to walk on a field of urban streets with a designated path that consists of potential conflicting vehicles coming from different directions relative to pedestrians. The participants wore a mobile eye tracker to record the world they saw and capture their eye fixations; in particular, the study used head-turning and eye fixation frequencies as the proxy variables of attention.

4.1 Effect of walking time

The analysis results showed that both head-turning and eye fixation frequencies were significantly positively associated with walking time. The result is consistent with our expectations as walking time was an exposure variable. In the model development process, we tested both linear and quadratic effects of the walking time variable, and only the model of eye fixation on turning vehicles exhibited significant estimates for both the linear and quadratic walking time variables. The linear effect maintained positive as the models reported in the previous section, and the quadratic effect was negative, meaning that the rate of eye fixation on turning vehicles was rising first and then declining when the walking time was long enough.

To have a better sense of the quadratic effect of walking time variables, we report the marginal effect plots (Figure 5). Compared to the original model, the model that added a quadratic form changed the estimation result only slightly; the significance of the remaining variables stayed the same with a similar effect magnitude. Adding the quadratic form of the walking time variable did not improve the overall goodness of fit of the model. However, the relationship of walking time with eye fixation frequency on turning vehicles becomes more intuitive by adding this variable. At the beginning of a crossing, pedestrians may maintain a certain level of eye fixation rate (the pink segment of both Figure 5(a) & (b)) and raise the eye fixation rate because of encountering conflicting vehicles (the green segment of both Figure 5(a) & (b)). However, it is unlikely that the eye fixation rate keeps increasing with the increase of walking time without any decline (Figure 5(a)); a peak eye fixation rate would be expected (Figure 5(b)). The wide range of confidence intervals indicate that the data collected contains a certain level of noise. Further studies with a larger sample size would be needed to clarify the relationship between walking time and eye fixation frequency.

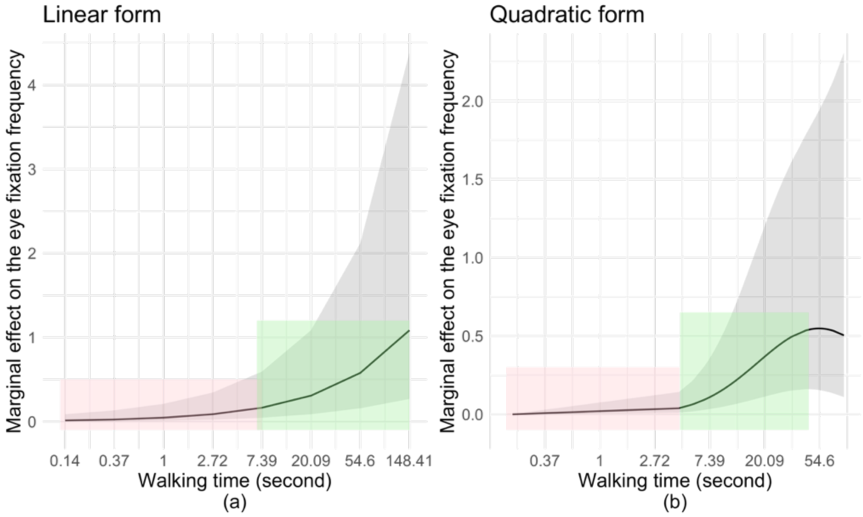


Figure 5 Marginal effect of walking time on the frequency of eye fixation on turning vehicles: linear (left) and quadratic form (right)

4.2 Effect of the refuge island

Refuge island has been considered as having safety benefits by providing pedestrians a place to rest during crossing, especially a wide street. A two-stage crossing allows pedestrians to focus on oncoming traffic from one direction only (King et al., 2003; Zegeer et al., 2004), which reduces pedestrians' burden on attention allocation. The analysis result of the present study is consistent with the literature. We showed that the participants exhibited fewer eye fixations, including total frequency, and the frequency of turning vehicles when walking across a crosswalk segment protected by a refuge island than without being protected by a refuge island.

On the other hand, the study did not find any significant difference in head-turning rates between road segments with and without a refuge island. Head-turning is usually required when turning vehicles are coming from the back of the pedestrians. The statistically insignificant result may be due to insufficient sample size. However, it is also possible that the participants still felt threatened by turning vehicles even with a refuge island on the road. Further studies would be needed to shed light on this issue.

4.3 Effect of the intervention

The study designed an intervention that informed the relatively high risk of vehicle-pedestrian collision where vehicles were running from the back toward pedestrians. The result showed that the intervention was effective; the head-turning rate and the rate of eye fixation on turning vehicles both enhanced after the intervention. Therefore, we could conclude that the designed intervention is effective in raising pedestrians' situational awareness, at least shortly. This result is consistent with the meta-analysis findings indicated by Phillips et al. (2011) that personal communication or roadside media was beneficial to traffic accident (including vehicle-pedestrian) reduction.

Previous studies relevant to safety education have had a particular focus on children pedestrians; the way to deliver effective safety education to children has also been confirmed by studies such as Zare et al. (2019). The present study has shown a possibly positive safety effect of safety education on pedestrians of other ages. However, the study is limited to a small group of young adults aged between 20 and 30. Further studies are thus clearly needed to identify the effects of safety education on the general public.

4.4 Recommendations for improving pedestrian safety in Taiwan

Traffic safety education has been a recent focus in Taiwan. In addition to school education, the governments have spent tremendous efforts in raising the awareness of vehicle drivers to yield to pedestrians and of pedestrians to turn heads and pay attention properly during crossing signalized intersections. The findings of the present study support the continual implementation of these safety campaigns. On the other hand, present safety campaigns in Taiwan focused on telling pedestrians what to do but not why to do (or not to do). The idea is to keep the campaign materials as simple as possible. However, adding information such as safety facts relevant to target behavior change could also be beneficial, as demonstrated in the present study. Most theories in social and health psychology assume that intentions cause behaviors though the intention-behavior consistency may be moderated by factors such as intervention characteristics (Webb and Sheeran, 2006). Accordingly, the study recommends adding such "why" information in the safety campaign materials.

Current safety campaign materials in Taiwan recommend pedestrians check traffic signals and look to left and right before crossing a road. The material does not ask pedestrians to maintain alert during crossing a road. This is understandable as pedestrians have rights of way on crosswalk given that the pedestrians do not violate traffic laws; vehicle drivers should be the one that pays full attention. However, the fact is a certain portion of vehicle drivers failed to yield to pedestrians. According to a field survey conducted in Taipei in 2021 (Chung, 2021), approximately 42% to 56% of left-turn vehicle drivers did not yield to pedestrians; that is, the turning vehicles and pedestrians were overlapped within three-meter length on crosswalks. Therefore, it is also necessary to advise pedestrians to maintain alert not merely at the beginning of crossing but also during crossing roads.

The present study is limited to its small sample size; further data need to be collected and investigated before the analysis findings can be extended o general public. Older pedestrian safety is becoming more crucial than before because some cities in Taiwan has been stepping into a super ageing society and so have been in many other cities in the world. It is thus also worth of expanding the study population particularly to older pedestrians as their head-turning and visual search behaviors could be restrained from deteriorating physcial conditions.

Acknowledgment

The author appreciates the financial support from the Mitsui Sumitomo Insurance Welfare Foundation and the ROC Ministry of Science and Technology (MOST 110-2410-H-A49-046-MY3). He also appreciates the help of Mr. Wei-Hung Wu, Mr. Tzu-Hsiang Su, and Mr. Pei-Yu Tsai for collecting the experimental data.

References

Bates, D., Mächler, M., Bolker, B., Walker, S. (2014) Fitting linear mixed-effects models using lme4. *Journal of Statistical Software* 67, 1-48.

Construction and Planning Agency, Taiwan (ROC) (2021) *Safety Evaluation of Urban Street Pedestrian Facilities*. Taipei, Taiwan.

Oregon Transportation Research and Education Consortium (2013) *Improved pedestrian safety at signalized intersections operating the flashing yellow arrow*. Report No. OTREC-RR-13-02. Oregon Transportation Research and Education Consortium (OTREC), Portland, OR.

King, M.R., Carnegie, J.A., Ewing, R. (2003) Pedestrian safety through a raised median and redesigned intersections. *Transportation research record* 1828, 56-66.

Kovesdi, C.R., Barton, B.K. (2013) The role of non-verbal working memory in pedestrian visual search. *Transportation Research Part F: Traffic Psychology and Behaviour* 19, 31-39.

Phillips, R.O., Ulleberg, P., Vaa, T. (2011) Meta-analysis of the effect of road safety campaigns on accidents. *Accident Analysis & Prevention* 43, 1204-1218.

Pratt, M.P., Songchitruksa, P., Bonneson, J.A. (2012) Pedestrians and Left-Turning Vehicles: An Evaluation of Safety Treatments. *Presented at the 91st Annual Meeting of the Transportation Research Board*, Washington, D.C.

R Core Team (2013) R: A language and environment for statistical computing. R Foundation for Statistical Computing. Vienna, Austria.

Tom, A., Granie, M.A. (2011) Gender differences in pedestrian rule compliance and visual search at signalized and unsignalized crossroads. *Accident Analysis and Prevention* 43, 1794-1801.

Urbanik, T., Tanaka, A., Lozner, B., Lindstrom, E., Lee, K., Quayle, S., Beaird, S., Tsoi, S., Ryus, P., Gettman, D., Sunkari, S., Balke, K., Bullock, D. (2015) *Signal Timing Manual - Second Edition*.

Webb, T.L., Sheeran, P. (2006) Does changing behavioral intentions engender behavior change? A meta-analysis of the experimental evidence. *Psychological bulletin* 132, 249.

Whitebread, D., Neilson, K. (2000) The contribution of visual search strategies to the development of pedestrian skills by 4-11 year-old children. *British Journal of Educational Psychology* 70, 539-557.

Zare, H., Niknami, S., Heidarnia, A., Hossein Fallah, M. (2019) Traffic safety education for child pedestrians: A randomized controlled trial with active learning approach to develop street-crossing behaviors. *Transportation Research Part F: Traffic Psychology and Behaviour* 60, 734-742.

Zegeer, C.V., Esse, C.T., Stewart, J.R., Huang, H.F., Lagerwey, P. (2004) Safety analysis of marked versus unmarked crosswalks in 30 cities. *ITE journal* 74, 34-41.