Can Time Pressure Compromise Pedestrian Safety? Exploring Situational Awareness in Virtual Reality

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SHORT SUMMARY

Situational awareness of pedestrians under time constraints may vary substantially, indicating shifts in their decision-making procedures. Therefore, this study aims to provide a comprehensive understanding of the effects of varying levels of time pressure on situational awareness indicators like looking towards traffic and signal lights. In addition, this study also examines the influence of crossing speed, non-compliance behaviors and several others on these indicators. A virtual reality pedestrian simulator setup was used to capture the movements of sixty participants at a four-legged signalized intersection. The results show that pedestrian attention to traffic signals and thorough traffic checks while waiting are substantially decreased while they were under high time pressure. Additionally, sides of the crosswalk, i.e., near-end and far-end, also play a significant role in situational awareness. Through this investigation, the study emphasizes the necessity of the preventative measures needed to raise pedestrian safety at signalized intersections by improving situational awareness.

Keywords: Time pressure; Situational awareness; Virtual Reality; Pedestrians; Signalized Intersection.

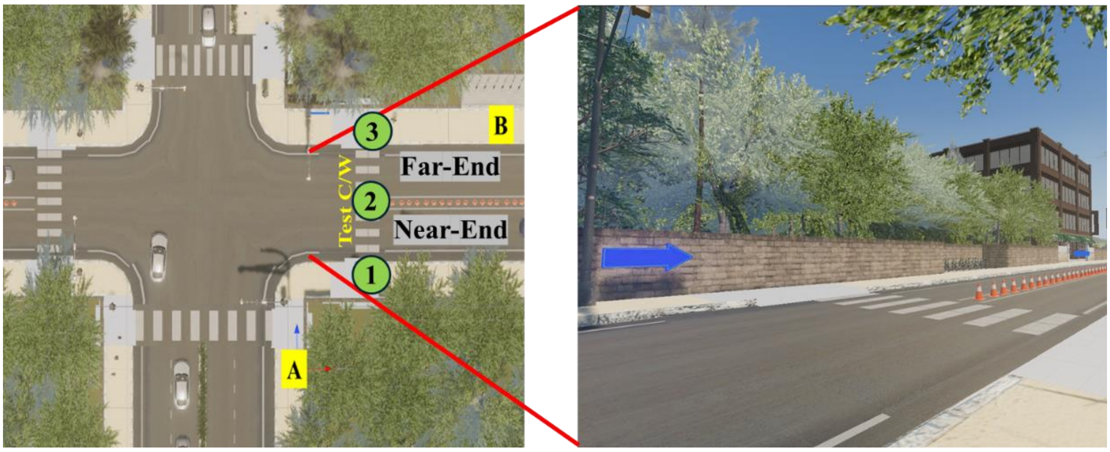
1. INTRODUCTION

While traffic signals aid in directing pedestrian traffic, they frequently fall short of guaranteeing pedestrian's adherence to signal instructions due to their dynamic behavior (Sisiopiku and Akin 2003). Several studies have identified significant signal non-compliance rates (Afshari, Ayati, and Barakchi 2021; Dhoke, Kumar, and Ghosh 2021) and carried out questionnaire surveys to determine the cause. It was discovered that hurried pedestrians mostly violate the signal (Mukherjee and Mitra 2019). It implies that time pressure (i.e., crossing in hurry) would increase such non-compliance by indulging pedestrians into impulsive decision and crossing judgments (Dhoke and Choudhary 2023). At signalized intersections, vehicles constantly moves making area more unpredictable, necessitating that pedestrians remain responsive to unforeseen events (Aghabayk et al. 2021), especially under time pressure. Therefore, pedestrians must maintain a heightened situational awareness (SA) to navigate through these areas safely. SA is defined as an ongoing process of assessing the environment and making decisions from the time one enters the intersection (the pre-crossing stage) until one safely exits it (active-crossing stage) (Luu et al. 2022). This awareness is gained through certain cautious behaviors like looking towards traffic (Thompson et al. 2013) and watching signals (Dommes et al. 2015). Throughout the crossing pedestrians should be well aware of their surroundings to assess the potential hazards. Nevertheless, only a handful of research has thoroughly examined SA across these two stages, especially under time pressure. Four SA indicators are identified: two during pre-crossing stage, i.e., (i) looking towards traffic before crossing and (ii) looking at signals before crossing; and the remaining two during active-crossing stage, i.e., (iii) looking towards traffic while crossing and (iv) looking at signals while crossing. Therefore, the current study aims at estimating the influence of various factors on SA before and while crossing under varying time pressure

2. METHODOLOGY

The current study utilized pedestrian simulator setup, for studying pedestrian behavior at a 4-legged signalized intersection (Figure 1), under three time pressure conditions: No Time Pressure (NTP), Low Time pressure (LTP) and High Time pressure (HTP). Three time-pressure conditions: No Time Pressure (NTP), Low Time Pressure (LTP), and High Time Pressure (HTP), were intentionally created to comprehend the variation in the situational awareness of pedestrians at various levels of time constraints. In the NTP condition, the pedestrians were asked to cross and navigate through the intersection with no time restrictions and at their own preferred speed. The time participants took to travel or finish the task in NTP was noted to impose LTP and HTP conditions on pedestrians. To create time pressure, participants were given 10% and 20% less time to walk in the LTP and HTP conditions, respectively, than the time that they had taken in the NTP condition (Pawar and Velaga 2020). Additionally, in order to motivate pedestrians to finish their tasks within the time constraint, they were also instructed to assume two distinct hypothetical scenarios: ‘I am running late to see a friend’ and ‘I am late for a college lecture’ under LTP and HTP settings, respectively (Morrongiello et al. 2015; Pawar and Velaga 2020). In addition, to reinforce the sense of time pressure, a stopwatch countdown timer was displayed on the virtual screen continuously in both LTP and HTP conditions (Kalantarov, Riemer, and Oron-Gilad 2018; Tian et al. 2022). In addition, no prior information was given to the participants regarding the approach employed to impose time pressure conditions. The time pressure levels were presented in the following preset sequence: NTP → LTP → HTP.

For each participant, the experiment started at location A (Figure 1(a)). The participants were asked to follow the blue directional arrow (shown in Figure 1(b)) to reach the destination B. At the intersection, pedestrians often face varied signal timings upon reaching the sidewalk. Therefore, in the present study, the pedestrian signal scenarios that were shown to participants as they entered the intersection were divided into three categories: (i) End of Green (EG), (ii) Middle of Red (MR), (iii), and End of Red (ER). During the EG scenario, the pedestrian signal indicated that only fifteen seconds are available before it changed from green to red, prompting participants to make a rapid decision about the situation and determine whether to wait or cross safely. During the MR scenario, the countdown timer showed that nearly 60 seconds remained before the signal turned green from red, resulting in a prolonged waiting period that tested the participants' patience and ability to stay attentive. In the ER scenario, 15 seconds were remaining until the light turned green, assessing the pedestrian’s caution and judgment in deciding whether to start crossing or keep observing the traffic and signals. Furthermore, sixty individuals were equally divided to perform crossing experiments in (i) End of Green (EG), (ii) Middle of Red (MR), (iii), and End of Red (ER) signal scenarios (i.e., 20 participants in each scenario). Their behaviors were recorded at Near-end (NE) and Far-end (FE) sides of crosswalk (Figure 1). Ultimately, the crossing performance yielded a total of 360 observations (20 participants x 3 Scenarios (EG, MR and ER) x 3 Conditions (NTP, LTP and HTP) x 2 Crosswalk Sides (NE and FE)).



(a) (b)

Figure 1: Scenario of signalized intersection: (a) Intersection layout in virtual environment with "test crosswalk (C/W)" (b) View of the test crosswalk

3. RESULTS AND DISCUSSION

Dependent and Independent Variables with Descriptive statistics

The SA indicators were considered as dependent variables (Figure 2). When the participant was within the waiting area, turning their head towards approaching traffic was referred to as 'looking towards traffic before crossing' and moving head to check the signals was referred to as 'looking at signal before crossing'. Similarly, turning the head to check out traffic or signal lights while moving within crossing area, was interpreted as 'looking towards traffic while crossing' and 'looking at signal while crossing', respectively. The independent variables, includes demographics, experimental conditions, signal scenarios, and crosswalk side, waiting-time, speed, SNC, and TNC (Figure 2). The statistical details of these variables across time pressure conditions are presented in Table 1.

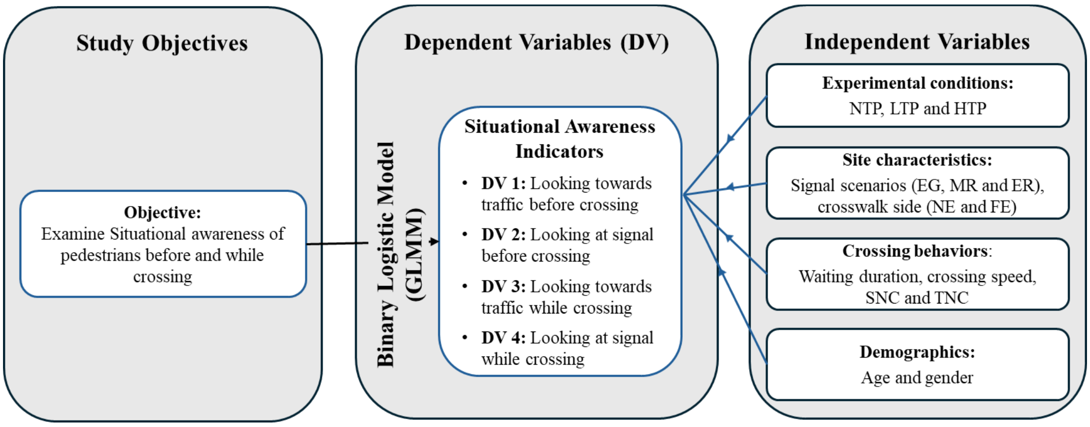


Figure 2: Schematic representation of dependent and independent variables

Table 1: Statistical details of variables obtained from simulator experiments

<table>
<tr><th colspan="2" rowspan="2">Factors</th><th rowspan="2">Description</th><th rowspan="2">Response Category</th><th colspan="3">Mean (SD)/Freq (%) #</th></tr>
<tr><th>NTP</th><th>LTP</th><th>HTP</th></tr>
<tr><td rowspan="8">Dependent variables</td><td rowspan="2">Looking towards traffic before crossing</td><td rowspan="2">Turning head to look left/ right towards traffic at sidewalk.</td><td>Looked</td><td>46.67</td><td>38.33</td><td>38.33</td></tr>
<tr><td>Not Looked</td><td>53.33</td><td>61.67</td><td>61.67</td></tr>
<tr><td rowspan="2">Looking at signal before crossing</td><td rowspan="2">Turning head to look at the signal light at the sidewalk</td><td>Looked</td><td>65.00</td><td>52.50</td><td>35.83</td></tr>
<tr><td>Not Looked</td><td>35.00</td><td>47.50</td><td>64.17</td></tr>
<tr><td rowspan="2">Looking towards traffic while crossing</td><td rowspan="2">Turning head to look left /right towards traffic while crossing</td><td>Looked</td><td>65.83</td><td>51.67</td><td>69.17</td></tr>
<tr><td>Not Looked</td><td>34.17</td><td>48.33</td><td>30.83</td></tr>
<tr><td rowspan="2">Looking at signal while crossing</td><td rowspan="2">Turning head to look at the signal while crossing street</td><td>Looked</td><td>65.00</td><td>37.50</td><td>30.00</td></tr>
<tr><td>Not Looked</td><td>35.00</td><td>62.50</td><td>70.00</td></tr>
<tr><td rowspan="6">Independent Variables</td><td>Waiting duration* (in Sec.)</td><td colspan="2">Difference between time of arrival near the crosswalk and time of initiating the crossing</td><td>4.37 (8.54)</td><td>1.92 (4.51)</td><td>1.49 (3.47)</td></tr>
<tr><td>Crossing speed* (in m/s)</td><td colspan="2">Speed of pedestrian while crossing the intersection</td><td>0.99 (0.38)</td><td>1.1 (0.51)</td><td>1.12 (0.56)</td></tr>
<tr><td rowspan="2">Spatial compliance behavior</td><td>Crossing on a designated crosswalk marking</td><td>Compliance</td><td>20.00</td><td>11.67</td><td>17.5</td></tr>
<tr><td>Crossing without using designated marking</td><td>Non-compliance</td><td>80.00</td><td>88.33</td><td>82.5</td></tr>
<tr><td rowspan="2">Temporal compliance behavior</td><td>Crossing during green pedestrian signal</td><td>Compliance</td><td>45.00</td><td>38.33</td><td>31.67</td></tr>
<tr><td>Crossing during red pedestrian signal</td><td>Non-compliance</td><td>55.00</td><td>61.67</td><td>68.33</td></tr>
</table>

Note: *Mean (standard deviation (SD)) for continuous variables and #Frequency (in percentage) for categorical variables

Model development and Results

The SA indicators are binary variables (*1* if looked and *0* if did not). Four individual binary logistic regression models, one for each indicator, are employed. To accounts for the heterogeneity due to repeated measurements from the same participant, a generalized linear mixed model (GLMM) is applied (Aghabayk et al. 2021). The final models are shown in Table 2.

From the results presented in Table 2, it was observed that crossing under LTP and HTP decreases the probability of looking at signal before crossing by 38.67% and 71.74%, respectively, in comparison to NTP. Likewise, under LTP, there was 56% and 74% and under HTP, 82% in each, decrease in the probability of looking toward traffic and the signal while crossing, respectively. These findings are consistent with the questionnaire survey of Yadav et al. (2023), which found that most participants frequently neglect to check for oncoming traffic while crossing the street under time constraints. However, the current study quantified the consequences of different levels of time pressure on situational awareness indicators. Further, results indicated that pedestrians crossing during the MR and ER scenarios were 2.68 and 2.46 times, respectively, more likely to look left-right towards traffic before crossing compared EG phase. It is possible that during MR and ER, vehicles would be maneuvering constantly, drawing pedestrians' attention towards them (Dommes et al. 2015), unlike during EG, where pedestrians generally had the right-of-way. In comparison to the NE side, pedestrians on FE side were found to be 78% and 52% less likely to check the traffic and signal before crossing. Likewise, while crossing on FE side showed 51%, and 55% decline in the probability of looking for oncoming vehicles and checking signal lights. This may be probably because at NE side, pedestrians are believed to have a greater responsibility to carefully consider their alternatives and assess the situation before deciding to cross the street (Iryo-Asano, Alhajyaseen, and Nakamura 2015). Such proactive situational awareness is an adaptive mechanism to reduce the complexity of decision-making while crossing and optimize their time. As a result, they might pay more attention to the signal and traffic movements at the NE side, both before and while crossing the intersection.

Table 2: Generalized Linear Mixed Effects Model for Situational Awareness Indicators

Situational Awareness Indicators	Situational Awareness Before Crossing				Situational Awareness While Crossing			
	Model 1		Model 2		Model 3		Model 4	
	Looking Towards Traffic Before Crossing		Looking at Signal Before Crossing		Looking Towards Traffic While Crossing		Looking at Signal While Crossing	
Covariates	**OR**	***p***	**OR**	***p***	**OR**	***p***	**OR**	***p***
Condition (RF: No Time Pressure (NTP))								
Low Time Pressure (LTP)	0.66	0.18	0.61	0.09*	0.44	≤0.01***	0.26	≤0.01***
High Time Pressure (HTP)	0.65	0.17	0.28	<0.01***	0.18	≤0.01***	0.18	≤0.01***
Signal Scenario (RF: End of Green (EG))								
Middle of Red (MR)	2.68	0.02**	0.99	0.98	1.18	0.71	1.31	0.58
End of Red (ER)	2.46	0.05*	1.28	0.58	1.09	0.85	0.99	0.98
Crosswalk Side (RF: Near-end (NE))								
Far-end (FE)	0.22	≤0.01***	0.48	≤0.01***	0.49	≤0.01***	0.45	≤0.01***
Temporal Compliance Behavior (RF: Temporal Compliance)								
Temporal Non-compliance (TNC)	1.86	0.09*	0.73	0.37	0.49	0.07*	0.43	0.04**
Spatial Compliance Behavior (RF: Spatial Compliance)								
Spatial Non-compliance (SNC)	-	-	-	-	1.14	0.75	1.15	0.74
Crossing Speed	-	-	-	-	1.08	0.83	0.45	0.05*
Waiting Duration	1.04	0.10	1.06	0.03**	1.08	0.04**	1.03	0.32
Age (RF: 18-22 years)								
23-27 years	2.03	0.107	1.51	0.33	1.47	0.41	1.10	0.85
28-32 years	2.59	0.06*	2.24	0.102	2.92	0.05*	1.74	0.35
Gender (RF: Female)								
Male	1.10	0.78	0.84	0.63	0.75	0.47	1.19	0.69

Note: RF- Reference

Significance codes: '***' p-value ≤ 0.01, '**' p-value< 0.05, p-value<0.1 '*'

TNC shows that pedestrians crossing red light were 86% more likely to look towards traffic before crossing and 51% and 57% less likely to check the oncoming vehicles and look at signals. Further, walking faster (i.e., 1 m/s increase in the crossing speed) contributes to a 55% decrease in the probability of looking at the signal lights while crossing. According to Dhoke & Choudhary (2024) and Kalantarov et al. (2018), pedestrians usually have a high speed while crossing under time pressure. Therefore, it may be possible that under time pressure like situation, they were more focused on completing the crossing which may have resulted in neglecting signal checks while crossing. Additionally, with a 1 sec increase in waiting duration, the probability of looking at the signal before crossing and probability of checking left or right for traffic while crossing increased by 6% and 8%, respectively. This would be probably because it gives them a while to engage in and comprehend their surroundings such as looking at signals, similar to the findings of Dommes et al. (2015). Additionally, with increased waiting duration, pedestrians were also more likely to look towards traffic while crossing. It implies that longer waiting pedestrians might be more cautious who waited at the sidewalk and assessed the signal before crossing. In a similar way, it is possible that these pedestrians accepted this cautious behavior while crossing the road and were therefore more likely to look at oncoming traffic. Besides, those in the age group of 28 and 32 years were 159% and 192% more likely to look towards traffic before crossing and while crossing, respectively, than those between the ages of 18 and 22 years. The increased awareness among the 28 to 32 age group may be due to cumulative experience, and caution evolved over time (Cœugnet, Cahour, and Kraiem 2019; Dommes et al. 2015).

4. CONCLUSIONS

The findings of the current study have made the following key contributions:

i. Due to time constraints, pedestrians cross the street more quickly and pay less attention to traffic and signal checks, which increases the likelihood of risky crossings. Basically, time pressure raises cognitive load, prompting people to make decisions rapidly (Beck, Daughters, and Ali 2013; Schneider, Ratter, and Bengler 2019). Therefore, it may have led to "tunnel vision", a situation where convenience dominates over safety precautions (Kuutila et al. 2020), due to their increased attention to reaching their target quickly. Ultimately, this might have lowered SA before and while crossing the street. To increase awareness, additional warning alerts may be installed at the intersection.

ii. Another major finding from the analysis was that it established a distinction between the behaviors of pedestrians at the NE and FE sides of crosswalks, demonstrating that the pedestrians are more attentive at the NE side of the crosswalk. To improve SA at the FE side of the crosswalk, two-stage signals or enhanced visibility can be implemented at the FE of the crosswalk.

The study emphasizes the role that behavioral elements play in traffic safety and recommends that initiatives aimed at raising pedestrian awareness and education should consider the psychological and situational aspects that impact pedestrians' decisions to cross. By highlighting existing gaps in the pedestrian's behaviors, this research establishes the foundation for further investigation into situational awareness and safety considerations in urban environments

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