UNDERSTANDING PEDESTRIAN CROSSING BEHAVIOUR: A CASE STUDY IN SOUTH AFRICA

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ABSTRACT

Pedestrians are vulnerable road users and are mostly over-represented in road traffic crashes, particularly in the developing world. In South Africa, pedestrian fatalities account for about 40 percent of road traffic crashes. The majority of which occur when pedestrians are crossing roads. Behaviour patterns of both pedestrians and motorists significantly influence the occurrence of pedestrian crashes in South Africa. This study investigates the crossing behaviour of pedestrians negotiating different types of pedestrian crossing facilities in the City of Stellenbosch, in South Africa. Video-based observations were used to investigate patterns of pedestrian behaviour at different categories of pedestrian facilities. The patterns investigated include pedestrian walking speed, pedestrian delay, gaze behaviour and the nature of conflicts between pedestrians and motorists. In addition to video observations, interviews were conducted with pedestrians to improve understandings of how beliefs and attitudes towards traffic control devices and the traffic environment influenced pedestrians' unsafe crossing behaviour. The findings of this study highlight important areas that should be targeted to address the pedestrian safety problem.

1. INTRODUCTION

Road crashes have been a global concern facing all countries since the introduction of motorized vehicles in the late 19th century and remain so today in many countries including South Africa. Approximately 1.2 million people are killed every year as a result of road crashes and 50 million are injured (World Health Organization, 2009). More than 90 percent of road fatalities occur in developing and emerging countries which have only 48 percent of the world's registered vehicles (World Health Organization, 2009). In South Africa, approximately 14,000 people die every year as a result of road crashes. This figure is equivalent to 38 fatalities per day or around 28 deaths per 100,000 human population (RTMC, 2009).

Pedestrians are vulnerable road users and are significantly over-represented in road traffic crashes. In South Africa, research has reported that about 60 percent of the South African population relies on walking as a primary means of transport (Albers et al., 2010). Pedestrian fatalities have always been a significant component of road traffic fatalities in South Africa; pedestrian fatalities account for about 40 percent of all road traffic crashes. The majority of those pedestrian deaths results from collisions with vehicles when pedestrians are crossing a roadway (e.g. Albers et al., 2010). A large number of studies and reports indicated that human factors of both pedestrians and motorists are the most influential factors of pedestrian crashes. As a component of human factors, pedestrian crossing behaviour significantly influences the occurrence of pedestrian crashes. In turn, research has identified a number of factors that have an effect on pedestrian crossing behaviour. These factors include road user variables (e.g., gender, age), roadway characteristics (e.g., road width, existence of central refuge, traffic controls), situational factors (e.g., group size, traffic volume, distraction) and environmental factors (e.g., time, weather conditions).

Numerous studies have addressed pedestrian behaviour and attitudes, but very little has been done in the context of developing and emerging countries like South Africa. In addition to this limited information, the existing research that has been conducted in that context has often focused on crossing behaviour at single pedestrian crossings. In this study however, a more holistic approach was attempted by exploring crossing behaviour at various categories of crossing facilities. The aim of this study was to investigate the patterns of pedestrian crossing behaviour at a variety of pedestrian crossing facilities and to identify the possible influential factors. Patterns of crossing behaviour investigated throughout this study included pedestrian walking speed, pedestrian delay, pedestrian gaze behaviour, pedestrian-vehicle conflicts and pedestrian compliant behaviour with traffic rules. The findings of this study are significant for understanding pedestrian behaviour and designers, planners and policy makers need to take these into account in order to facilitate the needs and characteristics which affect pedestrian safety, comfort and convenience on roads.

2. PEDESTRIAN BEHAVIOUR AT CROSSING FACILITIES

2.1. Pedestrian walking speed

A value of 1.2 m/s is recommended by most design manuals to be adequate for determining pedestrian clearance intervals for traffic signals (e.g. TRB, 2000). A review of international literature indicates varying values of pedestrian walking speed. Research has identified a list of factors that affect the pedestrian walking speed. This list includes factors such as demographic variables, group size, disability, encumbrance, density and space, distraction, type of pedestrian facility, quality of walking surface, time and weather.

2.2. Pedestrian delay

Pedestrian delay is defined as the additional travel time experienced by a pedestrian while crossing a roadway. Models to estimate pedestrian delay in different traffic situations have been summarized in the study by Rouphail et al. (1998). Several factors associated with pedestrian delay have been found in research. These factors include signal cycle length, demographic variables, familiarity with crossing facilities, traffic volumes, pedestrian arrival phase, road characteristics and type of crossing facility (e.g., Ishaque and Noland, 2008).

2.3. Pedestrian compliance with traffic rules

A review of the existing literature on pedestrian compliant behaviour has shown a wide variation of level of non-compliance with traffic rules among pedestrians, with generally much higher levels in the developing world than in the developed world. Violating traffic rules is a strategy adopted by many pedestrians to reduce the delay, regardless of the higher risk associated. It has been reported that waiting time (e.g., Keegan and O'Mahony, 2003), crossing distance and traffic volume (e.g., Virkler, 1998) influence the level of pedestrian compliance with traffic rules. With regard to spatial non-compliance, the location of a crossing facility relative to the pedestrians' desire lines appears to be the most influential factor (e.g., Behrens, 2010). Social psychological variables together with demographic variables have also been accentuated in research to explain the pedestrian propensity to violate traffic rules (e.g., Yagil, 2000; Muyano Diaz, 2002).

3. METHODOLOGY

The study was carried out at 17 pedestrian crossings located in the city of Stellenbosch, in South Africa. Pedestrian crossings were selected on the basis of geometric and operational characteristics. The selected pedestrian crossings were in seven main categories:

- Category No 1: Signal-actuated crossings located on four-lane divided roads;
- Category No 2: Signal-actuated crossings located on four-lane undivided roads;
- Category No 3: Unsignalized crossings located on T-junctions;
- Category No 4: Unsignalized crossings located on two-way and four-way-stop intersections;
- Category No 5: Unsignalized mid-block crossings located on two-lane roads;

- Category No 6: Unsignalized mid-block crossings located on four-lane undivided roads; and
- Category No 7: Sidewalks.

Crossing behaviour data was collected by the use of three techniques: manual data collection, image videotaping and interviews. Video-based observations consisted of behaviour data of 1104 pedestrians crossing the road perpendicularly at designated crossings and 181 pedestrians walking on sidewalks. In addition to video observations, a total number of 231 pedestrians participated in on-street interviews conducted at 5 signalized intersections and one informal mid-block crossing. These on-street interviews were designed to reveal motivational factors determining the two unsafe crossing behaviours commonly observed in this study namely, crossing during the red man phase and crossing outside the designated crossing (jaywalking).

Pedestrians who crossed at selected pedestrian crossings were filmed unobtrusively by a roadside camera. Video-taped data was recorded in 15-minute periods during weekdays, covering peak and off-peak hours. Nevertheless, data was gathered on the weekend at targeted pedestrian crossings to observe behavioural patterns of particular categories of pedestrians (e.g., shoppers). Recorded data was reduced and transferred to Microsoft Excel spreadsheets to expedite calculations and the process of statistical analysis. Data variables required in the analysis of pedestrian crossing behaviour were coded into 6 main categories: general information, crossing facility and roadway characteristics, traffic flow conditions, pedestrian characteristics, behaviour crossing patterns and type of pedestrian-vehicle conflict. Given that the proportion of elderly pedestrians was insignificant in the sample (2 percent), only two age groups were considered in this study; the younger group (<25 years old) and the older group (>25 years old).

4. RESULTS

4.1. Pedestrian crossing speed and normal walking speed

A summary of crossing speeds and normal walking speeds for different categories of pedestrians is presented in Table 1. The 15th percentile crossing speed for all pedestrians observed while crossing was found to be 1.13 m/s whereas the mean crossing speed was found to be 1.48 m/s. Walking speed on sidewalks was found to be slower than crossing speed, with the 15th percentile speed being 1.18 m/s and a mean walking speed of 1.41m/s. Tests for statistical difference in pedestrian speed were carried out to detect the effect of a variety of demographic, situational and roadway variables on pedestrian speed (see Table 1).

Table 1: Pedestrian crossing speeds

Pedestrian characteristics	Number	%	15th percentile (m/s)	Median (m/s)	Mean speed (m/s)	Standard deviation (m/s)	Statistical test
Gender							
Male	637	58	1.20	1.50	1.55	0.43	p=3.62E-12<0.05
Female	467	42	1.07	1.41	1.39	0.34	
Age group							
Younger	630	57	1.20	1.47	1.54	0.42	p=2.39E-09<0.05
Older	474	43	1.07	1.39	1.40	0.36	
Group size							
Single	559	51	1.25	1.50	1.58	0.45	ANOVA
Pair	373	34	1.07	1.41	1.39	0.32	F=42.9>Fcrit=3.0
3+over	172	16	1.07	1.32	1.33	0.29	p=0.00<0.05
Encumbrance							
Encumbered	669	61	1.14	1.45	1.45	0.36	p=0.002<0.05
Unencumbered	435	39	1.13	1.45	1.53	0.46	

Distraction							
Distracted	454	41	1.07	1.36	1.40	0.36	p=1.54E-09<0.05
Non-distracted	650	59	1.20	1.49	1.54	0.42	
Conflicts							
Conflicting	366	33	0.99	1.42	1.51	0.59	p=0.18>0.05
Non-conflicting	738	67	1.20	1.45	1.47	0.27	
Crossing stage							
1st half crossing	180	50	1.27	1.48	1.65	0.55	p=0.073>0.05
2nd half crossing	180	50	1.20	1.60	1.78	0.76	
One-stage crossing	55	23	1.39	1.63	1.69	0.39	p=0.64>0.05
Two-stage crossing	180	77	1.24	1.51	1.66	0.57	
Crossings vs sidewalks							
Crossing speed	1104	86	1.13	1.45	1.48	0.40	p=0.0293<0.05
Normal walking speed	181	14	1.18	1.33	1.41	0.37	
Overall	1104	100	1.13	1.45	1.48	0.40	

On average, males walked faster than females (1.55 versus 1.39 m/s) and younger pedestrians walked faster than older pedestrians (1.54 versus 1.40 m/s). The highly significant differences in crossing speed between male and female pedestrians (p=3.62E-12<0.05) and between younger and older pedestrians (p=2.39E-09<0.05) demonstrated a noteworthy influence of demographic variables on pedestrian crossing speed.

With regard to situational factors, a significant effect of group size on pedestrian crossing speed was noticeable in this study. The differences in mean speed between the categories of pedestrians by group size appeared to be highly significant (ANOVA: $F=42.9>F_{crit}=3.00$; p=0.00<0.05). It can be argued that the higher the number of pedestrians in the group, the slower the walking speed (see Table 1). Crossing speeds of distracted pedestrians were significantly lower than those who were not (p=1.54E-09<0.05). Similarly, carrying a load while crossing was found to affect pedestrian crossing speed; a significant difference (p=0.002<0.05) emerged between crossing speeds of encumbered and unencumbered pedestrians. Surprisingly, no significant difference in crossing speed appeared between conflicting and non-conflicting pedestrians (p=0.18>0.05).

Two roadway variables, namely crossing distance and crossing stage failed to significantly influence the crossing speed. Pedestrians exhibited a slightly higher mean speed in the second half than in the first half of the crossing (1.78 versus 1.65 m/s) but the difference in mean speed was not statistically significant (p=0.073>0.05). Similarly, the crossing speed in a one-stage crossing was slightly higher than the average of crossing speeds in a two-stage crossing (1.69 versus1.66 m/s), but the statistical test showed no significant difference between them (p=0.64>0.05).

The variability of pedestrian speed also depended on the type of pedestrian facility. A significant difference (p=0.0293<0.05) emerged between the speed of pedestrians crossing at crossing facilities and that of pedestrians walking on sidewalks. The type of pedestrian facility also appeared as a factor influencing pedestrian crossing speed as it can be seen from Figure 2. A one-way ANOVA identified a significant difference ($F=22.17>F_{crit}=2.11$; p=6.14E-25<0.05) in pedestrian speed among different categories of pedestrian facilities.

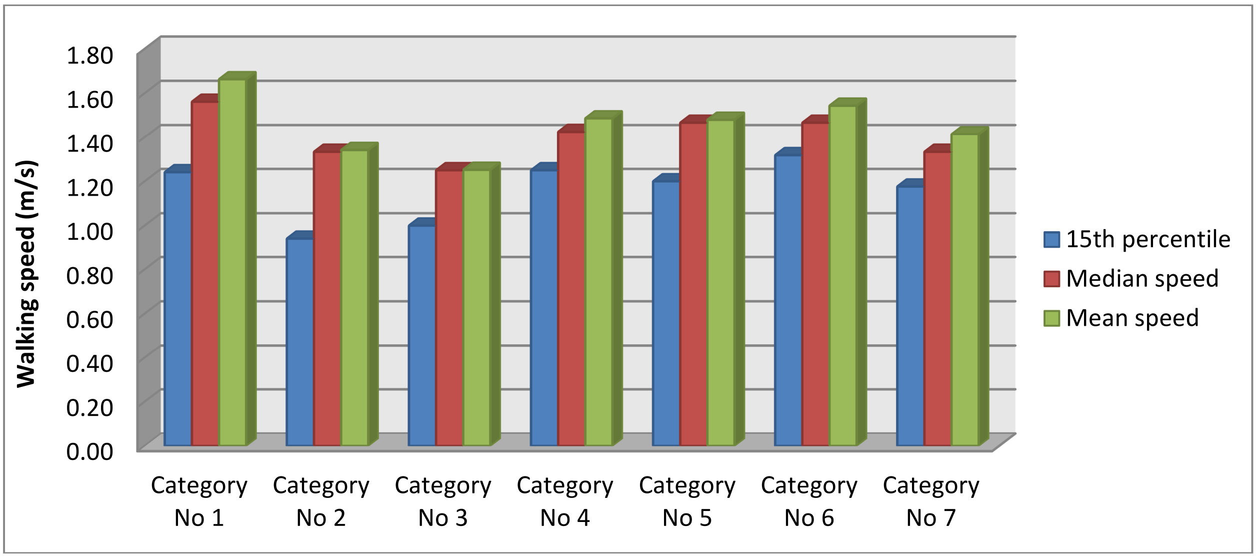


Figure 1: Pedestrian walking speed per category of pedestrian facility

4.2. Pedestrian delay

A breakdown of the delay experienced by pedestrians into gender and age group is presented in Table 2. A mean delay of 5.10 seconds was found for the whole sample. Females were delayed longer than males (5.86 versus 4.54 seconds) and this difference in delay was found to be significant ($p=0.026<0.05$). As it was expected, a strong association between delay and pedestrian age emerged in this study. The statistical test showed a highly significant difference ($p=4.22E\text{-}12<0.05$) between the delay of younger and older pedestrians.

Table 2: Pedestrian total delay by gender and age group

Pedestrian characteristics	Number	%	Median delay (sec)	Mean delay (sec)	Standard deviation (sec)	Statistical test
Gender						
Male	637	58	1.20	4.54	9.63	p=0.026<0.05
Female	467	42	2.00	5.86	9.80	
Age group						
Younger	630	57	1.20	3.28	7.51	p=4.22E-12<0.05
Older	474	43	3.07	7.52	11.62	
Overall	1104	100	1.94	5.10	9.72	

Pedestrian delays per category of crossing facility are presented in Table 3. The kerb delay was taken as the waiting time at the kerb. The crossing delay was calculated by subtracting the ideal crossing time from the actual crossing time. The ideal crossing time was calculated by multiplying the width of the crossing by the mean walking speed of non-conflicting pedestrians. A negative value of delay explains that a pedestrian gained time by walking at higher walking speed than the ideal walking speed (non-conflicting speed).

Table 3: Pedestrian delays per crossing facility category

Group No	Category of crossing facility	Type of delay	Pedestrian delay (sec)		
			Median delay	Mean delay	Standard deviation
Category No 1	Signal-actuated crossings on four-lane divided roads	Kerb delay	3.00	9.23	11.52
		Crossing delay	-0.80	-0.74	3.45
		Total delay	4.20	8.49	12.70
Category No 2	Signal-actuated crossings on four-lane undivided roads	Kerb delay	6.00	11.54	13.98
		Crossing delay	0.72	1.76	4.60
		Total delay	8.72	13.29	15.15
Category No 3	Unsignalized crossings on T-junctions	Kerb delay	1.00	1.40	1.38
		Crossing delay	0.00	0.42	2.32
		Total delay	1.84	1.81	2.98
Category No 4	Unsignalized crossings on two-way and four-way-stop intersections	Kerb delay	1.00	2.00	0.90
		Crossing delay	0.00	0.16	2.56
		Total delay	1.00	1.45	2.85
Category No 5	Unsignalized mid-block crossings on two-lane roads	Kerb delay	1.00	1.24	0.96
		Crossing delay	0.00	0.23	1.37
		Total delay	1.20	1.47	1.68
Category No 6	Unsignalized mid-block crossings on four-lane undivided roads	Kerb delay	1.00	3.82	5.76
		Crossing delay	0.94	0.82	2.54
		Total delay	2.00	4.63	7.06

The distribution of the mean delay per category of crossing facility can be clearly seen from Figure 2. The findings indicated that the mean kerb delay always comprises an immense proportion of the total delay. However, the mean crossing delay peaked at the Category No 2 (signal-actuated crossings located on four-lane undivided roads) and the Category No 1 (unsignalized mid-block crossings located on four-lane undivided roads). The variability in pedestrian delay is much higher at signalized crossings (Category No 1 and Category No 2) as indicated by higher values of standard deviation in Table 3.

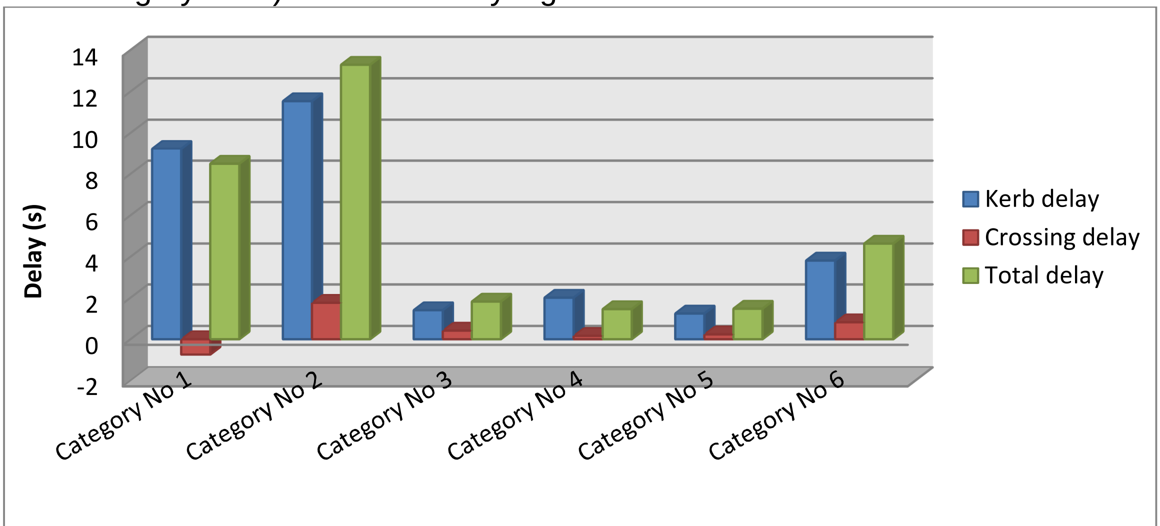
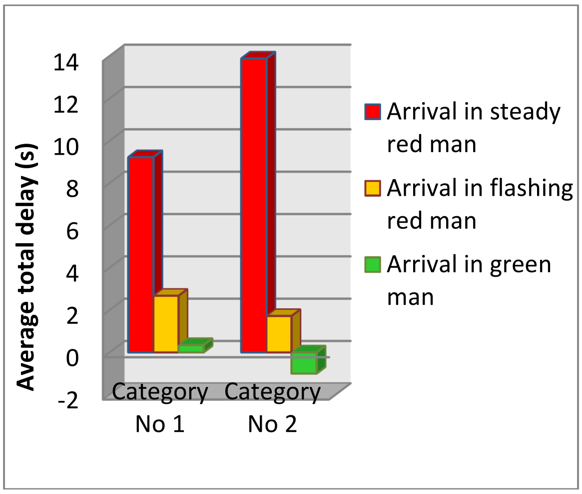


Figure 2: Mean pedestrian delays per category of crossing facility

The status of traffic signals while arriving at the kerb and when crossing the road also affected the pedestrian delay. As it was expected, arriving in pedestrian green phase was found to be associated with shorter delays (see Figure 3). However, pedestrians who crossed during the green phase experienced longer delays than those who crossed in red phase (see Figure 4). This situation may be explained by the fact that violating the traffic signal is always associated with a gain in time.



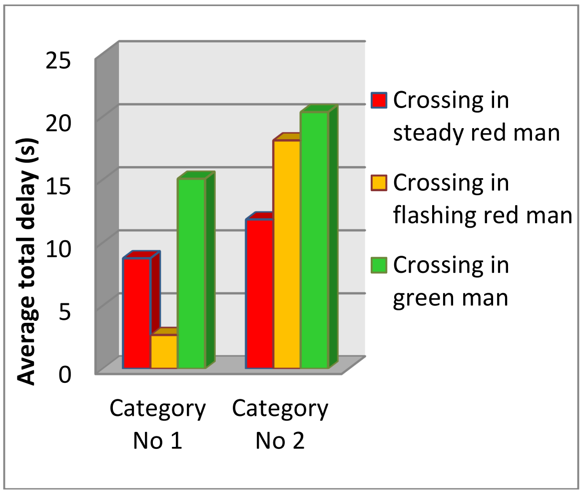


Figure 3: Mean delay per arrival crossing phase

Figure 4: Mean delay per crossing phase

The expected delay which was defined in this study as the signal calling time (difference in time between the signal actuation and the display of green man signal display) was calculated at signalized intersections (Category No 1 and Category No 2). The mean expected delays of 43.25 and 31.53 seconds were found at these intersections, respectively. Compared to the corresponding actual delays (8.49 and 31.53 seconds), a gain in time of 34.76 and 18.24 seconds was found at the respective categories of crossing facilities as a result of violating the pedestrian traffic signals. For the sake of an understanding of pedestrians' response to traffic signals, an insight into the start-up time (the difference between the times at which a pedestrian stepped off the kerb to cross the road and the green man signal was displayed) was also explored in this study. The results showed a mean start-up time of 2.3 seconds.

4.3. Gaze behaviour

A study of gaze behaviour was carried out by observing the number of head movements a pedestrian performed while waiting at the kerb and while crossing a roadway. The average number of head movements ranged from 2 to 5 at the kerb and from 3 to 5 while crossing. This study revealed that more attention was directed when pedestrians were crossing than when they were waiting at the kerb as it can be seen from Figure 5. Furthermore, higher number of head movements were found at the pedestrian crossings with longer crossing distances (Category No 2, Category No 6 and Category No 1). It was also revealed in this study that more attention was directed to the right side when pedestrians were waiting at the kerb. However, when pedestrians were crossing, the direction ahead and to the left side received more attention.

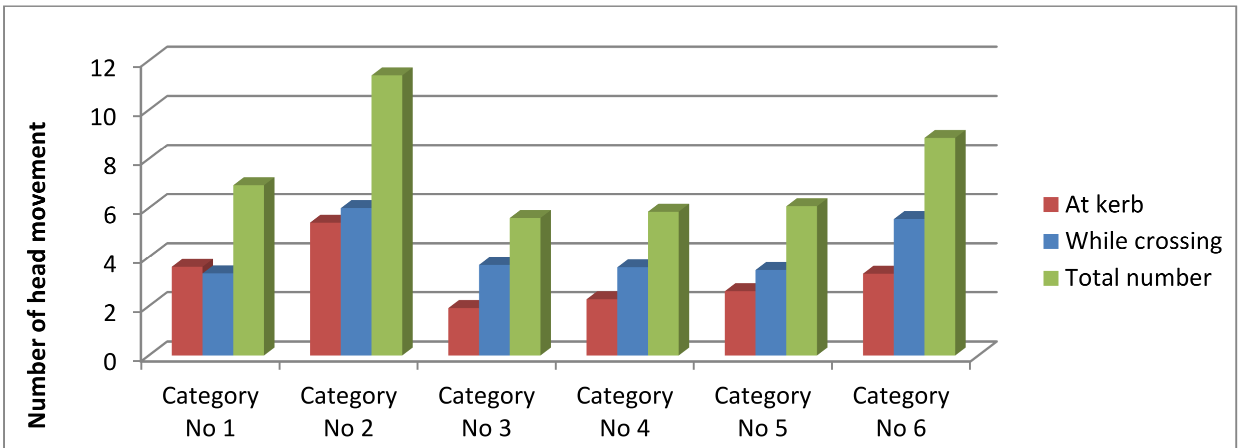


Figure 5: Average total number of head movements at the kerb and while crossing

4.4. Conflict study

In pedestrian-vehicle conflict situations, five evasive actions were identified throughout this study. Running was found to be predominant at wider roads with high traffic volume (Category No 1, Category No 2 and Category No 6) as it can be seen clearly from Figure 6. Using hand signs to request right-of-way was observed in higher proportions at unsignalized pedestrian crossings (Category No 6 and Category No 5).

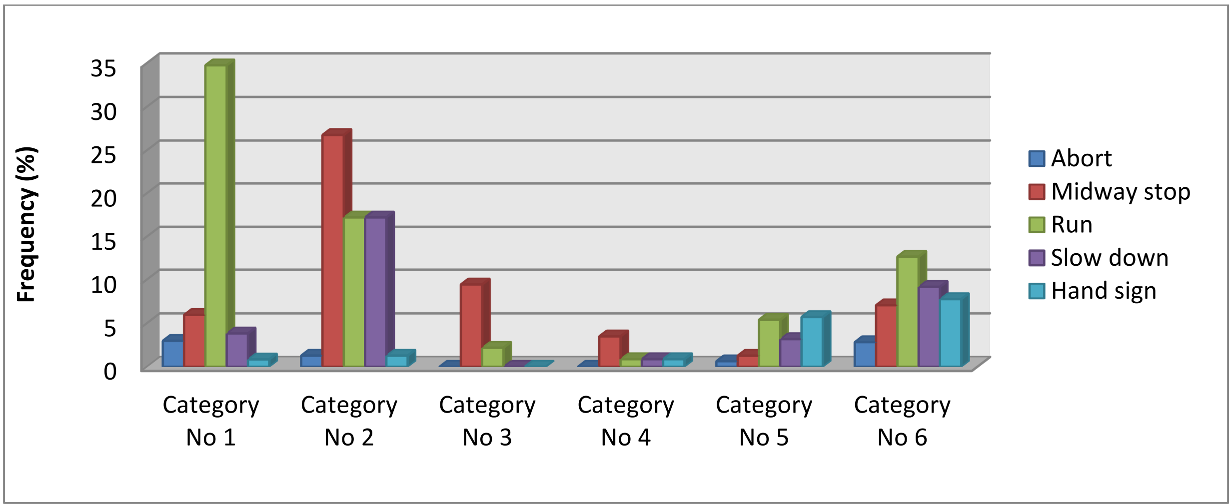


Figure 6: Distribution of conflicts observed at pedestrian crossings

4.5. Compliance behaviour

The majority of observed pedestrians (64 percent) failed to stop at the kerb before crossing the road to check oncoming vehicles. It was also found that not all pedestrians who started crossing within the crossing area remained within the area as they crossed. Levels of red light violation were found to be considerably higher at Category No 1 and Category No 2, with 96 and 85 percent, respectively. These rates also included pedestrians who crossed during the clearance phase. The findings from the on-street interviews revealed that perceived benefits like savings in time and the complexity of crossing at signalized intersections significantly explained the higher levels of pedestrian spatial non-compliance. Factors such as traffic conditions (e.g. low traffic volume), perceived benefits associated with violating the pedestrian red light (savings in time), beliefs and attitudes towards traffic control devices emerged as significant motives for violating the red light for pedestrians. The ignorance of traffic rules also emerged from the reported answers as another motive for breaking road traffic rules.

5. DISCUSSIONS

In this study, faster pedestrian speeds were found at crossing facilities than on sidewalks, supporting the findings of previous studies (e.g., Shi et al., 2007). A possible explanation for this finding may be the fact that pedestrians tend to increase their walking speeds to minimize the risk exposure associated with crossing a roadway. The mean walking speed across our sample (1.48 m/s) corresponds to some of the highest pedestrian speeds reported in previous international literature. This may suggest that pedestrians in the South African context walk generally at higher speeds. The demographic characteristics of our sample (98 percent younger than 55 years old and 58 percent of males) may also partially explain the faster walking speed found in this study. In addition, safety concerns and higher levels of non-compliance at pedestrian crossings may encourage pedestrians to shorten the crossing time.

In line with a large number of previous studies, factors such as age, gender, group size, encumbrance, distraction and type of pedestrian facility significantly affected the pedestrian speed. However, another list of factors including conflicts, crossing stages and crossing distance did not have an influence on the crossing speed. Given that the attempt to elucidate the effects of crossing distance and crossing stages was limited to only one crossing facility (Category No 1), the finding from this study may be inconclusive. In conflict situations, two predominant kinds of evasive actions were involved; either running or reduction in speed (midway stopping or slowing down). Therefore, the variability of the conflicting speed vis-à-vis the non-conflicting speed appeared insignificant. The 15th percentile non-conflicting speed (1.20 m/s) is suggested in this study as the appropriate walking speed for design purposes and coincides with the design speed adopted in South Africa.

The calculated and reported benefits in terms of time savings may be a great incentive for pedestrians to violate traffic rules. The higher levels of red light violation are one of the worst in the world. Longer crossing delays are indicative of conflict situations in which pedestrians were forced to reduce their speed (e.g., Category No 2 and Category No 6). Apart from signalized intersections, longer delays were also observed at unsignalized mid-block crossings on four-lane roads. This suggests that the traffic volume may have an effect on pedestrian delay as reported in much international literature (e.g., Fitzpatrick et al., 2006).

An attempt to rate the safety, comfort and convenience of the six categories of crossing facilities was done in this study. The patterns of crossing behaviour in terms of crossing speed, conflict types, delay and number of head movements were ranged in an ascending order per category of crossing facilities (see Figure 7).

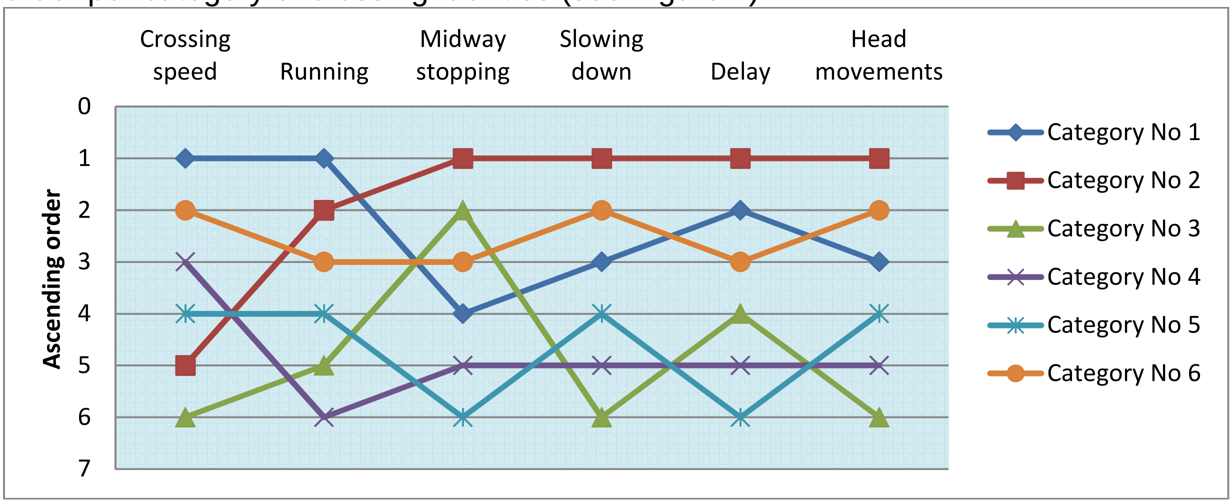


Figure 7: Comparison of the patterns of pedestrian crossing behaviour per category of crossing facilities

On average, all patterns of pedestrian crossing behaviour peaked in three categories of pedestrian crossings (Category No 1, Category No 2 and Category No 6). The common characteristics of these crossings are longer crossing distances, high traffic volumes and fast-moving vehicles. Of them, two categories are located at signalized intersections and one category includes unsignalized mid-block crossings on four-lane roads (Category No 6). Generally, it can be seen from Figure 7 that the crossing speed peaked in the categories of pedestrian crossings in which running was predominant. Similarly, the crossing speed declined at categories in which midway stopping and slowing down were predominant. It can be also argued that the number of head movements increased with the crossing distance and that pedestrian delay increased with traffic volumes.

In the light of the findings in Figure 7, the safest and most convenient categories of crossing facilities appeared to be the Category No 3 (unsignalized crossings located on T-junctions), the Category No 4 (unsignalized crossings located on two-way and four-way-stop intersections) and the Category No 5 (unsignalized mid-block crossings located on two-lane roads). However, T-junctions, followed by mid-block crossings have been reported to have the worst pedestrian crash record in Stellenbosch (Roux, 2010). This ironic finding may be explained by the false sense of safety that pedestrians have when they cross at unsignalized pedestrian crossings. In contrast, pedestrians who cross at complex signalized intersections are aware of the risk associated and tend to increase their attention.

This comparison indicates important areas that should be targeted while mobilizing the interventions aimed at improving the safety, comfort and convenience of pedestrians. For example, these interventions should include speed reduction techniques (e.g. speed limitation, traffic calming and enforcement), signal cycle time that are pedestrian-friendly, regular maintenance of signal controllers and reducing crossing distance (e.g., pedestrian refuge and kerb extension). Education programmes aiming at behavioural change should also target both pedestrians and motorists.

6. CONCLUSIONS

The findings presented in this study showed what the patterns of pedestrian crossing behaviour are and the several factors that affected these pattern were explored. This study showed that pedestrians generally walk at a higher speed than the walking speed recommended for design purposes. Pedestrians were found to be impatient in traffic conditions and engaged predominantly in unsafe crossing behaviour. It can be surmised that pedestrians in the traffic environment behave in a way that suits them in terms of convenience and perceived benefits associated with violating road traffic rules regardless of potential risks that may be involved. This study indicated pedestrian needs, characteristics and areas that need special emphasis to enhance pedestrian safety, comfort and walking attractivess in general. A set of interventions that could mitigate the pedestrian safety problem were also recommended in this study.

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