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RESEARCH ARTICLE

Evaluation of Pedestrian Walking Speed Change Patterns at Crosswalks in Palestine

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Abstract:

Background:

Pedestrians and vehicles are the two most important elements in designing roads and highways. However, for a long time, the designer focused on vehicle issues and did not give sufficient attention to pedestrian safety. Recently though, pedestrians have become the subject of much research and many studies. Moreover, most transportation codes include specific considerations and standards for pedestrians. One of the main pedestrian issues considered in facilities and traffic signal design is pedestrian walking speed. It is, therefore, necessary to evaluate the walking speed change patterns at crosswalks and the appropriate design walking speed for pedestrians, which can then be used to design pedestrian facilities and traffic signals.

Methods:

In this study, the crossing speeds of 4,301 pedestrians were collected from six different locations in Nablus, the second-most populous city in Palestine. Three of these locations were at unsignalized crosswalks, and the other three locations were at signalized crosswalks.

Results:

The collected data considered the factors of pedestrians' age, gender and the type of traffic control at the crosswalk. After analyzing the collected data and performing the Z-test and ANOVA Test for each of the factors, the results showed that male pedestrians walk faster than female pedestrians.

Conclusion:

The study also concluded that age significantly influenced pedestrian crossing speed. Moreover, the values of pedestrian crossing speed at unsignalized crosswalks were insignificantly higher than those at signalized crosswalks. Finally, the average and 15th percentile crossing speeds were determined, since these values are critical to design pedestrian facilities and traffic signals.

Keywords: Pedestrian crossing speed, Walking speed, Pedestrian characteristics, Pedestrian behavior, Pedestrian speed, Pedestrians in Palestine, Nablus.

1. INTRODUCTION

Developing pedestrian facilities and traffic signals has been recognized as a highly important issue because pedestrians have become a key element for any transportation system.

One of the important factors in the design of any pedestrian facility is pedestrian speed. The pedestrian walking speed at crosswalks is an essential parameter in traffic signal design.

The 15th percentile of pedestrian walking speed distribution is used in signal design as the design pedestrian walking speed [1].

Generally, it is recommended that the 15th percentile of pedestrian speed can be used as design speed, assuming that 85 percent of pedestrians walk faster than this. However, the mean pedestrian walking speed or crossing speed will be considered in specific cases [2].

Among several factors that influence the walking speed, those given primary consideration are density, gender, size of platoon (group), percentage of the older population, people

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with disabilities pedestrian population, and child pedestrian population. A walking speed of 1.2 m/s is appropriate for typical groups of pedestrians [3]. The same value was suggested in the Manual on Uniform Traffic Control Devices 2009 for Streets and Highways, which recommended speed of 1.2 m/s as the appropriate pedestrian speed at crosswalks [4].

In discussing the speed of 1.2 m/s with some longtime members of the National Committee on Uniform Traffic Control Devices (NCUTCD), it was found that the 1.2 m/s speed was introduced following research done in 1952 by James Exnicios when he was a graduate student at Yale University. In his unpublished research on pedestrians crossing streets in downtown New Haven, Connecticut, Exnicios showed that the speed frequency distribution curve had a breakpoint corresponded to a 15th percentile walking speed. Exnicios indicated that a walking speed of 1.2 m/s could be considered as a design walking speed for pedestrians [5].

Pedestrian crossing speed varies, depending on pedestrian characteristics and behavior. To improve pedestrian safety, transportation planners and engineers are predominantly concerned with understanding and modeling pedestrian crossing behavior to increase walkability and to reduce the interaction between pedestrians and vehicles at signalized intersections under mixed traffic conditions [6].

This necessitated the need to evaluate the walking speed change patterns at crosswalks in Palestine and to determine the appropriate design walking speed for pedestrians, which can then be used to design pedestrian facilities and traffic signals.

2. LITERATURE REVIEW

During the last three decades, several research studies have addressed the pedestrian behavior and the effect of all subject factors on the pedestrian walking speed at crosswalks.

Li *et al*. [7] studied the pedestrian behavior at unsignalized mid-block crosswalks in the downtown area of Beijing, China. The study analyzed the characteristics of four crossing behaviors (crossing speed, waiting time before crossing, running across the street, not looking before crossing). 579 pedestrians were observed. The results showed that pedestrians' crossing speed on the second half of the crosswalk is systematically faster than the first half; moreover, children's crossing behaviors are influenced by adults.

Likewise, Onelcin and Alver [8] investigated the pedestrian's crossing speeds, delay, and gap perceptions at six signalized intersections in Izmir, Turkey. Each intersection was observed on weekdays during the afternoon peak (12.30-13.30) and evening peak (17.00-18.00) hours using video cameras. In total, 2,694 pedestrian crossing events were observed, and the 15th percentile crossing speed was found to be 1.07 m/s.

Moreover, Muley *et al*. [9] analyzed three types of pedestrian speeds (entry speed, crossing speed, and exit speed) at three signalized crosswalks in the State of Qatar. Pedestrian movements were tracked using *Traffic Analyzer* software, then the data were analyzed. The results indicated that the crossing speeds were positively correlated with crosswalk length.

Another study was conducted by Kadali and Vedagiri [10]

in order to examine the pedestrian crossing speed change patterns at selected unprotected mid-block crosswalks in Mumbai, India. The study investigated the effect of pedestrian behavioral characteristics on pedestrian crossing speed. The results showed that younger pedestrians have more probability of exhibiting crossing speed change patterns as compared to the elderly pedestrians at mid-block crosswalks.

Similarly, in Singapore, a study conducted by Tanaboriboon *et al*. [11] to examine characteristics of pedestrians in Singapore showed that the mean walking speeds of Singaporeans is 1.23 m/s. This speed is relatively slower than that of the American counterpart.

In Sri Lanka, a study by Morrall *et al*. [12] was conducted to determine the characteristics of pedestrians in the central business district. Data of walking speed, flow, and density for sidewalks of varying widths were collected. The study concluded that Asian pedestrian walking speeds for all groups are significantly lower than those observed in Calgary and Canada.

In Jordan, a study by Tarawneh *et al*. [2] was conducted in order to recommend pedestrian design speed values to represent pedestrians in Jordan. Data of nearly 3,500 pedestrian crossing operations were collected at 27 crosswalks in the Greater Amman Area. The study concluded that the average and 15th percentile pedestrian speeds in Jordan were 1.34 and 1.11 m/s, respectively.

As a result, some of the previous studies investigated pedestrian behavior and crossing speed at signalized crosswalks; whereas, other studies investigated these issues at unsignalized crosswalks. In this study, the behavior of pedestrians and crossing speeds at both signalized and unsignalized crosswalks were studied in order to compare the results. Moreover, in this study, gender, age, and type of control factors were addressed; whereas, these factors were partially addressed in the previous studies. Finally, this study aims to determine the appropriate pedestrian design speed for Palestinian pedestrians, since there is no previous study that addressed this issue in Palestine.

3. OBJECTIVE OF THE STUDY

This study aims to:

- Evaluate the pedestrian walking speed change patterns at crosswalks of different types of control and based on different factors related to pedestrian characteristics.
- Determine the influence of traffic control at crosswalks (signalized or unsignalized) on pedestrian crossing speed. For this purpose, six locations were selected to represent both signalized and unsignalized crosswalks.
- Determine the effect of essential factors such as age and gender on the pedestrian crossing speed in order to calculate the appropriate crossing speed that takes into consideration the different characteristics of pedestrians at various locations.
- Calculate the 15th percentile pedestrian crossing speeds that can be used as a design pedestrian walking speed in the design of traffic signals that fit the characteristics of pedestrians in Palestine.

4. METHODOLOGY

A total of 4,301 pedestrian crossing events were counted at all six crosswalks (signalized and unsignalized). Among these events, 2,519 pedestrian crossing events were counted at unsignalized crosswalks, and 1,782 pedestrian crossing events were counted at signalized crosswalks, as shown in Table **1**.

Table 1. Crosswalks locations and number of counted pedestrians.

Location	Type of Traffic Control	Number of Pedestrians
Sophian Street (downtown)	Unsignalized Crosswalk	872
Almontaza Intersection	Signalized Crosswalk	287
Tunes – Rafedia Intersection	Signalized Crosswalk	326
In Front of An-Najah National University (New Campus)	Unsignalized Crosswalk	769
In front of Nablus Municipality	Unsignalized Crosswalk	878
In front of Alwatany Hospital	Signalized Crosswalk	1169
Total	-	4301

A stopwatch was used to measure pedestrian crossing time; then, the crossing speed was calculated by dividing the length of a crosswalk by the pedestrian crossing time. However, the people collecting the data attempted to record the crossing time of all pedestrians using the crosswalk, some pedestrian crossing events could not be recorded during peak periods. The pedestrians were asked about their ages in some cases when the observers could not identify their ages. This study focused on individual pedestrians; therefore, crossing speeds were measured for individuals only, and no data for pedestrians in groups were recorded. However, considering pedestrians in groups can provide a clearer image of pedestrians' behavior and characteristics, pedestrians in groups can lead to more complex factors, such as the number and age of people in each group, and these are not easy to be measured. The age of the pedestrians was one of the main factors considered in this study; therefore, pedestrians were divided into four categories: (1) children younger than 13 years old, (2) pedestrians 13 to 29, (3) pedestrians 30 to 64, and (4) pedestrians 65 and older. In order to make it easier for observers to recognize the age of the pedestrians, a wide segmentation of age was used; otherwise, more observers or a questioner should be used. Since some of the data were collected in very crowded areas, it was very difficult to use questioners for collecting age data, or even to increase the number of observers.

Due to the perceived difference in the physical attributes of males and females, the gender of the pedestrians was considered in this study and the data were divided into two groups, female and male.

To reduce the possibility of error and attain more reliable results, the following crossing events were excluded from the data counts [13, 14].

- Pedestrians walking in groups.
- Pedestrians carrying load (*e.g.* children, heavy bags, suitcases).
- Pedestrians walking with bicycle or pets.
- Pedestrians pushing strollers.
- Pedestrians holding hands (couple) or assisting other pedestrians.
- Disabled pedestrians.
- Running pedestrians.
- Pedestrians crossing diagonally and
- Stopping and resting pedestrians.

After collecting all data, the data were classified into specific categories according to the type of traffic control at crosswalks (signalized and unsignalized crosswalks). IBM SPSS 25 software was then used to calculate the mean and 15th percentile pedestrian crossing speeds, as these values are very important to the design of traffic signals and pedestrian facilities.

Finally, Z-Test was applied in order to determine if there was a significant difference in the crossing speeds according to gender and the type of control at a crosswalk. In addition, a One-way ANOVA Test was applied in order to determine if there was a significant difference in the crossing speed of different age groups.

Through the stages of data collection, several limitations were faced. The first limitation was the difficulties in recognizing the age of pedestrians at crosswalks in general and at shopping areas, specifically since it was very crowded and observers could not ask pedestrians or use a questionnaire. The second limitation was collecting data for pedestrians in groups since it was very difficult to collect the data manually. In order to keep a reasonable accuracy, a wide age segmentation (interval) was used, and the pedestrians in groups were excluded.

5. RESULTS AND DISCUSSION

After collecting pedestrian crossing speed data, the data were classified according to the type of traffic control at the crosswalks, age, and gender of the pedestrians. The results showed a variation in pedestrian crossing speed within each category. Depending on the type of traffic control at crosswalks, the mean and 15th percentile crossing speeds at signalized crosswalks overall categories were 1.35 m/s and 1.06 m/s, respectively, whereas the values at unsignalized crosswalks were 1.39 m/s and 1.09 m/s, respectively. Thus, the mean and 15th percentile pedestrian crossing speed values at unsignalized crosswalks were higher than those at signalized crosswalks, as shown in Table **2**.

Table 2. Crossing speeds (m/s) summary, based on type of traffic control.

Signalized	Factor	Level	Count	Mean	15th
	Gender	Male	935	1.394	1.129
		Female	847	1.303	1.030
	Age	<13	165	1.312	1.030
		13-29	770	1.450	1.147
		30-64	726	1.291	1.091
		≥65	121	1.126	0.886
	Over All Categories		1782	1.351	1.060
Unsignalized	Gender	Male	1617	1.429	1.070
		Female	902	1.324	1.055
	Age	<13	121	1.225	0.942
		13-29	1738	1.423	1.129
		30-64	583	1.372	1.044
		≥65	77	1.090	0.800
	Over All Categories		2519	1.391	1.090

By applying the Z-Test for both signalized and unsignalized groups, using IBM SPSS 25 software, the resulting P-value was 0.134, and thus the difference in crossing speed at both signalized and unsignalized crosswalks was insignificant, as illustrated in Table **3**. Therefore, the data of signalized and unsignalized crosswalks can be used together in order to determine the appropriate pedestrian design speed. However, the data were analyzed separately in order to compare the characteristics of pedestrian speed between both types of control and with studies in other countries.

Age was one of the most important factors that affected pedestrian crossing speed. As shown in Table **4**, the highest mean and 15th percentile speeds were found for pedestrians 13 to 29 years old, with values of 1.43 m/s and 1.14 m/s, respectively. Pedestrians 65 years and older had the lowest mean and 15th percentile speeds, with values of 1.11 m/s, 0.89 m/s, respectively.

In order to determine the significance of the difference in pedestrian crossing speeds among all age categories, a One-way ANOVA Test was performed, as illustrated in Table **5**. The results showed that the variance in crossing speeds among age categories was significant.

Table 3. Z-test results for pedestrian crossing speeds (m/s) at signalized and unsignalized crosswalks.

-	Signalized	Unsignalized
Known Variance	0.068	0.121
Observations	1782	2519
z	-1.499	-
P(Z<=z) two-tail	0.134	-
z Critical two-tail	1.960	-

Post hoc analysis was performed in order to find the source of the significant difference in crossing speed in age categories. Results showed that the greatest mean difference was between the categories of pedestrians 13 to 29 years old and pedestrians 65 and older, with a value of 0.32 m/s.

Table 4. Crossing speeds (m/s) summary, based on all factors.

Factor	Level	Count	Mean	15th	Mean Difference
Traffic Control	Signalized	1782	1.351	1.090	Insignificant
	Unsignalized	2519	1.391	1.060	
Gender	Male	2552	1.416	1.100	Significant
	Female	1749	1.314	1.050	
Age	<13	286	1.275	1.011	Significant
	13-29	2508	1.431	1.140	
	30-64	1309	1.327	1.080	
	≥65	198	1.112	0.887	

Table 5. Anova test results based on factor of gender, using IBM SPSS 25.

-	Sum of Squares	Mean Square	F	Sig.
Between Groups	2.501	.834	8.947	0.000
Within Groups	36.052	0.093	-	-
Total	38.553	-	-	-

Table 6. Z-test results for pedestrian crossing speeds (m/s), depending on gender, using IMB SPSS 25.

-	Male	Female
Known Variance	0.123	0.058
Observations	2552	1749
z	3.411644	-
P(Z<=z) two-tail	0.000646	-
z Critical two-tail	1.959964	-

According to gender, crossing speed values were divided into two groups, male and female. The mean and 15th percentile crossing speeds for males overall categories were 1.42 m/s and 1.10 m/s, respectively, whereas the values for females were 1.31 m/s, 1.05 m/s, respectively. Thus, males were faster than women when using crosswalks, as shown in Table **4**.

In order to determine the significance of the difference in pedestrian crossing speeds between the female and male, Z-Test was applied using IBM SPSS 25 software. The results showed that P-value was 0.00, and thus the difference in crossing speed was significant between male and female categories, as shown in Table **6**.

The result of the study showed that the mean crossing speed at unsignalized crosswalks was 1.39 m/s. However, this value is slightly higher than the value that Tarawneh *et al*. [2] concluded in his study of pedestrian crossing speed at unsignalized crosswalks in Jordan, which was 1.34 m/s. Whereas, the result was almost equal to the result that Morrall *et al*. [12] concluded in his study for Canadian pedestrians, with a mean speed of 1.40 m/s. Furthermore, Asian countries like Singapore had a lower mean crossing speed at unsignalized crosswalks, as concluded in 1991 by Tanaboriboon *et al*. [11], with a value of 1.23m/s. As a result, there is a variation in the mean pedestrian walking speed at the unsignalized crosswalks among the different countries, since the physical characteristics of the pedestrians vary based on the geographical area.

CONCLUSION

After analyzing the pedestrian crossing speed data for all categories (type of traffic control at crosswalks, gender, and age), conclusions were offered in order to be used in traffic signal and pedestrian facilities design. The following conclusions represent the walking speed change patterns for Palestinian pedestrians only and are not valid for other countries' pedestrians due to change in physical characteristics and cultural variation based on geographical location. Moreover, pedestrians in groups are not included in the following conclusions:

- Types of control at crosswalks, gender, and age contribute to the difference in a pedestrian walking speed patterns at crosswalks.
- At unsignalized crosswalks, the mean and 15th percentile pedestrian crossing speeds were 1.39 m/s and 1.09 m/s, respectively.
- The mean and 15th percentile speeds at signalized intersections were 1.35 m/s and 1.06 m/s, respectively.

- Beginning with those who had the highest crossing speed, pedestrians 13 to 29 years old were the fastest among all groups; next, were pedestrians 30-64 followed by those younger than 13 years old and lastly, pedestrians 65 and over had the slowest crossing speed.
- Male pedestrians overall categories were faster than female pedestrians, at both signalized and unsignalized crosswalks.
- It is recommended to use 1.4 m/s pedestrian walking speed (the 15thpercentile walking speed) as design walking speed at crosswalks instead of the currently used value of 1.2 m/s (recommended by MUTCD) since the Palestinian pedestrians tend to walk faster than the American pedestrians.
- The data showed that there is a significant difference in pedestrian walking speed at crosswalks based on age and gender; whereas, there is an insignificant difference in pedestrian walking speed based on the type of traffic control at a crosswalk.
- There is a variation in the mean pedestrian walking speed at the unsignalized crosswalks among the different countries since the physical characteristics of the pedestrians vary based on the geographical area.
- It is highly recommended to study the crossing speed for people walking in groups and handicapped people in any future work since these issues were not studied in this work.

CONSENT FOR PUBLICATION

Not applicable.

AVAILABILITY OF DATA AND MATERIALS

The authors confirm that the data supporting the findings of this research are available within the article.

CONFLICT OF INTEREST

The authors declare no conflict of interest, financial or otherwise.

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