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Pedestrian Road Crossing at Uncontrolled Mid-Block Locations: Does the Refuge Island Increase Risk?

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Abstract: The study investigates the behaviour of pedestrians crossing a road with a refuge island in an urban area to assess whether refuge islands deliver their expected benefit. This type of pedestrian crossings aims at providing a half-way shelter and protection while pedestrians are crossing a road with two-traffic streams. Data has been collected using two video cameras from an urban location in Edinburgh on gaps in traffic flow, rejected and accepted gaps, and critical gaps of pedestrians while crossing from the curb or the median. Data have also been examined to estimate and assess vehicle and pedestrians' speeds, vehicle type, waiting time, group size and other demographic characteristics of pedestrians. The statistical modelling techniques used include Multiple Linear Regression and Generalised Estimating Equations (GEE). The results show that the critical gap for crossing from the median to the curb is much shorter than that from the curb to the median. Pedestrians appear to be less cautious when crossing from the median to the curb as they are more likely to accept a shorter gap in traffic. This could indicate a shortfall in the design and/or operation of this type of crossing. Further considerations and investigation of what measures could be implemented to enhance safety and reduce risky behaviour at this type of crossing are recommended and certainly encouraged.

Keywords: refuge islands; pedestrian crossing behaviour; generalised estimating equations; multiple linear regression

1. Introduction

The design and operation of road systems is a challenging process. Mobility maximisation and impacts on safety, travel time and cost of travel are often conflicting. In order to be able to offer recommendations to policy makers it is important to gain understanding of the nature of conflict and be able to judge its significance. The majority of accidents in which pedestrians are killed or seriously injured (KSI) occur on urban roads. In 2016, of the 5588 killed or seriously injured pedestrians, 84% of the accidents occurred on urban roads. This is due to greater population densities in urban areas and also due to more pedestrians crossing busier roads which leads to a greater number of interactions between vehicles and pedestrians, increasing the risk of accidents. Over three quarters (78%) of pedestrians killed or seriously injured (KSIs) in 2016 occurred whilst the pedestrian was crossing the road away from a pedestrian crossing, such as zebra crossings, signalised mid-block crossings and pedestrian refuges [1].

A pedestrian refuge island is a form of pedestrian crossing. It is a raised section of pavement between two lanes of traffic moving in opposite directions. The islands, also termed medians, normally have yellow and white plastic bollards with a blue arrow to remind motorists to keep left. Curbs are dropped at both sides of the road, usually with tactile paving where the pavement slopes towards the road. The refuge provides some protection from traffic in the centre of the road, while the pedestrian waits for a safe gap in the second direction of traffic. Without a refuge, the pedestrian needs to judge a safe gap between both directions of traffic at the same time which is more difficult and may increase risk. It has been estimated that vehicle speeds at pedestrian refuges is reduced by 6%. Various studies have looked at pedestrian mid-block crossing behavior and the results suggest that pedestrian-vehicle conflict rates are reduced by the presence of a raised pedestrian refuge [2–5].

While refuge islands are intended to reduce pedestrian exposure as well as to slow traffic down because they narrow the road and should remind drivers that pedestrians could be crossing the road, pedestrians do not have priority; rather vehicle traffic has the priority. Furthermore, the dimensions of some refuge islands make them less easy to wait at while looking for an appropriate gap in the opposite direction of traffic. Thus, pedestrians who are waiting to cross at the refuge island might be more motivated to reach the opposite side and therefore be less cautious and willing to take higher risk than when they are crossing from the curb to the refuge island. Therefore, instead of the refuge island providing a shelter for pedestrians while crossing, it might be leading to more risky crossing situations. A previous study [6] at signalized intersections in India has indeed suggested that pedestrians are much more cautious when crossing from the curb to the refuge than when they cross from the refuge to the curb on the opposite side. The current study evaluates pedestrians' observed gap acceptance behaviour at an unsignalised midblock location where pedestrians are not aided by a traffic signal or a zebra crossing. This would allow us to extend Das et al. [6] findings beyond the signalized crossing situation. Furthermore, cultural differences between countries may well affect crossing behaviour characteristics.

Some previous studies assessed the impact of various factors that affect pedestrian crossing behaviour and demonstrated the advantages of the presence of signalized and unsignalised pedestrian crossing facilities [5–13]. However, pedestrian mid-block crossing behaviour at a location where a two-stage crossing is encouraged through a central refuge island is generally lacking in research. At such locations, when crossing, pedestrians have to wait for an appropriate gap in traffic. This can pose an uncertain crossing situation compared to other types of crossings, especially in heavy traffic. Therefore, for pedestrians to be able to cross safely, they need to be able to make a good judgement of traffic speed and gaps in traffic. Various demographic variables such as gender and age might also impact risk-taking behavior. For example, two large studies in the USA by [9,13] studying mid-block locations with and without crosswalks, respectively, as well as Yannis et al. [14] study on a mid-block location without a crosswalk or a refuge island, found that gender is a significant predictor in a discrete choice model of gap acceptance. However, the only other similar observational study, conducted in the UK by [15], did not include gender data in their discrete choice gap acceptance model. Therefore, the current study is making a contribution in understanding the role of gender on pedestrian crossing behaviour in the UK.

The current study addresses the general lack of models of pedestrian unprotected mid-block crossing behaviour in the United Kingdom. Detailed models of unprotected mid-block crossing gap acceptance have been produced in the USA [9,16] Greece [14], India [6,11,12,17], China [5,18], and Egypt [19]. However, fewer studies have focused on gap acceptance behaviour in the UK and there are likely to be differences in pedestrian attitudes, customs, infrastructure design and quality, as well as legal restrictions. One UK-based study was conducted in 1955 in Manchester by [1] and did not involve video recording. More recently, [10,15] investigated gap acceptance behaviour of pedestrians in London before and after road re-development works. The aim of their study was to investigate the changes in gap acceptance behaviour related to converting a road into a shared space. The current study expands on this investigation of road crossing behaviour in the UK [15] and on the reviewed past research on pedestrian behaviour at refuge islands [4,6] to produce an investigation of two-stage mid-block gap acceptance behaviour aided by a refuge island in the UK.

In previous studies, gap acceptance behaviour has been analysed using multiple linear regression modelling [20], binary logistic regression [14,15] and ordered probit models [12]. However, there are known problems associated with multiple rejected gaps and independence of observations. A single pedestrian often rejects more than one gap; therefore, analyzing each rejected gap as a separate observation does not account for the fact that it is rejected by the same person. [6] analysed gap acceptance of initial gaps (lags) separately from the acceptance of all observed gaps using an ordered probit model [14] deal with the independence of the observations problem by using only the largest gap rejected by each pedestrian and all their accepted gaps. However, these methods result in a loss of a significant amount of observations per pedestrian. The current study is the first to use generalised estimating equations in constructing a binary model of pedestrian crossing behaviour. This model allows the repeated observations for each pedestrian to be taken into account. The next section presents the methodology adopted in this investigation, with details on the location, data collection and data examination. Results are discussed in two sections; descriptive analysis and modelling analysis. Finally, the conclusions section summarises the main findings of the research.

2. Methodology

Pedestrian crossing behaviour during road crossing can be studied using monitoring, observations, reporting responses simulation of pedestrians and their crossing choices. Examples of previous studies include [6,8,16]. The current study investigates pedestrian gap acceptance behaviour when crossing a road with a refuge island through the observation of pedestrian crossing using video recording of pedestrians' movements. In order to assess the impact of a central refuge on pedestrians crossing and on gap acceptance behaviour, the data will be analysed taking into account whether pedestrians are crossing from the curb or from the refuge island and thus evaluate the role of the refuge island in pedestrian decision-making and risk-taking.

3. Location Description

The aim of the study was to assess and investigate pedestrian crossing behaviour at a mid-block location with a refuge island, in an urban area with a high observed pedestrian accident frequency. An initial list of areas of interest was made through the use of accident data involving pedestrians (available through crashmap.co.uk). After an initial selection of possible areas, a pre-data-collection visit was made at each area and the number of crossings observed were recorded manually. A final location was then designated for recording that maximises the number of pedestrians' crossings.

The chosen refuge island site is located on Morningside road, a two-way single carriageway road that is classified as an urban distributor (Figure 1). This is a pedestrian mid-block crossing location where a two-stage crossing is encouraged through the central refuge island. The choice of the location is meant to capture road crossing decision-making which is not regulated by traffic lights or the presence of zebra crossings and is thus solely dependent upon the judgement and risk perception of the participants in the encounter (drivers and pedestrians).

The road link falls within the 20 mph restriction imposed in central Edinburgh, with an average daily traffic flow of 14,500 vehicles in both directions. Pedestrian movements are heavy during the morning and evening peak periods and include many students travelling to and from nearby education hubs, work, school and shopping centres. Figure 2 shows the area layout. There are two small side roads both North (Hermitage terrace) and South (Maxwell street) of the refuge island. The effect of the two side roads was taken into account during data reduction and analysis. The total road width at the location of the refuge is 4.19 m per lane while the refuge island measures 2.05 m in width and 3.76 m in length. The distance between Maxwell street and Hermitage terrace is 33 m. Furthermore, in the time period analysed, there were only 39 vehicles overall which used these two side streets. Cases where a vehicle took a turn into one of the side streets and the pedestrians used this opportunity to cross were excluded from the analysis. The yellow markings preceding the refuge measure approximately 26.46 m on side A (South) and 19.42 m on side B (North). These markings are of interest as their length is used for calculating the speed of the oncoming vehicles.

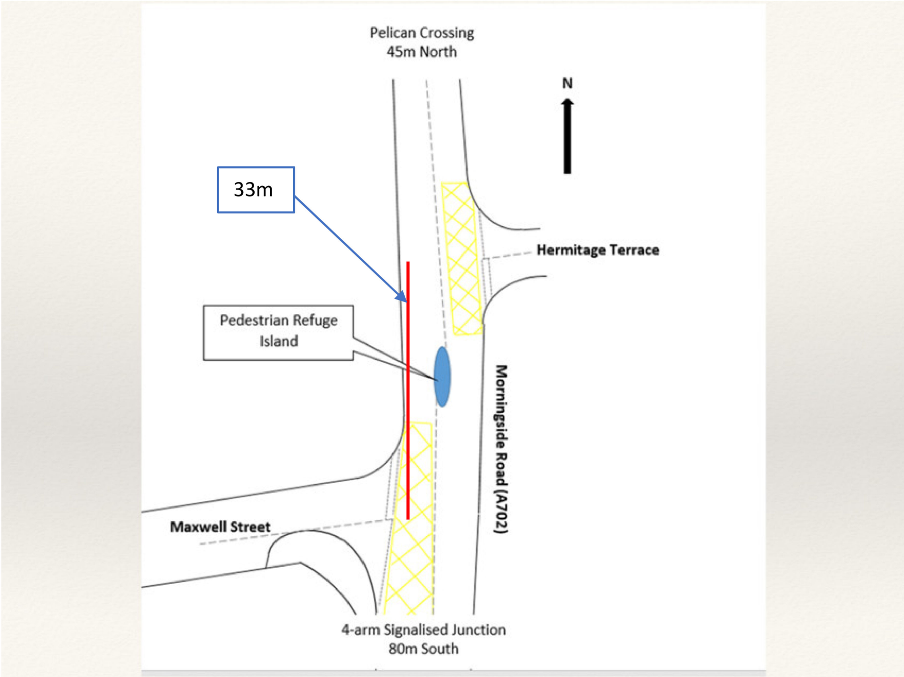


Figure 1. Case study area layout.

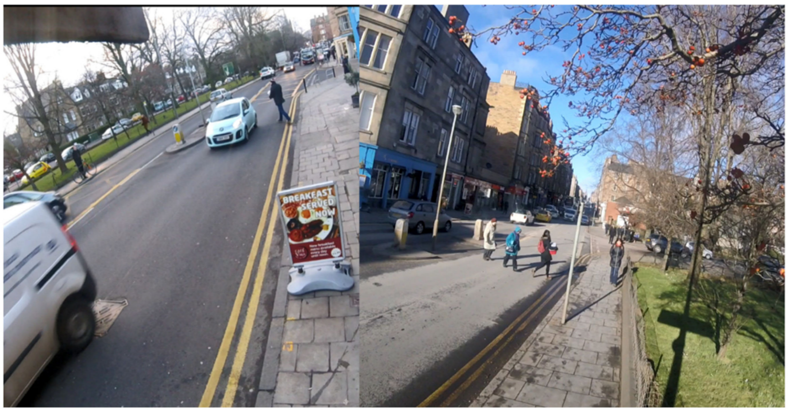


Figure 2. Camera positions layout of the area: observing side A (left) and side B (right).

4. Data Collection

The study adopts the definition of a gap in the traffic as the "the elapsed time interval (time headway) between arrivals of two successive vehicles in the major stream at the same reference point" [21]. According to gap acceptance theory, pedestrian crossing behaviour is determined by a critical gap, the shortest gap that the pedestrian would accept. Pedestrians monitor the gaps available to them and compare them to their critical gap, crossing is attempted when the available gap is equal to or greater than the critical gap [22,23].

Data was collected using two GoPro cameras, one camera for each traffic direction. The cameras were attached to high poles (signposts, road signs) at a level above the eye sight of the average adult pedestrian. Figure 2 shows the view from each of the two cameras. The size of the cameras and their locations made them discreet so pedestrians were not observed to be paying attention to the cameras.

A total of 500 observations were collected over a 3 day period of recording that was conducted in November, January and February (2017–2018). A total of 8 h and 15 min of recording was obtained and analysed. All recordings were made on dry days with good visibility. The data was viewed on the video software Media Player Classic Home Cinema which provides millisecond detail in its time code.

Two independent scorers worked on reducing the video recordings to the chosen variables. At the first stage of data reduction, the information was entered in Excel and then transferred to SPSS and R in a long format where each gap occupies a new row in the dataset. Each gap was measured from the time of arrival of the first vehicle at the hypothetical collision point with a pedestrian waiting to cross, until the arrival of the following vehicle at the same point. Lags, where the gap is measured from the time of arrival of the pedestrian at the curb or median until the arrival of the first vehicle, were analysed together with the rest of the gaps.

Dynamic and static road variables affect pedestrians' crossing behaviour. Speed and vehicle size were significant predictors of gap acceptance in Hyderabad, India [10,11]. These two factors have been considered in this study. Vehicle speed was obtained through measuring the time it took each car to cross the first and last yellow lines on the ground (Figure 2). The vehicle type variable reflects the size of the vehicle associated with each gap due to the low number of motorcycles observed, they were merged with the category of small vehicles (Table 1).

Table 1. Variable description.

Variable	Description	Measurement
Cumulative waiting time until each vehicle	Cumulative waiting time which is calculated for each individual gap faced by the pedestrian from formula: Car arrival time - pedestrian arrival time. Used in the Generalised Estimating Equations (GEE) binary model.	Seconds; continuous
Total waiting time	Total waiting time for each pedestrian until they accept a gap. Variable used in the linear regression model.	Seconds, continuous
Gender	As observed on video.	Categorical male and female
Age group	Pedestrians are categorised with approximation based on visual characteristics. Children supervised by adults were not included as separate pedestrians making decisions.	Categorical approximately: Young (17–35), middle age (35–55), old (55+)
Group size	For rejected gaps, this is the size of the group waiting to cross, on same side and opposite side of the road. For accepted gaps, the group size is the number of people who crossed together. If a pedestrian crossed on their own and other waiting pedestrians did not cross with them, then the group size for the accepted gap for the crossing pedestrian is 0.	Continuous
Time to cross (proxy for pedestrian speed)	Calculated from departure and completion times for crossing from curb/median	Seconds, continuous
Cross from curb/median	If the pedestrian was crossing from the curb or median.	Categorical curb and median
Vehicle speed	Speed of vehicle measured from distance and time between two static points (first and last yellow lines shown on Figure 1).	km/h, continuous
Type of vehicle	Categorised as observed on video: Small (all cars, motorcycles and some small vans), medium (mostly vans or small service trucks), large (buses and most trucks).	Categorical small vehicle, medium vehicle, large vehicle
Accepted gap	The gap between pedestrian departure time from the curb and arrival of next vehicle.	Milliseconds, continuous
Rejected gaps	The elapsed time headway between the arrival of two successive vehicles at the hypothetical crossing line of the pedestrian.	Milliseconds, continuous

Roads are heterogeneous and their characteristics and layout influence pedestrian crossing behaviour. Road factors include road width, a determinant of crossing behaviour with the tendency to cross at mid-block decreasing as the width of the road increases [24]. The effect of road width and central refuge width and type (painted or restricted) on crossing decisions are demonstrated by [24] through a field stated preference study. In the current study, both lanes of traffic are of the same width (4.19 m), therefore this factor was not considered in the analysis. High traffic volume decreases pedestrians' tendency to cross at mid-block while low traffic volume or congestion have the reverse effect [8]. Traffic volume was not considered as an independent variable in the current study as both lanes have the same traffic volume. The variables gap size and vehicle speed reflect the characteristics of the traffic at this location.

The age group and gender of all pedestrians were also considered (Table 1). Age-related changes in cognition, speed and the need to compensate for decreased movement capability are some of the factors affecting crossing in older people [25,26]. Observational studies have shown that elderly pedestrians leave longer distance gaps but not longer time gaps which leads to risky situations when the vehicle is travelling at higher speed [27]. There was an opportunity to look into the effects of gender in the present study.

There are a number of psychological variables that could influence decision to cross. For example, some pedestrian behaviour is likely to vary with the purpose of the pedestrian's trip: People who walk for leisure would be less likely to take risks than those who are under time constraints to complete a task [8,25]. Furthermore, pedestrians tolerate more risk as their waiting time at the curb increases [6], as well as when the pedestrian is part of a group [28,29], the latter being explained by the pedestrian feeling "more visible" to the vehicles [30]. While the current study will not be able to gain insight into the trip purpose of pedestrians due to its observational nature, waiting time and "crossing in a group" variables are included in the analysis. The cumulative waiting time was calculated to reflect the time elapsed since arrival of the pedestrian, until each individual gap in the traffic. The total waiting time until crossing was also calculated. Similarly, we took into account the characteristics of the surroundings in terms of whether there were other people waiting to cross and the number of people crossing together. The group variables (a binary variable reflecting whether or not there were other pedestrians waiting to cross at each gap and a continuous variable reflecting the number of pedestrians crossing together at the accepted gap) were updated for each individual gap in order to reflect the dynamic changes in the social environment.

Papadimitriou et al. [8,31] attempted to measure and include human factors in their models by integrating a questionnaire in their study. They were able to identify three types of pedestrians: Risk-takers (optimisers), conservative, and leisure trips. The participants were observed making route decisions in real life. [8] investigated risk-taking with regards to route choice and recruited participants who were aware of being part of a study. The current study attempts to replicate their findings through an observational methodology.

5. Data Analysis

The statistical methods used for analysing the obtained data include binary logistic regression based on generalised estimating equations (GEE) and multiple linear regression modelling. In the recent literature it has been common to analyse the discrete choice of gap acceptance through binary logistic regression [14,15] and ordered probit models [12]. However, when pedestrians are faced with a stream of traffic, they often reject more than one gap or in some cases reject and then accept a gap. In most cases this leads to more than one observed decision per pedestrian. Thus, the observed choices (reject or accept) which are being modeled are not independent of each other. Perhaps due to this issue, [12] analyse gap acceptance of initial gaps (lags) separately from the acceptance of all observed gaps. Yannis et al. [14] deals with the independence of observations problem by using only the largest gap rejected by each pedestrian and all their accepted gaps. However, this does not account for the fact that the rejected and accepted gaps might still be the choices of the same pedestrian. Furthermore, this resulted in the loss of a significant amount of observations per pedestrian. The current study attempts to improve previous modeling approaches by using the generalised estimating equations method [32]. This method is an extension of the generalised linear model which accounts for the hierarchical structure of data. In the current case, the binary outcome variable "choice - reject or accept" is taken from hierarchical clusters, each cluster being each individual pedestrian.

A multiple linear regression model is used for investigating the relationship of the various predictor variables to the size of the accepted gap. While gap size is a predictor in the discrete choice model described above, using it as a dependent variable can give more insight into gap length choice and will also provide converging evidence for the findings from the GEE.

6. Results

6.1. Descriptive Statistics

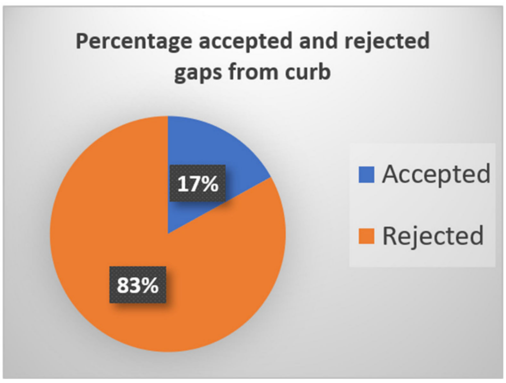
An investigation of the properties of the obtained variables was carried out. Table 2 shows the mean lengths of the accepted and rejected gaps and vehicle speed at the curb and median. The mean length of the accepted gaps at the curb (7.922 s) was slightly longer than that at the median (7.528 s).

Furthermore, pedestrians tended to accept gaps associated with slightly faster vehicle speed when crossing from the median (29.2 km/h) than when crossing from the curb (27.6 km/h).

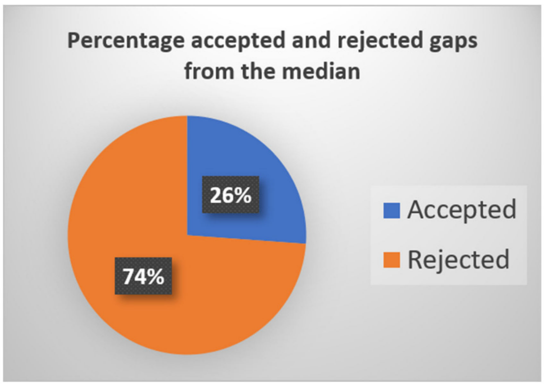
Table 2. Descriptive statistics for the variables gap and vehicle speed.

Variable	Accepted from Curb	Accepted from Median	Rejected from Curb	Rejected from Median
Number of gaps	136	149	601	403
Gap length (s)				
Mean	7.922	7.528	3.391	3.473
Standard deviation	2.724	2.597	1.744	2.202
Coefficient of variation	0.344	0.345	0.514	0.633
Vehicle speed (kmph)				
Mean	27.554	29.198	27.831	27.700
Standard deviation	7.686	7.505	7.109	8.339
Coefficient of variation	0.279	0.267	0.255	0.301

Figure 3 shows that from all gaps that the pedestrians encountered at the curb and median, when crossing from the median they accepted 26% and when crossing from the curb they accepted 17% of the available gaps. To look into the possibility that more convenient gaps presented themselves at the median than at the curb, we looked at the distribution of all gap lengths and all vehicle speeds at curb and median. Figure 4 shows that the gaps that were encountered at the median were slightly longer (4.53 s) than those at the curb (4.16 s) while the mean vehicle speed at the median (28.11 km/h) and curb (27.78 km/h) was similar (Figure 5). The availability of slightly longer gaps at the median likely contributes to the higher percentage of accepted gaps from the median. The multiple linear regression undertaken in this study looks at the effect of crossing from curb or median on accepted gap size. As participants accept shorter gaps from the median (Table 2) despite being presented with longer gaps on average (Figure 4), a significant effect of curb/median in predicting accepted gap size would strengthen the suggestion that pedestrians are likely to choose shorter gaps at the median (even when longer gaps are available). For the generalised estimating equations model in the current study, curb/median crossing is used as a predictor of choice to accept or reject a gap and this allows us to control for the effect of crossing from curb or median when interpreting the contribution of the rest of the variables to the final model.



(a)



(b)

Figure 3. Percentage accepted and rejected gaps from curb (**a**) and median (**b**).

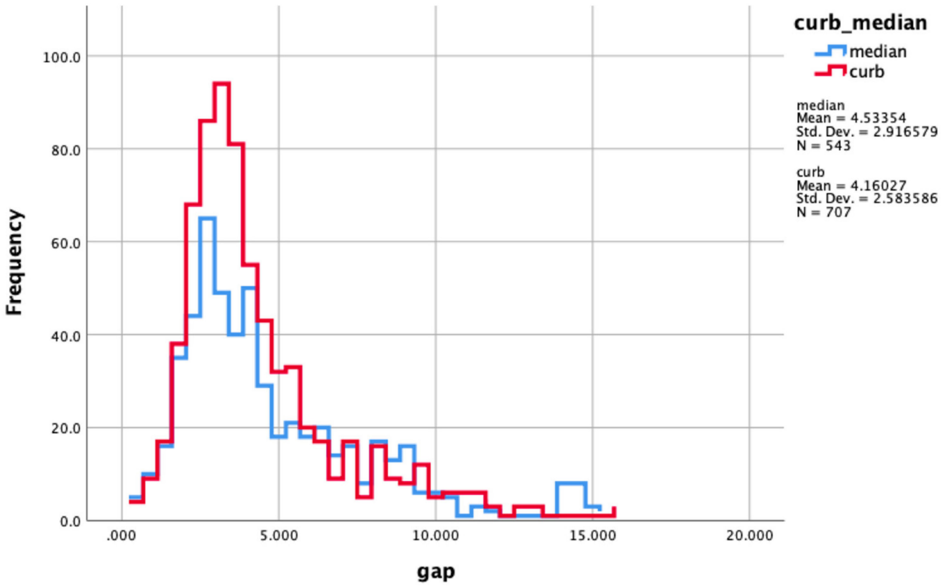


Figure 4. Frequencies of all gaps at curb and median.

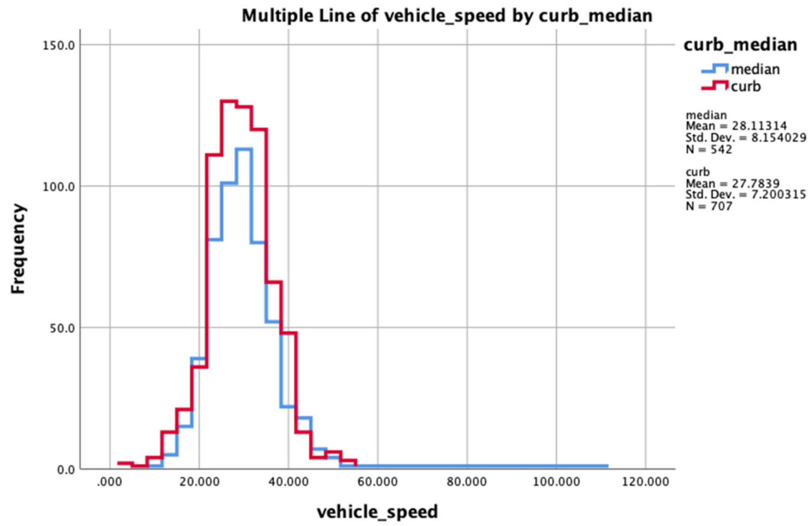


Figure 5. Distribution of vehicle speed (km/h) at the curb and median.

Table 3 shows that the mean value of waiting time at the curb of 9.260 s is about 40% longer than the waiting time at the median (6.148 s) which could be explained by a combination of availability of more convenient gaps at the median and an increased tendency to accept gaps at the median.

Table 3. Descriptive statistics for the variables total waiting time and crossing time.

Variable	Curb	Median
Total waiting time (s)		
Mean	9.260	6.148
Standard deviation	11.480	8.993
Coefficient of variation	1.240	1.462
Crossing time (s)		
Mean	3.357	3.722
Standard deviation	0.924	0.924
Coefficient of variation	0.275	0.269

Figure 6 shows the frequencies of accepted gaps at different gap lengths. Gap acceptance from the median showed bimodal distribution with pedestrians accepting shorter gaps from the median in the range of 4–7 s. Thus, the shortest gaps in the sample were accepted from the median as can be observed on Figure 6.

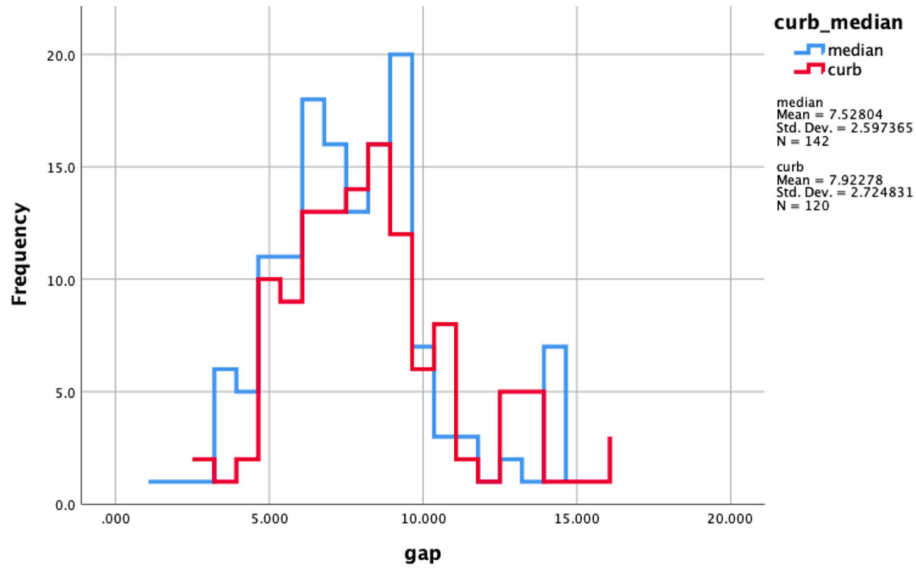


Figure 6. Frequencies of the accepted gap lengths from curb and median.

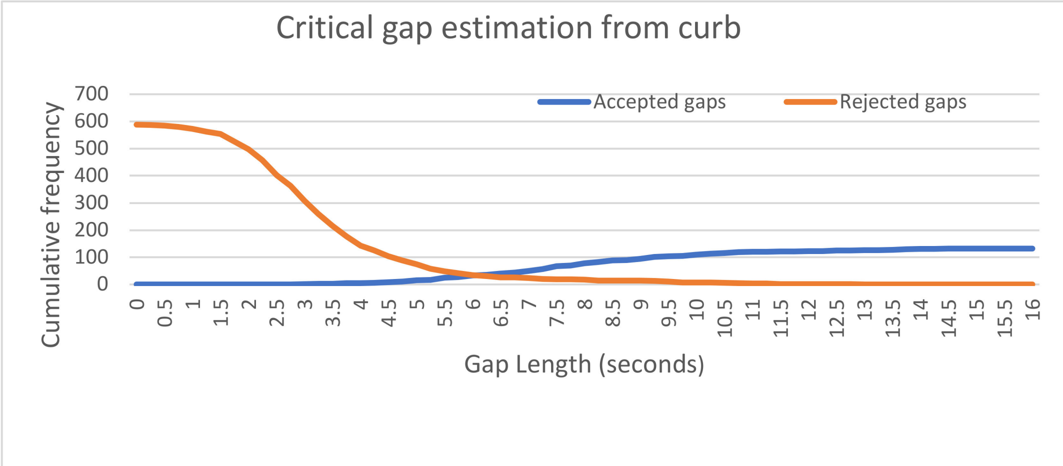
Intercorrelations between the independent variables are presented in Table 4. The variable "accepted gap" was used as a dependent variable in the multiple linear regression and it showed a significant correlation with all continuous predictors apart from total waiting time until crossing and group size on the opposite side of the road. There was also a significant negative correlation between the variables vehicle speed and cumulative waiting time until each vehicle, as well as a positive correlation between total waiting time and group size on the opposite side of the road. This could be explained by participants being less likely to attempt crossing when cars approach at higher speed which subsequently increases their cumulative waiting time until accepting a gap as well as the number of people waiting to cross accumulating with time.

Table 4. Correlations between the continuous predictor variables.

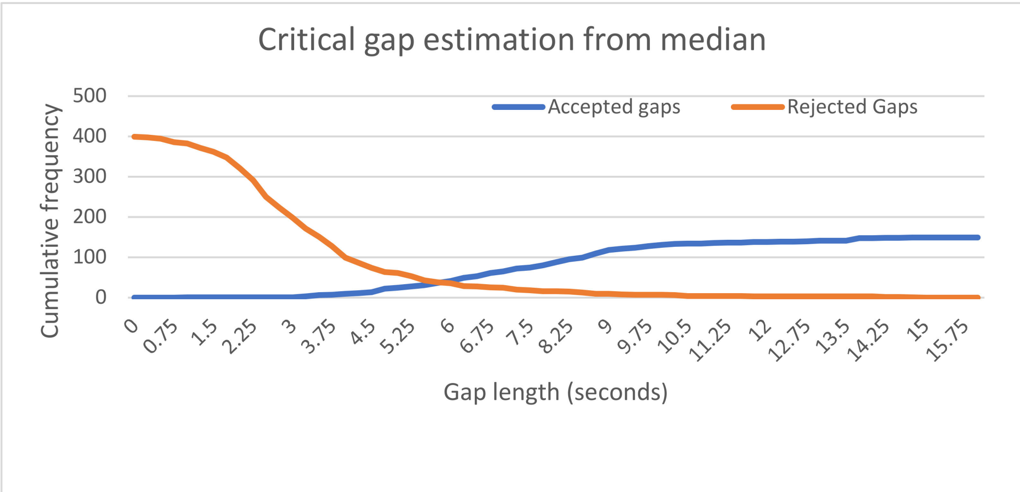
		Time to Cross	Group Size (Same Side)	Waiting until Vehicle	Vehicle Speed	Gap	Total Waiting Time
Time to cross	Pearson Correlation	1	0.113	−0.026	−0.047	0.219 **	−0.05
	Sig. (2-tailed)		0.069	0.673	0.45	0	0.426
Group size	Pearson Correlation	0.113	1	0.047	−0.021	0.184 **	−0.01
	Sig. (2-tailed)	0.069		0.449	0.741	0.003	0.875
Waiting until vehicle	Pearson Correlation	−0.026	0.047	1	−0.165**	0.154*	0.690 **
	Sig. (2-tailed)	0.673	0.449		0.007	0.012	0
Vehicle Speed	Pearson Correlation	−0.047	−0.021	−0.165 **	1	−0.129 *	−0.069
	Sig. (2-tailed)	0.45	0.741	0.007		0.036	0.266
Gap	Pearson Correlation	0.219 **	0.184 **	0.154 *	−0.129 *	1	0.095
	Sig. (2-tailed)	0	0.003	0.012	0.036		0.127
Total waiting time	Pearson Correlation	−0.05	−0.01	0.690 **	−0.069	0.095	1
	Sig. (2-tailed)	0.426	0.875	0	0.266	0.127	

** Correlation is significant at the 0.01 level (2-tailed). * Correlation is significant at the 0.05 level (2-tailed).

The cumulative frequencies of the accepted and rejected gaps are plotted and the critical gaps are established using the [33] method where the intersection between the two cumulative frequencies is considered the critical gap. Crossings from the median the critical gap fell into the 5.75 s data bin (Figure 7a) while crossings from the curb fell into the 6.25 s data bin (Figure 7b).



(**a**)



(**b**)

Figure 7. (**a**) Critical gap from the curb. (**b**) Critical gap from the median.

6.2. Multiple Linear Regression

Accepted gap size was entered as the dependent variable and the variables crossing time, number of people crossing (group size), total waiting time, vehicle speed, vehicle type, curb/median, age group and gender are tested as predictor variables. The stepwise regression modelling function ols_step_both_*p* {olsrr} in R was used to select the best predictors by entering and removing predictors based on *p*-values. Total waiting time was not a significant predictor (p = 0.184) and neither was vehicle speed (p = 0.081). The final model comprised the predictors curb/median, crossing group size and time to cross (Table 5). The final specified model has the form of Equation (1).

$$\text{Accepted gap size} = 4.77 + 0.742 \times \text{curb/median} + 0.565 \times \text{crossing time} + 0.409 \times \text{group} \quad (1)$$

Table 5. Linear regression model summary.

	Gap		
Predictors	Estimates	CI	*p*
Intercept	4.77	3.55–5.99	<0.001
Curb/Median	0.74	0.10–1.38	0.023
Group	0.41	0.14–0.67	0.003
Time to Cross	0.57	0.26–0.87	<0.001
Observations 261			
R^2/R^2 adjusted 0.092/0.082			
F-statistic: 8.722 on 3 and 257 DF, *p*-value: 1.569e-05			

6.3. Generalised Estimating Equations

The impact of crossing from the curb or from the median was further investigated using generalised estimating equations. In this case, a binary model of gap acceptance was defined where the variable choice (accept/reject) is predicted by the specified variables. The predictors tested were: Gap size, crossing time, vehicle speed, cumulative waiting time until vehicle, gender, age group, curb/median, group size. Due to the significant correlation between vehicle speed and cumulative waiting time until vehicle, the variables were considered separately by constructing two models where the only difference was either vehicle speed or cumulative waiting time until vehicle is used. Both vehicle speed (0.022) and waiting time until vehicle (p = 0.003) were significant predictors when considered separately from each other in the initial model. Gender, age group, vehicle type were not found to be significant predictors of choice to cross.

Unlike multiple linear regression, there are no formalised variable selection methods for generalised estimating equations, both possible models with either vehicle speed or waiting time are presented below in Tables 6 and 7. Finally, a composite model with both vehicle speed and waiting time entered, as well as all other significant variables which are presented in Table 8. It is noted that despite waiting time until vehicle and group size not being significantly correlated, once waiting time is controlled for, group size is no longer a significant predictor. Thus, we omit it from the final proposed model in Table 9.

Table 6. GEE model with vehicle speed variable.

	Choice		
Predictors	Estimates	CI	*p*
Intercept	−0.09	−0.22–0.05	0.193
Gap	0.09	0.08–0.10	0.023
Curb/Median	−0.08	−0.12––0.04	0.003
Group	−0.02	−0.04––0.00	<0.001
Time to cross	−0.04	−0.06––0.01	
Vehicle speed	0.00	0.00–0.01	
N_{ped_no} 489			
Observations 1244			

Table 7. GEE model with waiting until vehicle variable.

		Choice	
Predictors	Estimates	CI	*p*
Intercept	0.03	−0.07–0.13	0.567
Gap	0.09	0.09–0.10	**<0.001**
Curb/Median	−0.07	−0.11–−0.03	**<0.001**
Group	−0.02	−0.04–0.00	0.053
Time to cross	−0.03	−0.05–−0.01	**0.001**
Waiting until vehicle	0.00	−0.01–−0.00	**0.003**
N_{ped_no} 489			
Observations 1244			

Table 8. GEE with all variables in.

		Choice	
Predictors	Estimates	CI	*p*
Intercept	−0.07	−0.20–0.06	0.282
Gap	0.10	0.09–0.10	**<0.001**
Curb/Median	−0.07	−0.11–−0.03	**<0.001**
Group	−0.02	−0.03–0.00	0.093
Time to cross	−0.03	−0.05–−0.01	**0.002**
Vehicle Speed	0.00	0.00–0.01	**0.029**
Waiting until vehicle	0.00	−0.01–0.00	**0.004**
N_{ped_no} 489			
Observations 1244			

Table 9. Final GEE model proposed.

		Choice	
Predictors	Estimates	CI	*p*
Intercept	−0.11	−0.23–0.02	0.092
Gap	0.09	0.09–0.10	**<0.001**
Curb/Median	−0.07	−0.10–−0.03	**0.001**
Time to cross	−0.03	−0.05–−0.01	**0.002**
Vehicle Speed	0.00	0.00–0.01	**0.020**
Waiting until vehicle	0.00	−0.01–0.00	**0.002**
N_{ped_no} 489			
Observations 1244			

7. Conclusions

While there has been previous research on signalised and zebra pedestrian crossing locations, not a lot of reported research on unprotected at-grade pedestrian crossings has been found. The current study investigates risk-taking by adopting an approach of observing and investigating pedestrian crossing decisions at a refuge island location. The choice of the location was designed to capture road crossing decision-making which is not regulated by traffic lights or the presence of zebra crossings and is thus solely dependent upon the judgement and risk perception of the participants in the encounter (drivers and pedestrians). A total of 500 observations were collected using two GoPro cameras, one camera for each traffic direction.

Results show that the critical gap values for crossing from the curb are significantly higher than those crossing from the median. Results also show higher dispersion of the values when crossing from the curb to the median than when crossing from the median to the curb. This might indicate that pedestrians tend to be more cautious and heterogeneous when crossing from curb to the median.

When they are waiting at the median, they might tend not to feel safe, and therefore accept a shorter gap in traffic.

Generalised estimating equations were adopted to further investigate gap length and crossing behaviour. The results examined the lengths of the accepted and rejected gaps for pedestrians crossing from the median and from the curb, and were calibrated as a function of a number of independent variables. The variables tested in the model were crossing direction, crossing time, pedestrian speed, vehicle speed and whether the pedestrian was crossing in a group. The results show that "crossing from the curb" indicates positive significance associated with the length of the gap. Waiting time to cross, as well as presence of group and group size were also all positively associated with the critical gap length. On the other hand, pedestrians' speed was found to be negatively associated with the length of gap accepted. Finally, the results show that as the vehicle speed increased, the length of gap accepted increased too. Again, these all seem to be intuitive results.

While this research provides one of very few investigation and modelling of pedestrian crossing behaviour in the UK, further research is definitely required in this area. This further research should include investigations of the impact of traffic volumes and types of vehicles, more social and behavioural factors such as purpose of travel, gender, age, and impacts on risk-taking while crossing different types of at-grade crossings. Gender impact on crossing behaviour has not been found significant in the calibrated model in this paper. Using questionnaires to ask pedestrians on their preferences, choices and attitude can contribute to a greater understanding of their behaviour. Investigations of future scenarios are important, such as automation and smart mobility and the importance of understanding pedestrian crossing and walking behaviour using such facilities. Recommendations to policy and decision makers can be made from such investigations. Efficient and appropriate pedestrians' crossing facilities will surely have positive impacts on encouraging all types of individuals to walk more and to improve their safety.

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