Safety Science 143 (2021) 105418

Contents lists available at ScienceDirect

Safety Science

journal homepage: www.elsevier.com/locate/safety

Risky pedestrian behaviour and its relationship with road infrastructure and age group: An observational analysis

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ARTICLE INFO

Keywords:
Pedestrian behaviour
Road safety
Age group
Independence analysis
Road infrastructure

ABSTRACT

Research related to road safety and pedestrian behaviour from observations has been concentrated in high-income countries, so advancing its implementation in low- and middle-income countries nurtures the literature on these issues. This research aim is to study pedestrian behaviour at seven high crash occurrence locations near schools in the city of Manizales, Colombia. Based on direct observations at the points, behaviours related to crossing location, distractions while crossing, interactions with motorized actors, and people's crossing speed were analysed. Inference statistical analyses were carried out between variables taking into account the location of the points studied, the typology of the road and the type of intersection, and their relationship with age groups. Among the main results, it was found that most of the behaviours are independent of age group, except at points near primary roads where there is a high-motorized flow. Finally, the analyses by grouping variables avoid falling into Simpson's paradox.

1. Introduction

Globally, about 1.35 million lives are lost due to road crashes (World Health Organization, 2018). Low- and middle-income countries (LMICs) have crash fatality rates three times higher than high-income countries (HICs), so actions to achieve a Vision Zero road safety policy have greater challenges in the former. Besides, developed countries has different political, social, scientific and professional contexts. Road safety is a phenomenon of geographic implication; consequently, differences across countries are significant, generating independence between statistics and road users' behaviour. For example, in Colombia, 6826 fatalities were recorded in 2019, of which 25.59% were pedestrians and 53.71% motorcyclists, exceeding the global percentage of pedestrians (23%) and motorcyclists (28%) fatalities (World Health Organization, 2018).

Considering vulnerable road users and risk factors such as vehicle speed (Hussain et al., 2019; Rosén and Sander, 2009), distractions when crossing the road (Osborne et al., 2020), distractions when driving a car (Oviedo-Trespalacios et al., 2019), and even the misuse of road infrastructure (King et al., 2009) several studies have been carried out to improve road safety. This has made it possible to determine that human behaviour is a variable that is difficult to control and little interest in road safety in medium-sized cities in Latin America since most research is concentrated in large cities or developed countries.

1.1. Human behaviour in road safety research

Human behaviour studies have been applied in different areas with different methods and objectives, as they seek to analyse different user groups and variables that relate them to the existence of road safety conditions. For example, Moyano (2002) studied pedestrian behaviour in Santiago de Chile based on a questionnaire survey, which revealed that young men were more responsible for road incidents than other road users. Similarly, Sisiopiku & Akin (2003) used video observations and intercept surveys to assess pedestrians' risk behaviour and perceptions on a road corridor near Michigan State University, finding that most pedestrians crossed at unsignalized mid-block crossings (31%), given the remoteness of safe signalized crossings. King et al. (2009) conducted an in-depth observation of pedestrian crossing behaviour at a traffic light-regulated intersection in the Brisbane CBD (Australia), finding that most crossing behaviours were appropriate (79%) and those diagonal crossings (8.2%) were the most common risky behaviour. In

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https://doi.org/10.1016/j.ssci.2021.105418
Received 1 March 2021; Received in revised form 24 May 2021; Accepted 13 July 2021
Available online 2 August 2021

Spain, Meneses Falcón et al. (2010) analysed risk behaviour among adolescent four-wheeler and two-wheeler drivers based on questionnaires in the provinces of Madrid and Andalucia, finding that behaviours related to exceeding the speed limit (17.4%) and not using protection (16.2%) generally occur among motorcyle users.

Tom and Granié (2011) assessed differences in pedestrian behaviour by gender (male and female) in France through observations at signalized and unsignalized crossings. Havard and Willis (2012), who studied pedestrian behaviour in Edinburgh (UK) by mixing observations through video analysis and in-home questionnaires, carried out an impact analysis of the provision of a new zebra-type pedestrian crossing. Later, Granié et al. (2013) applied a survey on a sample in France to develop the Pedestrian Behaviour Scale (PBS), which assesses four factors: i) transgression, ii) lapses, iii) aggressive behaviour, and iv) positive behaviour. Similarly, Papadimitriou et al. (2013) identified the main patterns in pedestrian behaviours and attitudes based on a survey of 4290 people in 19 European countries. Three types of pedestrians were observed: pedestrians with positive behaviour and attitudes, pedestrians with negative behaviour and attitudes, and pedestrians with positive behaviour but mixed attitudes. On the other hand, Khatoon et al. (2013) assessed the impact on pedestrian behaviour at an intersection in Delhi (India) after the construction of an overpass, based on before and after video camera observations.

In 2015 Herrero-Fernández developed a rapid questionnaire to assess pedestrian risk behaviour from a study population in Vizcaya (Spain), while Deb et al. (2017) implemented a questionnaire to determine pedestrian behaviour in the United States taking into account the four factors found by Granié et al. (2013). Besides, Pešić et al. (2016) studied pedestrian behaviour at unsignalized intersection in Belgrade, Serbia regarding the use of mobile phones while crossings. They use direct observations at two intersections registered 1194 pedestrians with 11.5% of them using mobile phones during the cross. On the other hand, Alhajyaseen and Iryo-Asano (2017) studied the change in behaviour of pedestrians while crossing at signalized intersections over five points in Nagoya City (Japan), finding that pedestrians make sudden changes in their speed increasing the risk with vehicles making turning manoeuvres. Shaaban et al. (2018) analysed 2766 risky and illegal pedestrian crossing behaviour through 48 h of video recordings in a corridor on the main road in Doha (Qatar), taking into account differences in pedestrian behaviour according to gender and age. In contrast, Hasan et al. (2020) studied the behaviour of those who chose not to use pedestrian bridges in multiple cities in Malaysia, based on 295 intercept surveys (162 footbridge users and 133 non-users). McIlroy et al. (2019) applied the PBS on a sample located in six countries, economically and culturally different, seeking to validate the tool proposed by them, for this research, no country in America was considered.

In Latin America, Barrero et al. (2013) combined different methods such as questionnaires, observations, and interviews to validate a method to assess pedestrian behaviour at road intersections in Bogotá (Colombia). In this research, pedestrians crossing two road intersections with high traffic flow were interviewed and asked to recognize their behaviour in previously taken videos. Similarly, Poó et al. (2018) conducted an observational study of pedestrian behaviour at multiple intersections in Ushuaia (Argentina), e.g., 88% crossed completely outside the crosswalk at marked intersections. In Colombia, studies related to human behaviour have been carried out in Barranquilla (Oviedo-Trespalacios and Scott-Parker, 2017) and Bogotá (Cantillo et al., 2015) through intercept surveys, with the aim of building models that predict pedestrian crossing behaviour. In both, pedestrians' unwillingness to use pedestrian bridges and the permanent search for a shorter route to perform a crossing manoeuvre were identified. These results corroborated those obtained by Echeverry et al. (2005), who studied multiple high accident hotspots in Cali (Colombia) based on intercept surveys and observations. On the other hand, Vergel-Tovar et al. (2019) analysed the influence of environmental variables on road crashes in Bogotá considering data from 2012 to 2016 through purely quantitative methods.

Concerning drivers' risky behaviours, Riendeau et al. (2018) researched personality factors affecting driving safety using questionnaires and a driving simulator. Similarly, Oviedo-Trespalacios et al. (2019) studied, using driving simulators, the influence of mobile phone use while driving, understanding this behaviour as a risk factor in road safety. This type of method for assessing driver behaviour has been very popular in recent years, especially among developed countries (Li et al., 2020).

Taking into account the methods used, the users involved, and the features of the study areas, a short literature review of research related to human behaviour and road safety, especially among pedestrians, is shown in Table 1. The variables analysed include:

- Users Involved (UI): Pedestrian (P), Four-wheeler (FW) and Two-wheeler (TW) drivers.
- Variables considered (VC): Age (A), gender (G) and personality (P).
- Methods: Observation (O), Questionnaire surveys (QS), Interviews (I), Crash data analysis (CDA) and driving simulator (DS).
- Infrastructure type (IT): Corridor (C), Intersection (I) and Footbridge (F). N.A means that research does not involved infrastructure.
- Analysed points (AP): Unique (U) or Multiple (M).
- Type of country (TC): High-income country (HIC) and low and middle-income country (LMIC).

As can we see in the Table 1, the most common methods are related to intercept surveys or interviews, with observations being a validation or complementary method as it has occurred in research in high-income countries (King et al., 2009; Shaaban et al., 2018). In particular, pedestrian behaviour was studied based on direct observations that took into account crossing on unmarked routes, distractions when crossing, crossing speed, and confrontations with other road users (Mamidipalli et al., 2015), but the most common researches have been carried out at intersections or points located near universities (Oviedo-Trespalacios and Scott-Parker, 2017; Sisiopiku and Akin, 2003). On the other hand, research has been mainly conducted in high-income countries or cities with a considerable number of inhabitants (e.g. Barranquilla, Cali, and Bogotá in Colombia), leaving aside intermediate cities whose cultural dynamics and infrastructure provision can vary widely. In this case, we are contributing to closing a gap, especially in Latin America, addresses the issue of pedestrian behaviour through direct observations near educational institutions located in intermediate cities in a Low- and Middle-income country.

Our motivation is based on investigating pedestrian behaviour at high crash occurrence points located near educational institutions, so the pedestrian flow is high, especially for children under 18 years of age, who are the most vulnerable along with older adults. Therefore, the research's main objective is to study pedestrians' behaviour to determine the relationship between this pedestrian behaviour and the risk of crossing, distraction during the cross, crossing pedestrian behaviour related to traffic, and pedestrian crossing speed. These data were analysed from a descriptive and inference statistical point of view seeking to relate the incidence of behaviours according to the different age groups and points, road typology, and type of intersection. Besides, logit models were built as exploratory analysis to predict pedestrian behaviour. The research was carried out in the city of Manizales, Colombia.

After the introduction, the research methodology is described, the main results are presented and discussed, and finally, the main conclusions are presented.

2. Methodology

The research methodology consists of four consecutive stages, which are described below.

Table 1
Brief literature review on human behaviour and road safety.

Authors	UI			VC			Methods					Study Zone					
	P	FW	TW	A	G	Per	O	QS	I	CDA	DS	IT	AP	TC		City and Country	Continent
														HIC	LMIC		
(Shaaban et al., 2018)	X			X	X		X					C	U	X		Doha, Qatar	Asia
(Poó et al., 2018)	X			X	X		X					I	M		X	Ushuaiau, Argentina	Latin-America
(Khatoon et al., 2013)	X			X	X		X					I	U		X	Delhi-India	Asia
(Tom and Granié, 2011)	X				X		X					I	M	X		Paris and Ruan, France	Europe
(Cantillo et al., 2015)	X							X				I	U		X	Bogotá, Colombia	Latin-America
(Pešić et al., 2016)	X			X	X		X					I	M		X	Belgrade, Serbia	Europe
(Alhajyaseen and Iryo-Asano, 2017)	X						X					I	M	X		Nagoya City, Japan	Asia
(Echeverry et al., 2005)	X				X		X	X				All type	M		X	Cali, Colombia	Latin-America
(King et al., 2009)							X					I	M	X		Brisbane, Australia	Oceania
(Sisiopiku and Akin, 2003)	X			X			X	X				C	U	X		Michigan, United States	North-America
(Barrero et al., 2013)	X			X	X		X	X	X			I	M		X	Bogotá, Colombia	Latin-America
(Havard and Willis, 2012)	X			X	X		X	X				C	U	X		Edinburgh, United Kingdom	Europe
(Granié et al., 2013)	X			X	X			X				N.A	N.A	X		France	Europe
(Meneses Falcón et al., 2010)		X	X	X	X			X				N.A	N.A	X		Madrid and Andalucia, Spain	Europe
(Deb et al., 2017)	X			X	X			X				N.A	N.A	X		United States	North-America
(Herrero-Fernández, 2015)	X			X	X			X				N.A	N.A	X		Vizcaya, Spain	Europe
(Moyano, 2002)	X			X	X			X				N.A	N.A		X	Santiago, Chile	Latin-America
(Papadimitriou et al., 2013)	X			X	X			X				N.A	N.A	X		Multiple countries in Europe	Europe
(Riendeau et al., 2018)		X		X		X		X			X	N.A	N.A			No especificado	
(Oviedo-Trespalacios et al., 2019)		X									X	N.A	N.A	X		Australia	Oceania
(Vergel-Tovar et al., 2019)	X	X	X							X		All type	M		X	Bogotá, Colombia	Latin-America
(Hasan et al., 2020)	X			X	X			X				F	M		X	Multiple cities Malasia	Asia
(Oviedo-Trespalacios and Scott-Parker, 2017)	X			X	X			X				F	U		X	Barranquilla, Colombia	Latin-America
(McIlroy et al., 2019)	X							X				N.A	N.A	X	X	Multiple countries	Multiple Continents

2.1. *Study zone and points studied description*

Manizales (Colombia, see Fig. 1) is a medium-sized city with 446,160 inhabitants, 93.79% of whom live in the urban area. It is located in the centre-west of Colombia, at an altitude of 2150 m above sea level, on a steep and rugged topography. In recent years, the municipal administration has made strenuous efforts to reduce the number of road incidents and related fatalities. Since 2012, where 47 fatalities (11.36 per 100 thousand inhabitants) were recorded, there has been an increase to a peak of 56 fatalities (13.04 per 100 thousand inhabitants) in 2017 (Londoño, 2018). Considering the constant growth of fatalities and road incidents, during 2016 and 2017 the municipal administration analysed, together with Universidad Nacional de Colombia, 51 critical points of high crash rates through the execution of Road Safety Audits (Auditorias de Seguridad Vial - ASV). Because of the ASVs, a prioritization order was obtained for the intervention of these points to reduce the number of road incidents (Garzón et al., 2017; Londoño et al., 2017). On the other hand, during the last years, Manizales has been the Colombian city with the highest percentage reduction of fatalities due to road incidents with 8.9% in 2018 and 23.5% in 2019, which corresponds to a fatality rate per 100 thousand inhabitants of 8.85, close to values of high-income countries (ONSV, 2020).

The aforementioned ASVs had an important quantitative component as they studied operational features of vehicle volume and road design to determine the threats and level of risk to road actors, leaving aside the qualitative component of human behaviour, which is a major risk factor in road incidents (King et al., 2009; Shaaban et al., 2018; Sisiopiku and Akin, 2003). Therefore, together with the municipal administration, seven critical points were chosen (see Fig. 1) to study pedestrian behaviour through direct observations. The points selected were initially located near an educational institution of basic and intermediate level. Additionally, some points have land uses with high travel attraction such as parks and leisure (points 1, 2, 6, and 7), health facilities(points 1 and 7), religious and cultural (point 3), and commerce (point 5). On the other hand, the predominant land use in the unsignalized sites is mixed with residential and commercial areas. Fig. 2 shows the pedestrian crossings and the main type of road intersection. Four points are identified on main avenue corridors and one on a collector road, two four-branch road intersections and one "T" type intersection on secondary roads (Table 2) (Alcaldía de Manizales, 2017; Sisiopiku and Akin, 2003).

2.2. *Planning of direct observations*

The observation sheet was designed based on the application of two consecutive sub-phases: bibliographical systematization and operationalization of variables.

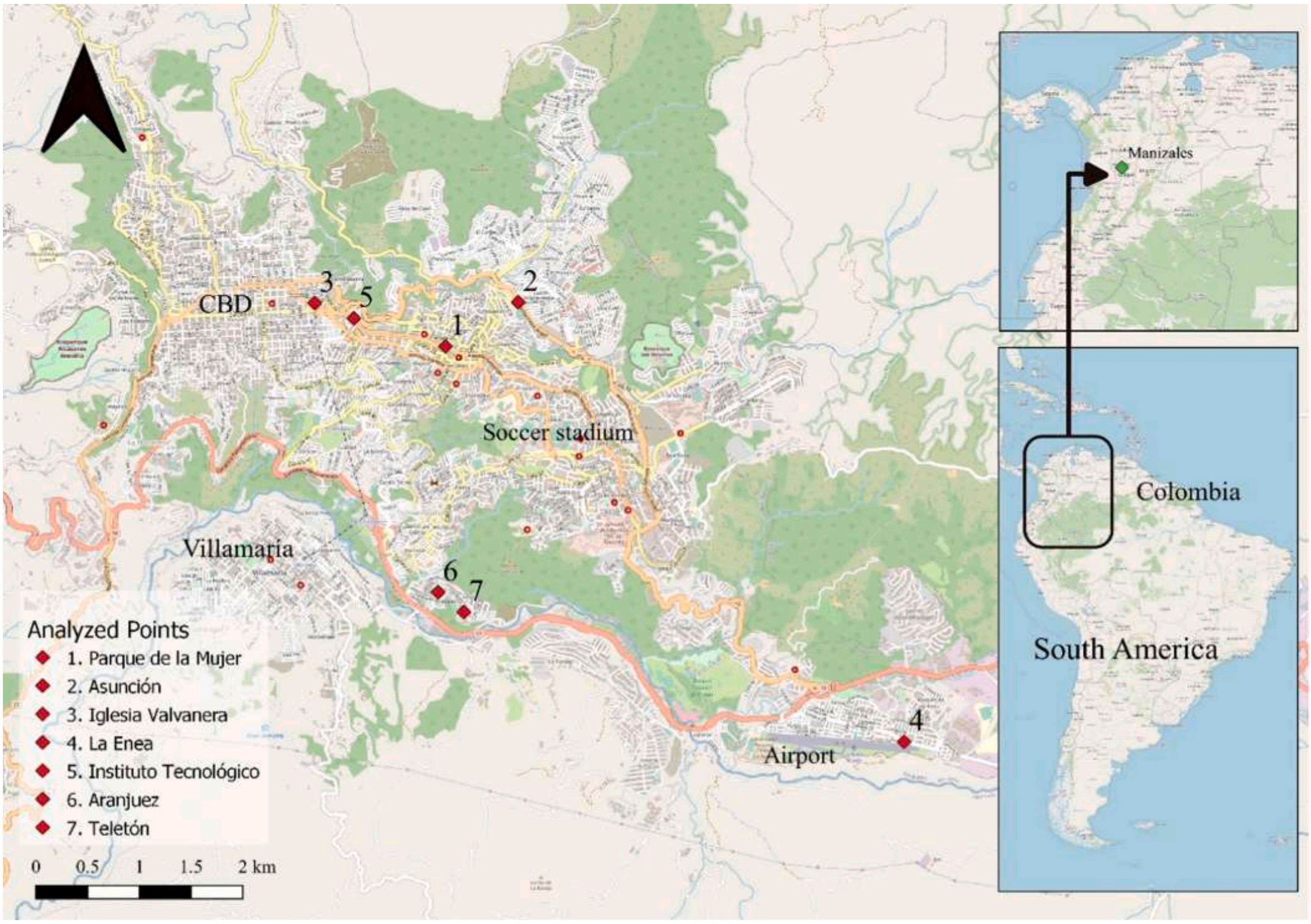

Fig. 1. Manizales urban zone and critical points location.

2.2.1. Bibliographic systematization

A bibliographic search related to road safety was carried out, which was classified according to the research objective, the method used, and the main results. Then, each research was ordered from 1 to 3, where 1 was very similar to the objective and methods to be used in our research and 3 was not related.

2.2.2. Operationalization of variables

In this process, the research question and objectives were taken and transformed from the abstract level to a concrete level to make them measurable through concrete questions. Here, research from the systematization of literature was considered to include questions in the observation sheet or to create new ones if necessary. For the observation sheet, questions from (Sisiopiku and Akin, 2003) and (Deb et al., 2017) research related to pedestrian crossing behaviour were used. Consideration was also given to the creation of new questions that fit the research objective and context. The observation sheet was organized taking into account four domains: i) socio-demographic, ii) environmental/ contextual, iii) cultural, and iv) road safety education; encompassed in 14 variables measured through 128 questions (see Appendix A: Observation sheet).

2.3. Direct observations implementation

Direct observations were made on 7 points, 4 road intersections, and 3 mobility corridors, located on main roads with high or medium vehicular flow. Direct observations were made at each point for 60 min, on two different days of the week, and three different times of the day: morning (6:30–8:30 am), mid-day (11:30 am–12:30 pm), and afternoon (5:30–7:30 pm), which coincide with the hours of highest vehicle volume in the study area (Alcaldía de Manizales, 2017). These observations made it possible to record the different interactions between road actors, mainly risky behaviours and preventive behaviours. The observations were carried out during September 2019 by anthropology professionals trained in road safety.

Direct observations allowed the recording of pedestrians' risky crossing behaviour, their main distractions, traffic-related behaviour at the crossing point, and crossing speed (Fig. 3). Pedestrians were classified into four age groups: i) childrens (0–13 years), ii) young adults (14–26 years), iii) adults (27–59 years), and iv) seniors (>60 years).

Initially, risky pedestrian crossing behaviour was divided into i) pedestrians crossing at designated locations, i.e., compliant pedestrian, ii) pedestrians crossing at non-designated locations, i.e., risky pedestrian, and iii) pedestrians crossing diagonally; the latter two types of pedestrian crossing are considered risky behaviours.

Secondly, the distracters when making a crossing trajectory were classified into i) crossing while carrying heavy baggage, ii) crossing while talking to other pedestrians, iii) crossing while talking on the cell phone, iv) crossing while looking at electronic devices, and v) crossing using headphones.

Thirdly, pedestrians' interaction with traffic (four-wheeler and two-wheeler) is reflected in their crossing behaviour: i) crossing without traffic, i.e., when the road is completely clear of vehicles, ii) crossing between vehicles that are stopped due to congestion, iii) crossing with little vehicle traffic, iv) crossing exposed to a nearby traffic trajectory and v) crossing without looking at traffic.

Finally, pedestrian crossing speed was taken into account, considering the following behaviours: i) walking slowly, ii) walking fast, iii)

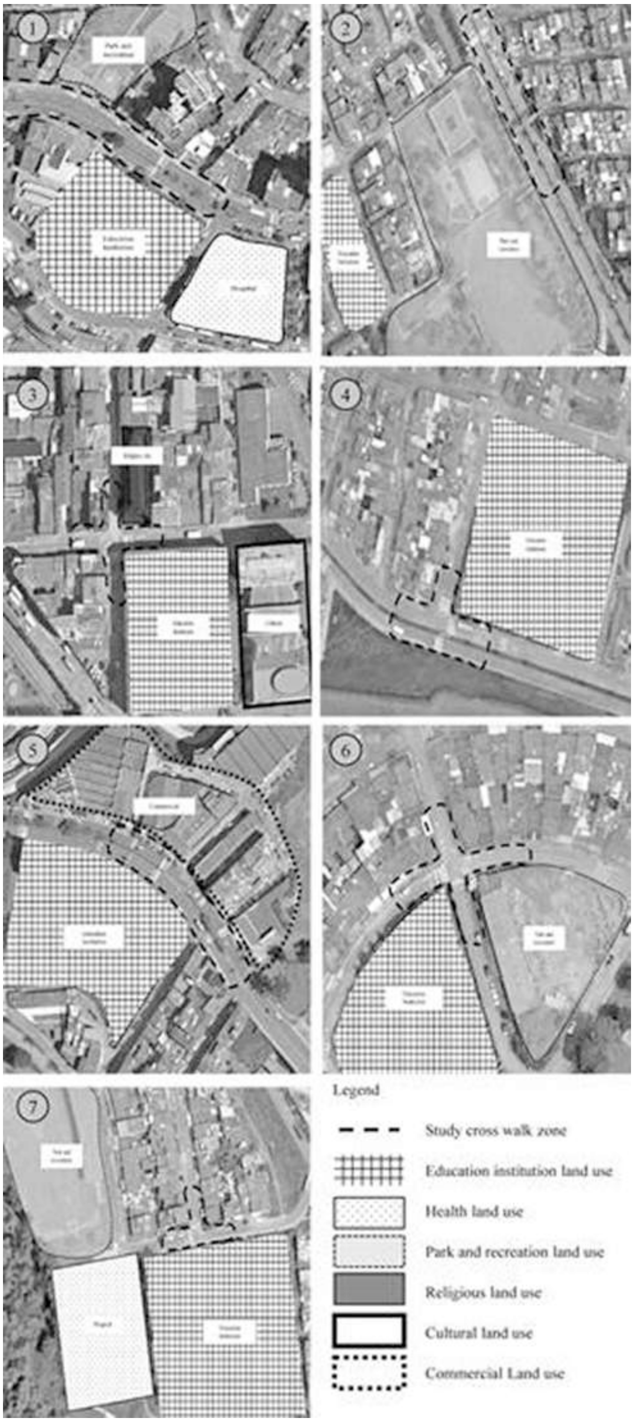

Fig. 2. Analysed critical points with land use and cross walk zones.

Table 2
Road intersections types and network typology per analysed point.

Point	Road intersection type	Network Typology
1	Corridor	Main
2	Corridor	Main
3	Four Leg intersection	Secondary
4	Corridor	Collector
5	Corridor	Main
6	Four Leg intersection	Secondary
7	“T” intersection	Secondary

running, iv) start crossing by walking and finish by running, and v) start crossing by running and finish by walking

2.4. Statistical analysis

The results were analysed considering descriptive and inference statistic, and logistic regression models. To choose the correct statistical analysis, we use the research protocol defined by Flores-Ruiz et al. (2017) where three points are considered, complemented with the exposed by Shankar and Singh (2014). Firstly, the research design is related to the number of groups and if they are related or independent. The research studied data collected on seven points with different infrastructure and typology characteristics and pedestrians classified per age group. Furthermore, the number of measurements of outcome variables was considered; in our research, direct observations were made during a specific period. Moreover, the nature of the variables is qualitative. Consequently, an inference analysis was performed using chi-squared (χ^2) test for independence with a p-value of 0.05 as a threshold and different limits for Cramer’s V (φc) to evaluate the variable associations ([0–0.2] no association, [0.2–0.6] moderate association and [0.6–1] strong association) (Flores-Ruiz et al., 2017; Shankar and Singh, 2014).

Descriptive and inference statistic analysis allowed us to built logit regression models to check the influence of independent variables such as age-group, the point, network typology and road intersection type on safe or unsafe pedestrian behaviour. Models were constructed to help exploratory data analysis of pedestrian behaviour.

3. Results

3.1. Descriptive analysis

A total of 33,561 pedestrians were observed during the study, Fig. 4 shows a summary of the observations categorized using the observed behaviour, point analysed and age group. Crossing behaviour was the most registered (13,587) while pedestrian distractions the least (1652). On the other hand, Parque de la Mujer registered the most pedestrian’s observations with 12,494 followed by Aranjuez with 7151. La Enea was the point where the least pedestrians’ observations happened (1480). Considering the age group, young adult and adults had a similar result with 11,878 and 11,905 observations. Child (5743) and Senior (4035) had less than fifty per cent of the observations of young adults and adults.

3.2. Pedestrian crossing behaviour

13,587 pedestrians were analysed in street-crossing behaviour, of which 65.19% were compliant pedestrians (Table 3). When analysing the results by age group, the independence of pedestrian crossing behaviour was tested using the chi-square test (χ^2 (6, n = 13587) = 313.76, $p < 0.001$, φc = 0.107), finding that children are the ones with more risky behaviour (30.33%) and older adults the ones who use more diagonal trajectories when crossing the street (23.12%).

When crossing the street, pedestrian behaviour is highly related to the points analysed (χ^2 (12, n = 13587) = 2707.29, p = 0, φc = 0.316) since at points such as Parque de la Mujer, La Asunción, and Instituto Tecnológico more than 70% of pedestrian compliance were observed, while the rest of the points are below 55% (Table 4). On the other hand, the independence of behaviour by age group was analysed at each point, finding that, at the points of Instituto Tecnológico and La Asunción, both related to main routes of high vehicular speed, the behaviours between the age groups are similar, instead at the rest of the points their behaviours when crossing are independent.

On the other hand, network typology (χ^2 (4, n = 13587) = 2266.61, p = 0, φc = 0.288) and intersection type (χ^2 (2, n = 13587) = 1989.25, p = 0, φc = 0.383) also showed independent behaviour when analysing

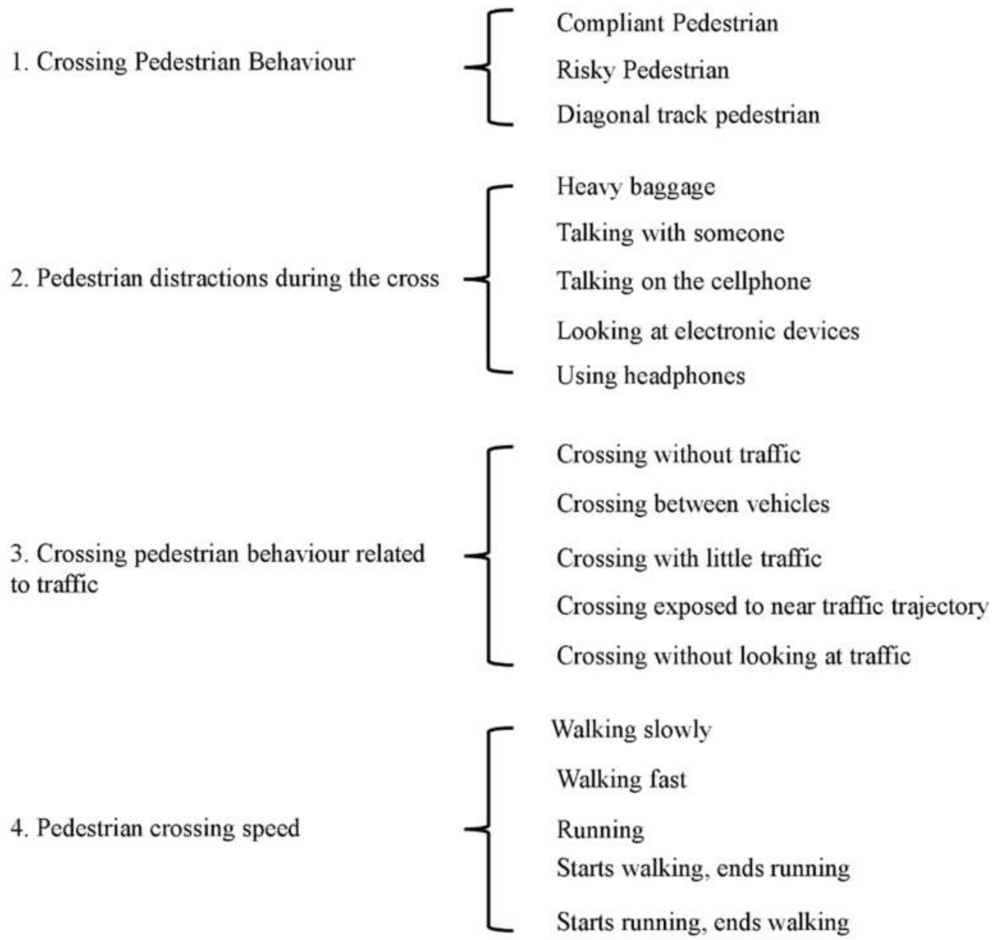

Fig. 3. Analysed behaviours in the study.

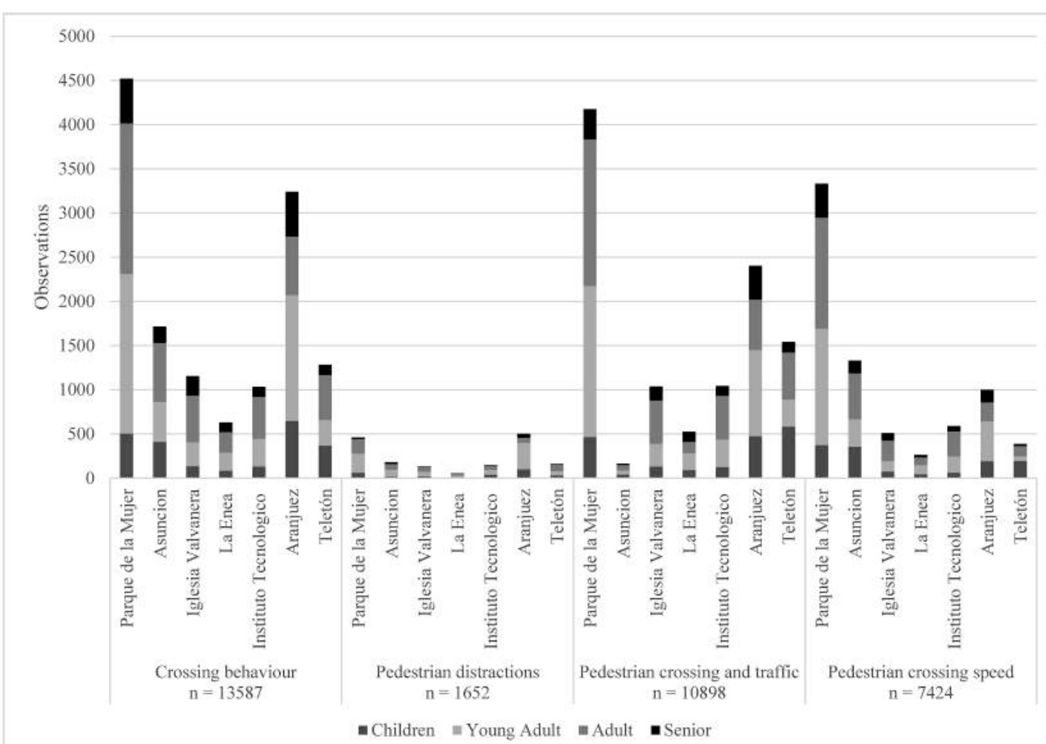

Fig. 4. Summary of pedestrian observations per analysed point and age-group.

Table 3
Pedestrian crossing behaviour.

User	Compliant Pedestrian	Risky Pedestrian	Diagonal Track	Total
Children	1337 (58.69%)	691 (30.33%)	250 (10.97%)	2278
Young adult	3323 (69.88%)	914 (19.22%)	518 (10.89%)	4755
Adult	3195 (66.82%)	939 (19.64%)	647 (13.53%)	4781
Senior	1002 (56.51%)	361 (20.36 %)	410 (23.12%)	1773
Total	8857 (65.19%)	2905 (21.38%)	1825 (13.43%)	13,587

Table 4
Pedestrian crossing behaviour per analysed point, network typology and road intersection type.

	Compliant Pedestrian	Risky Pedestrian	Diagonal Track
Point			
Parque de la Mujer *	3799 (84.01%)	464 (10.26%)	259 (5.72%)
Asuncion	1515 (88.23%)	87 (5.07%)	115 (6.70%)
Iglesia Valvanera **	645 (55.80%)	395 (34.17%)	116 (10.03%)
La Enea **	321 (50.71%)	206 (32.54%)	106 (16.75%)
Instituto Tecnológico	739 (71.47%)	150 (14.51%)	145 (14.02%)
Aranjuez **	1506 (46.47%)	1023 (31.56%)	712 (21.97%)
Teletón **	332 (55.80%)	580 (45.17%)	372 (28.97%)
Network Typology			
Main **	6053 (83.22%)	701 (9.4%)	519 (7.14%)
Secondary **	2483 (43.71%)	1998 (35.17%)	1200 (21.12%)
Collector **	321 (50.71%)	206 (32.54%)	106 (16.75%)
Road intersection type			
Corridor **	6374 (80.62%)	907 (11.47%)	625 (7.91%)
Intersection	2483 (43.71%)	1998 (35.17%)	1200 (21.12%)

Age group evaluation: * p-value < 0.05, ** p-value < 0.001.

pedestrian crossing behaviour. For example, pedestrian behaviour is much more appropriate on main roads (83.22%) compared to secondary roads (43.71%) or collector roads (50.71%). However, more appropriate pedestrian behaviour was observed on road corridors (80.62%), while on road intersections there are more recurrent risky behaviours: crossing the road at non-designated places (35.17%) and the use of diagonal paths (21.12%). When reviewing the independence between age groups according to the type of intersection and type of road network, we found it between these recorded behaviours (Table 4).

3.3. Pedestrians and their distractions while crossing

Table 5 shows a summary of the observations related to the main distractions of pedestrians when crossing the road; crossing while talking to another pedestrian (29.66%) and using headphones (27.06%) were found to be recurrent risky behaviours. When studying distracting behaviours according to age groups, we found independence (χ^2 (12, n = 1652) = 277.04, p < 0.001, φc = 0.236). Thus, infants and older adults are more likely to be distracted by talking to other pedestrians (44.03% and 39.29%, respectively), young people using headphones (30.41%) and adults talking on their mobile phones (30.24%).

Performing a disaggregated analysis of these distracting behaviours when crossing (see Table 6), it is found that they are independent of the location of the points examined (χ^2 (24, n = 1652) = 280.78, p < 0.001, φc = 0.206), network typology (χ^2 (8, n = 1652) = 141.15, p < 0.001, φc = 0.206), and intersection type (χ^2 (4, n = 1652) = 11.57, p < 0.001, φc = 0.259). For example, while talking to other pedestrians is the most frequent distracting behaviour at the Aranjuez point (48.71%), using headphones is the most frequent at points such as La Asunción (37.70%), La Enea (42.11%), Parque de la Mujer (31.24%), and Teletón (34.55%). Similarly, according to network typology, on collector and main roads, using headphones is a frequently observed behaviour among pedestrians, while on secondary roads, pedestrians often pass by talking to others. At T-junctions or four-branch intersections, pedestrians tend to cross while talking to others, while in corridors, they cross using headphones.

3.4. Pedestrians and their relationship with traffic when crossing

Table 7 shows the percentage distribution of pedestrian behaviour observations and their relationship with motorized road actors when crossing, in which crossing with little traffic (36.03%), safe behaviour, or exposure to a close vehicle path (29.54%), a risky behaviour. When analysing the behaviours according to age group, we found independence between them (χ^2 (12, n = 10898) = 677.31, p < 0.001, φc = 0.143). For example, young people and adults are more exposed to close vehicle trajectory than infants, who cross with little traffic, while older adults tend to wait until the crossing is completely clear.

These behaviours were analysed taking into account the points studied location (χ^2 (24, n = 10898) = 4647.24, p < 0.001, φc = 0.327), depending on the typology of the track (χ^2 (8, n = 10898) = 1199.97, p < 0.001, φc = 0.235), and depending on the type of road intersection (χ^2 (4, n = 10898) = 739.22, p < 0.001, φc = 0.260) (see Table 8). More than half of pedestrians were found to cross in Parque de la Mujer with close vehicle trajectory. A clearly risky behaviour. On the other hand, in places such as La Enea, Teletón, and La Asunción, pedestrian crossings is predominant when there is little or no vehicular traffic. Related to the typology of the road network, the most common behaviour in main roads is quite risky, crossing exposed to nearby vehicle trajectories (40.89%), while secondary and collecting roads are recorded more defensive behaviours. That is, waiting for the road to be cleared of vehicular traffic. Finally, considering the type of road intersection records that, on corridors, pedestrians are more exposed to nearby vehicle trajectories (37.95%), instead of over intersections pedestrians cross more when there is little or no traffic. In assessing the independence of these behaviours according to the age group, we find that points, track typology, and type of intersection generate independence, in other words, pedestrians according to their age group have particular behaviours. For instance, older adults expect much more than other age groups to have traffic completely clear to cross the street (see Table 8).

3.5. Pedestrian crossing speed

In this case, in general, 42.59% of pedestrians cross the street walking slowly, while about 13% cross the street running or end up running after starting to walk (Table 9). However, when analysing these behaviours according to age group, we find independence between them (χ^2 (12, n = 7424) = 236.30, p < 0.001, φc = 0.103), as crossing speed is

Table 5
Pedestrian distractions during the cross.

User	Heavy baggage	Talking with someone	Talking on the cell phone	Looking electronic devices	Using headphones	Total
Children	41 (15.30%)	118 (44.03%)	18 (6.72%)	30 (16.73%)	61 (22.76%)	268
young adult	108 (13.92%)	212 (27.32%)	101 (13.02%)	119 (15.34%)	236 (30.41%)	776
Adult	0 (0%)	116 (23.39%)	150 (30.24%)	83 (16.73%)	147 (29.64%)	496
Senior	42 (37.50%)	44 (39.29%)	19 (16.96%)	4 (3.57%)	3 (2.68%)	112
Total	191 (11.56%)	490 (29.66%)	288 (17.43%)	236 (14.29%)	447 (27.06%)	1652

Table 6
Pedestrian distractions during the cross per analysed point, network typology and road intersection type.

	Heavy baggage	Talking with someone	Talking on the cellphone	Looking electronic devices	Using headphones
Point					
Parque de la Mujer **	44 (9.54%)	90 (19.52%)	128 (27.77%)	55 (11.93%)	144 (31.24%)
Asunción **	28 (15.3%)	28 (15.3%)	37 (20.22%)	21 (11.48%)	69 (37.7%)
Iglesia Valvanera **	13 (9.7%)	31 (23.13%)	37 (27.61%)	21 (15.67%)	32 (23.88%)
La Enea **	3 (5.26%)	7 (12.28%)	4 (7.02%)	19 (33.33%)	24 (42.11%)
Instituto Tecnológico **	12 (8.05%)	44 (29.53%)	30 (20.13%)	27 (18.12%)	36 (24.16%)
Aranjuez **	86 (17.1%)	21 (4.17%)	245 (48.71%)	66 (13.12%)	85 (16.9%)
Teletón **	5 (3.03%)	45 (27.27%)	31 (18.79%)	27 (16.36%)	57 (34.55%)
Network Typology					
Main **	84 (10.59%)	162 (20.43%)	89 (11.1%)	114 (14.21%)	174 (21.7%)
Secondary **	104 (12.97%)	321 (40.02%)	195 (24.59%)	103 (12.99%)	249 (31.4%)
Collector **	3 (5.26%)	7 (12.28%)	4 (7.02%)	19 (33.33%)	24 (42.11%)
Road intersection type					
Corridor **	87 (10.24%)	169 (19.88%)	199 (23.41%)	122 (14.35%)	273 (32.12%)
Intersection **	104 (12.97%)	321 (40.02%)	89 (11.1%)	114 (14.21%)	174 (21.7%)

Age group evaluation: * p-value < 0.05, ** p-value < 0.001.

Table 7
Crossing pedestrian behaviour related to traffic.

User	Without traffic	Between vehicles	Little traffic	Exposed to near traffic trajectory	Without looking at traffic	Total
Children	554 (29.05%)	183 (9.6%)	715 (37.49%)	390 (20.45%)	65 (3.41%)	1907
Young Adult	701 (18.45%)	408 (10.74%)	1484 (39.05%)	1187 (31.24%)	20 (0.53%)	3800
Adult	733 (18.65%)	486 (12.36%)	1357 (34.52%)	1354 (34.44%)	1 (0.03%)	3931
Senior	528 (41.9%)	73 (5.79%)	371 (29.44%)	288 (22.86%)	0 (0.0%)	1260
Total	2516 (23,09%)	1150 (10,55%)	3927 (36,03%)	3219 (29,54%)	86 (0,79%)	10,898

Table 8
Crossing pedestrian behaviour related to traffic per analysed point, network typology and road intersection type.

	Without traffic	Between vehicles	Little traffic	Exposed to near traffic trajectory	Without looking at traffic
Point					
Parque de la Mujer **	330 (7.9%)	665 (15.93%)	995 (23.83%)	2184 (52.31%)	1 (0.02%)
Asuncion *	80 (48.78%)	0 (0.0%)	75 (45.73%)	0 (0.0%)	9 (5.49%)
Iglesia Valvanera *	88 (8.47%)	233 (22.43%)	294 (28.3%)	423 (40.71%)	1 (0.1%)
La Enea **	220 (41.83%)	0 (0.0%)	264 (50.19%)	41 (7.79%)	1 (0.19%)
Instituto Tecnologico *	258 (24.67%)	0 (0.0%)	770 (73.61%)	18 (1.72%)	0 (0.0%)
Aranjuez **	786 (32.7%)	0 (0.0%)	1275 (53.04%)	322 (13.39%)	21 (0.87%)
Teletón **	754 (48.83%)	252 (16.32%)	254 (16.45%)	231 (14.96%)	53 (3.43%)
Network Typology					
Main **	668 (12.4%)	665 (12.35%)	1840 (34.17%)	2202 (40.89%)	10 (0.19%)
Secondary **	1628 (32.64%)	485 (9.73%)	1823 (36.56%)	976 (19.57%)	75 (1.5%)
Collector **	220 (41.83%)	0 (0.0%)	264 (50.19%)	41 (7.79%)	1 (0.19%)
Road intersection type					
Corridor **	888 (15.02%)	665 (11.25%)	2104 (35.59%)	2243 (37.95%)	11 (0.19%)
Intersection **	1628 (32.64%)	485 (9.73%)	1823 (36.56%)	976 (19.57%)	75 (1.5%)

Age group evaluation: * p-value < 0.05, ** p-value < 0.001.

Table 9
Pedestrian Crossing Speed.

User	Walking slowly	Walking fast	Running	Starts walking ends running	Starts running ends walking	Total
Children	607 (47.05%)	281 (21.78%)	253 (19.61%)	103 (7.98%)	46 (3.57%)	1290
Young adult	1034 (40.6%)	820 (32.19%)	246 (9.66%)	335 (13.15%)	112 (4.4%)	2547
Adult	1042 (38.64%)	852 (31.59%)	346 (12.83%)	361 (13.39%)	96 (3.56%)	2697
Senior	479 (53.82%)	170 (19.1%)	84 (9.44%)	94 (10.56%)	63 (7.08%)	890
Total	3162 (42.59%)	2123 (28.6%)	929 (12.51%)	893 (12.03%)	317 (4.27%)	7424

directly related to age group. For example, more than half of older adults cross slowly, while one-third of young people and adults cross quickly. Such behaviours may be related to physical abilities in older adults and the young and adult age groups' social characteristics.

It was also assessed whether the crossing speed is independent of the points studied location, the type of road, or the type of intersection (see Table 10). Concerning the points studied location, the pedestrian crossing speed is independent ($\chi2$ (24, n = 7424) = 1262.11, p < 0.001, φc = 0.206). So that at some points, such as La Enea and Instituto Tecnológico, a high percentage of pedestrians crossing at a fast pace was observed. Besides, at the latter point, the highest percentage of pedestrians crossing at a fast pace was observed, with 23.05%. On the other

Table 10
Pedestrian crossing speed per analysed point, network typology and road intersection type.

	Walking slowly	Walking fast	Running	Starts walking ends running	Starts running ends walking
Point					
Parque de la Mujer **	1150 (34.47%)	1181 (35.4%)	365 (10.94%)	521 (15.62%)	119 (3.57%)
Asuncion *	713 (53.53%)	201 (15.09%)	171 (12.84%)	165 (12.39%)	82 (6.16%)
Iglesia Valvanera *	179 (35.03%)	147 (28.77%)	54 (10.57%)	99 (19.37%)	32 (6.26%)
La Enea	90 (34.09%)	137 (51.89%)	30 (11.36%)	3 (1.14%)	4 (1.52%)
Instituto Tecnologico	59 (10.0%)	228 (38.64%)	136 (23.05%)	98 (16.61%)	69 (11.69%)
Aranjuez **	727 (72.48%)	168 (16.75%)	90 (8.97%)	7 (0.7%)	11 (1.1%)
Teletón **	244 (62.89%)	61 (15.72%)	83 (21.39%)	0 (0.0%)	0 (0.0%)
Network Typology					
Main **	1922 (36.55%)	1610 (30.62%)	672 (12.78%)	784 (14.91%)	270 (5.14%)
Secondary **	1150 (60.46%)	376 (19.77%)	227 (11.93%)	106 (5.57%)	43 (2.26%)
Collector	90 (34.09%)	137 (51.89%)	30 (11.36%)	3 (1.14%)	4 (1.52%)
Road intersection type					
Corridor **	2012 (36.44%)	1747 (31.64%)	702 (12.71%)	787 (14.25%)	274 (4.96%)
Intersection **	1150 (60.46%)	376 (19.77%)	227 (11.93%)	106 (5.57%)	43 (2.26%)

Age group evaluation: * p-value < 0.05, ** p-value < 0.001.

hand, independence by age group was studied, and it was found that in La Enea and the Instituto Tecnológico there is a similar behaviour between the groups (see Table 10).

Pedestrian crossing speed behaviour is also independent of network typology (χ^2 (8, n = 7424) = 462.79, p < 0.001, φc = 0.177) and type of intersection (χ^2 (4, n = 7424) = 374.88, p < 0.001, φc = 0.225). According to the type of intersection, secondary roads have the highest percentage of pedestrians who cross slowly (60.46%), while on collector roads, more than half of the pedestrians have to walk fast to cross. Also, on primary roads, there is a high percentage of pedestrians who have to finish their crossing by running (14.25%). These results are similar when analysed by type of intersection.

3.6. Safe/Unsafe pedestrian behaviour models

To study the influence of the variables we built three logit regression models. Models were constructed as an exploratory analysis of pedestrian behaviour. We defined dichotomic categories (safe/unsafe pedestrian behaviour) grouping the variables of crossing behaviour, relation with traffic and crossing speed observations. Pedestrian distractions were not grouped because all their observations are considered as unsafe. The models' considerations are described below:

- Crossing behaviour: safe behaviour composes by compliant pedestrian and unsafe behaviour compose by risky pedestrians and diagonal track pedestrians.
- Relation with traffic: safe behaviour is related to cross with little traffic or without traffic. Unsafe behaviour is compound by cross between vehicles, exposed to near traffic trajectory or without looking at traffic.
- Crossing speed: In this case, walking slowly is related to safe cross behaviour, while cross walking fast, running, starts walking ends running and starts running ends walking are classified as unsafe.

As independent variables, age-group, point, network typology and road intersection types were used. The model was built using statsmodels library of Python 3.7 (Seabold and Perktold, 2010). Table 11 presents the main results of the models. In the crossing behaviour model, all the variables are significant considering the p-value, lower than 0.05. Age group and network typology influence a safe behaviour meanwhile the point and the road intersection type influence an unsafe crossing behaviour. On the other hand, relation with traffic model result in pseudo R^2 lower than obtained by crossing behaviour model. In this case, all the variables are significant except by road intersection type with p-value upper than 0.05. Similarly to crossing behaviour model, age-group and network typology influence an unsafe pedestrian behaviour. Finally, crossing speed model result in significance for all categories except by age-group. Network typology and road intersection type boost an unsafe behaviour within pedestrians.

4. Discussion

Research related to pedestrian behaviour through direct observations has been conducted outside Colombia (King et al., 2009; Poó et al., 2018; Shaaban et al., 2018) and although some research has taken into account this method (Barrero et al., 2013; Echeverry et al., 2005), has not been the main research tool, limiting the final results. For example, this research found that, concerning pedestrian behaviour across the street, 65.19% used designated and marked steps, below that reported in other research conducted in high-income countries, where the percentage reaches values of up to 79% (King et al., 2009), 86.5% (Tom and Granié, 2011). However, there are no research reports in Colombia to compare or validate these results. It is also necessary to take into account the large cultural difference, availability of infrastructure, and road safety education, when compared with other countries, as these variables, could create a significant bias when analysing pedestrian behaviour.

On the other hand, 23.12% of older pedestrians were found to cross using diagonal trajectories, much higher than other age groups and more than double that reported in related research (8,2% of diagonal

Table 11
Logit models' result.

	Crossing behaviour		Relation with traffic		Crossing speed	
	n	13,587	n	10,898	n	7424
	pseudo R^2	0.1347	pseudo R^2	0.0884	pseudo R^2	0.0607
	Coef	P-value	Coef	P-value	Coef	P-value
Age-group	−0,0489	0,001	−0,1181	0,000	0,0211	0,057
Point	0,0192	0,000	0,3266	0,000	0,2327	0,000
Network Typology	−0,9544	0,000	−0,9013	0,000	−0,1966	0,001
Road Intersection Type	2,1008	0,000	0,0919	0,260	−0,7197	0,000

crossings in King et al., 2009). In contrast, infants were the users who made the most unsignalized crossings (30.33%), a group that has been excluded from other research given the low flow of infants at the selected locations (Echeverry et al., 2005). In our case, the points were carefully chosen so that infants flows were representative since understanding their pedestrian behaviour at an early age can help in the construction of public intervention policies to improve road safety in the long term through educational processes that promote appropriate behavioural changes in the new generations of productive adults.

In this study, distracted pedestrians were categorized according to common behaviours such as crossing while carrying heavy baggage, talking to other pedestrians, talking on a mobile phone, looking at electronic devices, and using headphones (Zhuang and Wu, 2011). Overall, talking to other pedestrians remains the most frequent distraction compared to other research (Poó et al., 2018). However, behaviours related to the use of electronic devices have grown tremendously, especially the use of headphones, which can isolate noise from vehicles coming closer (Pešić et al., 2016). On the other hand, this type of variable has not been considered in previous research in Colombia or Latin America, so it has not been possible to compare results.

This research results showed that 36.03% of pedestrians wait for a sufficient gap between motor vehicles and the crossing point, close to the 40% reported by Shaaban et al. (2018). On the other hand, 23.09% of pedestrians wait for the street to be completely clear, as it is safer for them, especially among infants and older adults. Young people and adults take much more risk when crossing the road with close vehicle paths; inappropriate behaviour has given the high risk of accidents, especially at points where speeds have not been fully regulated to reduce the likelihood of fatal vehicle–pedestrian crashes (Hussain et al., 2019; Rosén and Sander, 2009). It is important to note that crossing speed was assessed subjectively and is highly correlated with the age group and locations analysed.

According to age group, seniors take more risk when crossing the street through unappointed areas or diagonally. Additionally, they cross the street slowly and carrying heavy luggage or talking to someone. However, they are cautious, as they mostly cross when the road is completely clear. A rather similar situation was experienced in infants, as these are the second most risky age group when crossing the street. They also use unsignalized areas, usually cross talking to someone and cross slowly when the vehicle volume is low or zero; looking at the above, these two age groups need greater educational reinforcement in terms of road safety, both normatively and in terms of consequences that lead to not being careful in their interaction with motor vehicles. On the other hand, young people are the age group who most frequently used designated or signposted areas quickly. However, they do not wait for the street to be clear, as they mostly face motor traffic and additionally using headphones. Concerning the adult age group, they mostly cross through designated or signposted areas and cross fast. However, they cross interacting with the motors and are the ones that cross most frequently using some electronic device that causes distraction. That is, the latter two age groups behave similarly, as do infants and seniors; a situation that is understood to be logical, but which demonstrates the need to reinforce citizen culture in terms of road safety and understanding of citizen norms and duties when engaging in mobility as an actor.

Models to explore the relations between independent variables (point analysed, age group, road intersection type and network typology) and safe/unsafe pedestrian behaviours showed valuable insights for future research related to the prediction of pedestrian behaviour like Pešić et al. (2016) did.

5. Conclusions

This research contributes to the literature on road safety and pedestrian behaviour in Latin American cities, with the understanding that behaviours are highly influenced by multiple variables, which may be independent by geographic area. In this case, multiple locations with different infrastructure conditions were studied, which allowed us to find statistical independence between observed behaviours and age group. These independencies suggest that a more in-depth analysis should be carried out by grouping the different categories and variables studied to create successful interventions.

Behaviours must be analysed particularly for each point, road typology, and type of intersection given the statistical independence of their distributions, a situation that has rarely been studied in the literature related to pedestrian behaviour, thus in this research, it was found that the human behaviour analysis can fall into a Simpson's paradox. This Simpson's paradox occurs when the trend presented by a group of data disappears when they are combined or grouped together. In our case, the first descriptive data show certain trends, which are reversed when the data are grouped by age group.

On the other hand, the study has limitans related to the method of the direct observations because they were conducted by anthropologists in specific periods of day and week. This could conduct to bias about subjective interpretations of pedestrian behaviours and constraints of second verifications, possible when video recordings are used. Furthermore, videos could capture behaviours and risky situations better, that allow for groupings between the different points analysed in this article. Videos would allow for a more in-depth behavioural analysis.

Future research could be complemented through traffic-related variables, i.e. vehicle volumes and vehicle speed. By relating these variables to pedestrian behaviours, it is possible to determine the reasons for some behaviours and create solutions to provide greater safety for the most vulnerable actor on the roads, the pedestrian. Moreover, video recordings will allow more in-depth analysis and the implementation of software to capture users' risky behaviours.

This analysis focused on the pedestrian's behaviour as they are one of the most vulnerable groups worldwide and the second most vulnerable in Colombia. However, future research should be conducted to analyse the behaviour of motorized users, especially motorcycles, as they are the most vulnerable in Colombia. Furthermore, complementing the analysis with environmental variables, a prediction model could be trained for pedestrian behaviour (safe or unsafe), using the logit model conducted in this research as direction.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgements

The researchers would like to thank Universidad de Caldas and Universidad Nacional de Colombia, Manizales, for funding project code 42190 "DESARROLLO TECNOLÓGICO BASADO EN LA METODOLOGÍA PROPUESTA PARA AUDITORIAS EN SEGURIDAD VIAL CON ENFOQUE EN EL COMPORTAMIENTO HUMANO Y LA EDUCACIÓN DE LOS ACTORES VIALES". Also, to the anthropology students Jeerson Alberto Pacheco Carmona and Cristy Yuliet Patiño Ospina for their help in making observations at the designated points.

Appendix A. Supplementary material

Supplementary data to this article can be found online at https://doi.org/10.1016/j.ssci.2021.105418.

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