Oliveira *et al.*
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Insights into critical urban pedestrian dynamics: an observational study spotlighting a small sample of blind pedestrians and electric vehicles

Anna Beatriz Espíndola de Oliveira[1*], Ana Maria César Bastos Silva[1] and Anabela Salgueiro Narciso Ribeiro[1]

Abstract

Observational studies, whether conducted on-site or through simulation, are practical options for investigating and comprehending pedestrian behaviour and validating the findings of similar studies that have already taken place on the same subject. Although they present difficulties in demographic characterisation and personal context, observation represents the adoption of actual behaviour, highlighting the different scenarios, contexts and characteristics of the environment and infrastructure in urban areas. However, with the growth in simulators, surveys, and data protection issues in Europe, field observation is less considered, and several studies have been left aside. Based on observation, this study answers behavioural and demographic questions, namely age and gender, using the data of six pedestrian crossings in Coimbra, Portugal. This experience occurred on different days of the week (the week before lockdown), registering blind (and non-blind) pedestrians' behaviour facing the electric vehicle in 6 crosswalks, 30 min in each crosswalk, morning or afternoon, with favourable weather conditions outside peak hours In total 180 (30*6) minutes were filmed and evaluated. The relationships between responsibility (when one pedestrian is guided by another) and group action in decision-making and crossing behaviour were also investigated. Another relevant aspect studied was the relationship between pedestrians and electric vehicles in different contexts. During the research, an electric vehicle was inserted in the observational experience, circulating in the streets to observe the pedestrians' reaction to the absence of noise. In this context, blind pedestrians were invited to perform crossings in these areas and identify the presence of the electric vehicle, to identify some differences in the behaviour of blind pedestrians and non-blind pedestrians. The results indicate that blind pedestrians tend to be more cautious than non-blind pedestrians, that younger and elderly pedestrians tend to have more dangerous and less calculated behaviours than other road users and that the differences are more perceptible in age than gender. It should be noted that when in a group, especially adolescents, they commit more traffic errors. Furthermore, regarding the absence of noise associated with the electric vehicle, in moments of pedestrian distraction, if the driver is not attentive, there is an increase in the risk of accidents.

Keywords Pedestrian, Pedestrian behaviour, Pedestrian crossing behaviour, Blind pedestrian, Electric Vehicles, Blind pedestrian crossing behaviour, US SDG 3, US SDG 11

*Correspondence:
Anna Beatriz Espíndola de Oliveira
anna.oliveira@student.uc.pt
Full list of author information is available at the end of the article

1 Introduction

Observational studies collect naturalistic data in environments where the behaviour of interest to road users occurs [1]. They represent a practical approach for studying and understanding pedestrian behaviour, particularly in cases where road users are not informed in advance of their participation in a research project. This methodology permits the observation of situational behaviours and processes that contribute to unsafe traffic events [2].

While demographic characterization and personal context assessment present challenges, observation provides insight into real behaviours, elucidating diverse scenarios, contexts, and environmental infrastructure characteristics in urban settings. Numerous studies underscore the significance of scrutinizing road user behaviour, as it constitutes a contributing factor in 94% of all accidents, while the environment and vehicles are partially responsible for 18% and 8% of all accidents, respectively [3–5].

According to [6], research methodologies for evaluating traffic safety fall into experimental and observational categories. In experimental research, traffic conditions can be manipulated to provoke events of interest, such as in simulations, or participants can be questioned about their responses in specific situations, as done in interviews. On the other hand, observational research relies on behaviours exhibited by users or test subjects in real-world environments. However, due to the proliferation of simulators, surveys, and data protection concerns in Europe, field observation has become less common, leading to the decline of many studies.

As stated by [2], observational studies lack control over the traffic situations participants encounter, necessitating various methodologies for behaviour observation. Naturalistic driving techniques involve using instrumented vehicles to gather detailed behavioural data from drivers, although participants are typically aware that they are part of a research experiment [7].

It is important to note that natural environments—in which road users are unaware that they are being observed- help mitigate bias caused by behavioural adaptation effects (i.e., changes in behaviour when individuals know they are being watched). This approach also enhances the likelihood of capturing a comprehensive range of risky and aggressive driving behaviours [6]. While it cannot be guaranteed that road users passing the observation site will remain unaware that their behaviour is being monitored, it is improbable that they will have sufficient time to alter their behaviour once observation equipment (e.g., human observers or cameras) has been detected [2].

Furthermore, behavioural observation studies encompass the behaviour of all road users passing the observation site, whereas naturalistic driving studies continuously observe specific participants. A unique type of behavioural observation study is traffic conflict observation, which specifically aims to assess traffic safety by estimating the expected number of accidents [8].

In this article, a behavioural observation study conducted at six different pedestrian crossings in the city of Coimbra, Portugal, was discussed, where road users were not informed about their participation in the project. Each crossing presented varying road characteristics, including factors such as the number of lanes, directions, presence of a centre divider, or proximity to a roundabout. Additionally, the interplay between responsibility (when one pedestrian is guided by another), group decision-making and crossing behaviour was explored.

Another pertinent aspect of this study was the examination of the interactions between pedestrians and electric vehicles in different contexts. Throughout the research, an electric vehicle was introduced into the observational setting, silently navigating the streets to observe pedestrians' reactions in the absence of noise. Subsequently, unique observations of the behaviour of blind pedestrians were conducted. These pedestrians were recruited during an ACAPO information session (the Portuguese Association of the Blind and Amblyopic), as it is not easy to find a spontaneous sample of blind pedestrians in the urban environment. The blind pedestrians were invited to cross in an urban environment at non-signalised pedestrian crossings and to identify the electric vehicle. These observations enabled us to discern potential differences in their behaviour compared to their non-blind counterparts.

According to a literature review based on a search in the Web of Science database using the keywords "electric vehicles" and "blind pedestrians", 50 articles were found. Of these, 36 were excluded in an initial analysis as they were related to issues concerning the mechanical aspects of the electric vehicles, the lack of noise related to electric mobility, the addition of Acoustic Vehicle Alerting Systems (AVAS), electric micro-mobility, autonomous devices for blind pedestrians or pedestrian behaviour in general rather than the behaviour of blind pedestrians. After this stage, 14 articles remained, but those unrelated to field surveys were not considered further. Of the remaining five articles, which involved the interaction of blind pedestrians and electric vehicles, in two, the pedestrians were in a stationary position [23, 24], and one study, conducted by Fleury et al. [9] did not involve blind pedestrians but rather blindfolded pedestrians. The study by Emerson et al. [10] involved fundamental interactions between blind pedestrians and electric vehicles; however, these interactions did not occur in urban traffic but in controlled environments. Finally, a study conducted in the United States by Kim et al. [11], like this

study, investigated the time and performance of critical street crossing decisions by visually impaired pedestrians at selected intersections.

Unlike the present study, in the one conducted by Kim et al. [11], visually impaired pedestrians and a sighted experimenter made street-crossing decisions by indicating when they would begin crossing using remote controls. The participants' decisions were compared with those of the sighted experimenter to determine the level of risk. Risky crossing decisions by the participants were significantly lower when decisions were made at lower ambient sound levels.

Therefore, the interactions between blind pedestrians and electric vehicles in an uncontrolled urban environment have not yet been adequately explored, particularly in Europe.

Therefore, the main objective of the present study is to recognise patterns in these interactions by creating profiles (based on another body of literature review) and comparing these interactions with those of non-blind pedestrians through observing behaviour in uncontrolled environments and everyday interactions. Subsequently, this objective contains another: to develop measures to make this contact safer for pedestrians and drivers of electric vehicles.

2 Methodology

2.1 Characterization of the observation locations

Regarding the interaction between blind pedestrians and electric vehicles, this study addresses behaviour and demographic issues, precisely age and gender. It draws upon field observations through on-site observation, and data was collected at six non-signalized pedestrian crossings in Coimbra, Portugal. The team to collect the data consisted of three persons: a lead investigator who accompanied the blind pedestrian during the crossing, a person responsible for the camera, and the driver of the electric vehicle. This experience occurred on different days of the week (the week before lockdown), registering blind (and non-blind) pedestrians' behaviour facing the electric vehicle in 6 crosswalks, 30 min in each crosswalk, morning or afternoon, with favourable weather conditions outside peak hours. In total, 180 (30*6) minutes were filmed and evaluated. The observations were conducted at the end of the winter season under favourable weather conditions characterized by the absence of rain and wind, considering situations with mild temperatures. The pedestrian crossings are illustrated in Fig. 1.

The locations represented in Fig. 1, which were selected beforehand to preserve heterogeneity during the research design – a fundamental characteristic for the development of subsequent studies – are listed below along with their respective characteristics:

1. Street Comandante Sacadura Cabral.

Characteristics: Soundtrack, few vehicles, and pedestrians

2. Street Monsenhor Augusto Nunes Pereira.

Characteristics: Normal tarmac and raised with stones, dual carriageway, high flow of vehicles

3. Street Dr. Manuel Rodrigues.

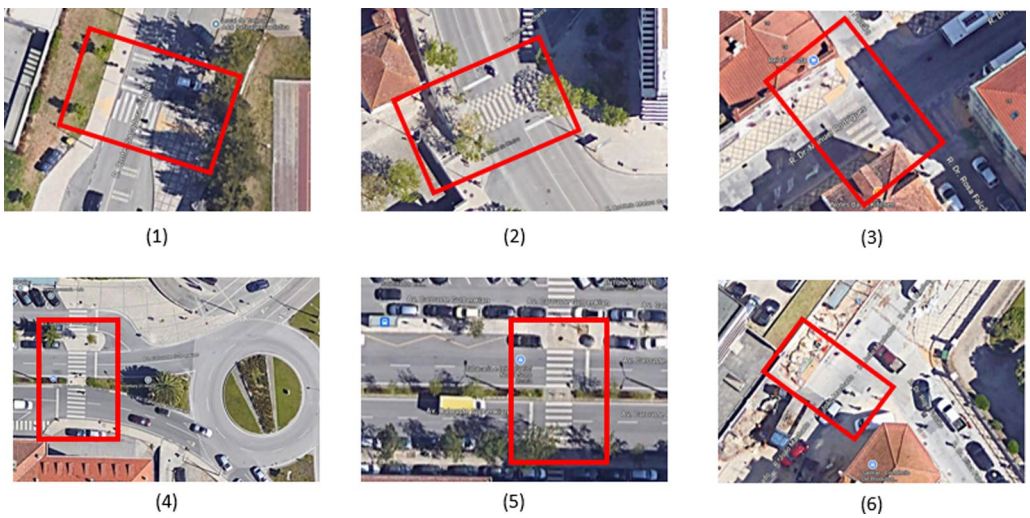

Fig. 1 Visual representations of the pedestrian crossings observed in Coimbra, Portugal. (Source: Google Maps)

Characteristics: Tarmac with a nearby bus stop, high flow of pedestrians and vehicles

4. Calouste Gulbenkian Avenue.

Characteristics: Central divider, reasonable flow of vehicles and pedestrians, near a roundabout with constant congestion

5. Calouste Gulbenkian Avenue.

Characteristics: Centre divider, reasonable flow of vehicles and pedestrians

6. Street João Machado.

Characteristics: Tarmac with a nearby bus stop, high flow of pedestrians and vehicles, approximately 8m crossing

This revised version provides a clear and organized presentation of the information about each pedestrian crossing location and its unique characteristics.

2.2 Observational criteria

The observations were derived from a set of 30 questions that considered relevant factors capable of influencing changes in reaction time or leading pedestrians to adopt risky behaviour. Additionally, an inquiry, known as the Pedestrian Behaviour Survey (PBS) proposed by [12], was employed to assess the pedestrians' behaviour.

- Demographic Observation

1. Gender and
2. Age

- Crossing characteristic

3. Crossing time;
4. Interaction with electric vehicle;
5. Whether they are carrying anything while crossing (shopping, bags, pushchairs);
6. Whether they have any distractions while crossing (mobile phone, headphones, company);
7. Whether there are other people crossing at the same time;
8. Whether there is any group effect while crossing;
9. Whether there are cars on the road at the time of crossing

- Behavioural:

10. The pedestrian looked to the left and/or right before starting to cross;
11. The pedestrian looked to the left and/or right before crossing the second half of the road;
12. On a road with two directions of traffic, cross the first half and wait at the centre line of the road for the opportunity to finish crossing safely;
13. The pedestrian shows intention to cross (puts their feet on the zebra crossing, makes some gesture with their hand);
14. Diverted pedestrians (those who have had to make an effort to use the pedestrian crossing or have changed their course of action);
15. The driver has given way or the pedestrian has forced his way through;
16. The pedestrian hesitates to cross when he sees the vehicle;
17. How the vehicle stopped, the distance the vehicle stopped before the pedestrian crossing;
18. The pedestrian thanks the driver for allowing him to cross;
19. Group effect: trusts the other, follows a person, crosses without looking;
20. How he crosses: straight, diagonally, outside the lane;
21. Changes speed while crossing;
22. Allows the vehicle to pass if there is no other behind him;
23. The pedestrian crosses even when vehicles are approaching;
24. Aggressive behaviour towards the driver/vehicle: shouts at the driver, makes some gesture;
25. Forces his way through pedestrians;
26. On a road with several lanes in the same direction, stop in the middle of the zebra crossing;
27. The pedestrian crosses in the area intended for cars;
28. Uses the zebra crossing or crosses close to the zebra crossing;
29. Stops in the zebra crossing for some reason;
30. While crossing, they remain watching the cars, look ahead, go back to what they were doing before they started crossing, or get distracted during the journey.

After this analysis, the pedestrian was classified into the following categories:

- Pedestrians' crossing behaviour.
- Pedestrians' crossing by actions.

- Pedestrians profile.

According to some related literature, pedestrians can be categorized based on their behaviour: prudent pedestrians adhere to traffic laws, such as looking before crossing and not crossing in front of moving vehicles, while reckless pedestrians disregard these rules, often crossing without looking or in front of approaching vehicles [13].

At non-signalized crossings, [14] classifies pedestrians by actions into different types:

31. Insecure pedestrians: These individuals do not interrupt traffic flow manually, waiting for an opportunity to cross safely. They consider an acceptable delay in the traffic flow to ensure a safe crossing.
32. Hesitant pedestrians: These pedestrians interrupt traffic flow but may vary their walking speed during the crossing, affecting the time taken to cross the lane.
33. Assertive pedestrians: These pedestrians also interrupt traffic flow but maintain a consistent walking speed throughout the crossing. Within this category, two variations can be observed:
34. Assertive attentive pedestrians: They make the entire crossing while actively observing traffic, seeking eye contact with drivers, and maintaining a steady pace.
35. Distracted assertive pedestrians: These individuals may start crossing but become distracted during the process. They may slow down, engage in conversations, or use electronic devices like mobile phones.

According to the literature, pedestrians can also assume different profiles, as presented in Table 1.

A general and concise summary of pedestrian classifications and their behaviour at the crossing is presented (see Fig. 2).

After introducing various pedestrian types and their behaviours, the following sections focus on the analyses that were conducted. Descriptive statistics were calculated, primarily examining the relationships between age and gender. Subsequently, a brief analysis of blind pedestrians' behaviour is presented, followed by a comparison with non-blind pedestrians. Additionally, there is a concise examination of pedestrians' interactions with electric vehicles and potential observations made in this context.

3 Analysis

3.1 Descriptive statistical analysis of pedestrian behaviour

Observations were made on 379 pedestrians, including 152 men and 227 women. Participant selection was based on those captured on film during specific periods, and there is no way to apply any other sampling technique that can guarantee representativeness from the population. However, this is a controlled group of observations

Table 1 Summary of different pedestrian profiles

Pedestrian Profile	Description	References
Obedient	Cross only at the green light or when a vehicle has stopped to allow pedestrians to cross	[15]
Opportunist	After a certain period of waiting, become impatient and cross at red lights, looking for a gap between vehicles. In the case of unsigned crossings, take advantage of another pedestrian crossing or an opportunity created by the driver	[15]
Influenced	Influenced by other pedestrians, they disregard red lights when crossing or approaching vehicles, simply copying what others do	[16]
Search for successive gaps	At multi-lane junctions, pedestrians assess one lane at a time, regardless of the presence of a central refuge. They don't know what's happening in the next lane until they reach it	[15, 16]
Crossing diagonally	Using a larger area than the safety zone, this behaviour is influenced by (i) the presence of physical barriers, (ii) traffic conditions, (iii) the time at which the pedestrian reaches the crossing, and (iv) route optimization	[17]
Daring	When initiating the crossing, the pedestrian assumes that the approaching vehicle will slow down while maintaining a certain safety distance. This behaviour may result in the vehicle either stopping or slowing down	[18]
Out of range due to route	Pedestrians choose their crossing points to optimize their route, considering the cost of crossing inside or outside the safety zone. They are drawn to the crossing when nearby, or they cross at the most convenient location when it's not nearby	[19, 20]
Pedestrian speed increase	Increase your crossing speed if you notice a reduction in the available time for crossing, in order to compensate for a potentially risky situation	[21]
Search for break in hiking	Pedestrians can walk along the road, observing potential gaps to optimize their travel time	[22]
Crossing in the crosswalk	Pedestrian crossings have a priority for pedestrians, but some drivers may disregard it, causing pedestrians to exhibit behaviours similar to those seen outside of crosswalks	[22]

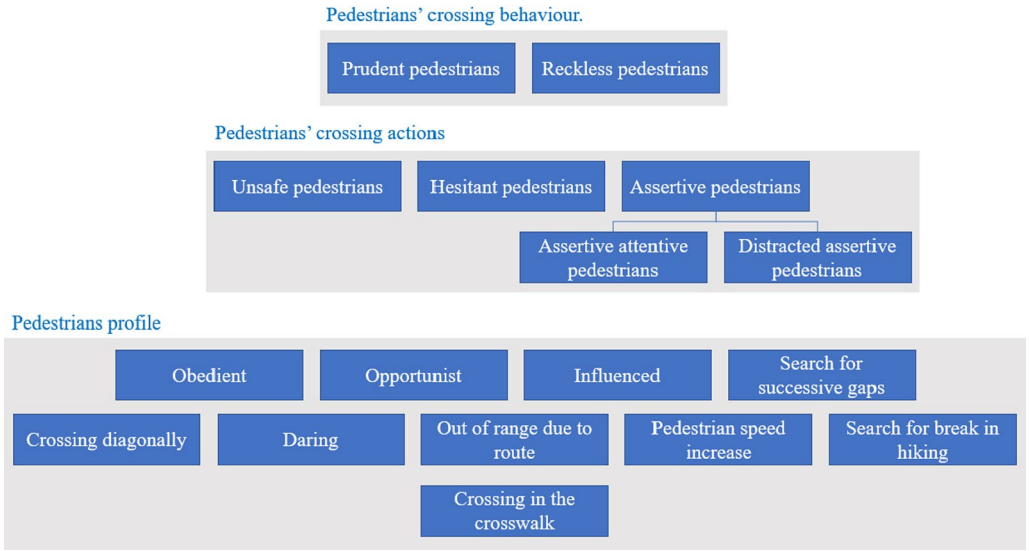

Fig. 2 Classification of pedestrians by category

(locals, days, hours, gender, age), and it can also be compared with other samples in further studies, extending the robustness of these results. Table 2 shows the number of crossings observed at each selected pedestrian crossing (see Sect. 2.1). The data is further broken down by gender and age classification based on appearance, and it also includes the number of crossings by a blind pedestrian and interactions with electrical vehicles.

The street with the highest number of observations, 120 pedestrians, is Rua João Machado, which is considered an important thoroughfare in the city due to its high pedestrian and vehicle traffic and its central location near various shops and services. The second road with the highest number of observations, 96 pedestrians, is Rua Dr. Manuel Rodrigues, which runs parallel to the street. Following closely is Rua Calouste Gulbenkian, a section situated near the roundabout. Despite not having many pedestrian crossings, the other roads exhibit varied and noteworthy behaviours for the study, particularly among children and the elderly.

After analysing the footage and the distribution by age and gender, the pedestrians were further classified according to the behaviours defined in Sect. 2.2, Table 3.

Table 2 Age and gender distribution by crosswalk

	(1)	(2)	(3)	(4)	(5)	(6)	Total
Gender							
Male	11	12	32	32	24	41	152
Female	13	14	64	47	10	79	227
Total	**24**	**26**	**96**	**79**	**34**	**120**	**379**
Age							
Children	5	0	0	1	1	2	9
Children / Teenager	1	0	1	0	1	1	4
Teenager	5	8	2	10	0	7	32
Young adult	4	5	16	33	5	10	73
Adult	6	8	38	18	16	57	143
Adult / Elderly	0	1	9	2	5	19	36
Elderly	3	4	30	15	6	24	82
Total	**24**	**26**	**96**	**79**	**34**	**120**	**379**
Other relevant informations							
Interaction with electrical vehicle	2	6	4	9	6	14	41

Table 3 Pedestrian Behaviour Classification (Literature Definitions)

	(1)	(2)	(3)	(4)	(5)	(6)	Total
Reckless	8	7	36	16	8	41	116
Prudent	16	19	60	63	26	79	263
Total	**24**	**26**	**96**	**79**	**34**	**120**	**379**
Insecure	3	1	19	9	2	10	44
Hesitant	1	4	3	2	6	7	23
Assertive	8	8	54	39	26	50	185
Attentive	10	11	11	15	0	26	73
Distracted	2	2	9	14	0	27	54
Total	**24**	**26**	**96**	**79**	**34**	**120**	**379**

Of the 379 pedestrians observed, 263 were classified as prudent, meaning they respected traffic laws when crossing, while 116 were considered reckless according to the defined terms. Regarding the behaviour adopted at the crossing, 48.8% exhibited assertive behaviour. If pedestrians were considered who behaved attentively (19.3%) and those who were distracted (14.2%), a total of 82.3% of pedestrians demonstrated assertive behaviour, which means they interrupted traffic flow but maintained a consistent walking speed throughout the entire crossing.

3.2 Understanding the behaviour of blind pedestrians

With respect to blind pedestrians, it's important to note that when they are alone, they consistently seek out pedestrian crossings indicated either by the road surface or guidance from another pedestrian. In collaboration with *Associação dos Cegos e Ambiolimpes de Portugal*, ACAPO, this study received information indicating that the pedestrians participating in the study, who receive assistance from the institution, are taught and supervised in how to navigate their primary routes. These routes include the journey from home to the market, from home to the institution, from home to work, and any other routes necessary for the pedestrian and their family.

The pedestrians who voluntarily participated in this study provided information while maintaining their anonymity. Below, will be present some relevant characteristics for the study, including gender, age classification, and the most frequent behaviour classification:

A. A young female who has been blind since birth, exhibiting a more cautious behaviour due to her visual impairment.
B. An adult male who lost his sight during childhood, actively engaged in projects for the visually impaired, and displaying a more assertive behaviour:
C. An adult female who experienced blindness as an adult and retains some ability to perceive light. This pedestrian tends to display a more hesitant behaviour compared to the others.

It's important to note that the limited sample size of blind individuals and local participants resulted from the study being conducted during a flexible period of the COVID-19 pandemic. Furthermore, the participation of blind individuals in this study was voluntary, which posed challenges to adherence, particularly regarding exposure to urban traffic.

The interactions between these pedestrians and the electric vehicle, along with the risky behaviours they exhibited, will be discussed in the following chapter.

3.3 Insights into pedestrian-electric vehicle interaction

Of the 379 pedestrians, 41 (representing 10.8% of the total sample) interacted with the electric vehicle. Among them, there were 20 male and 21 female pedestrians. In terms of age, the group included one child, four teenagers, six young adults, 13 adults, four classifieds as adult/elderly (when it is not possible to identify the precise age group), and 13 elderly individuals. The behaviours exhibited by these individuals, as per the behavioural classification, were detailed in Table 4.

Pedestrians are primarily prudent and assertive (82.9%) at crossings, which reduces the risk of accidents during such interactions. A prudent pedestrian adheres to traffic rules, while an assertive pedestrian demonstrates knowledge and confidence. In cases where reckless pedestrians exhibit hesitation, meaning they pause when they identify a vehicle, the risk can be mitigated by the pedestrian's quick reaction time. However, a low reaction time can be problematic when a pedestrian is both reckless and insecure, as this insecurity can make their behaviour unpredictable and potentially lead to an accident if, for example, they decide to increase their walking speed.

It's important to note that road characteristics can sometimes affect a pedestrian's ability to detect

Table 4 Electrical vehicle interaction—Age and gender distribution by classification

	Reckless	Prudent	Total	Insecure	Hesitant	Assertive	Total
Gender							
Male	3	17	**20**	2	1	17	**20**
Female	4	17	**21**	3	1	17	**21**
Total	**7**	**34**	**41**	**5**	**2**	**34**	**41**
Age							
Children	0	1	**1**	0	0	1	**1**
Teenager	0	4	**4**	1	0	3	**4**
Young adult	0	6	**6**	0	2	4	**6**
Adult	4	9	**13**	0	0	13	**13**
Adult / Elderly	0	4	**4**	2	0	2	**4**
Elderly	3	10	**13**	2	0	11	**13**
Total	**7**	**34**	**41**	**5**	**2**	**34**	**41**

approaching vehicles, whether electric or conventional. Furthermore, despite vehicles being in circulation throughout the filming period, there was no guarantee of interaction between pedestrians and vehicles, as the sample selection was entirely random.

4 Results and discussion

With all the elements of this study now presented, the initial analysis focuses on the behaviour of pedestrians on urban roads. This analysis begins by comparing genders and age groups with classifications of 'prudent' and 'reckless,' which pertain to their adherence to traffic rules and classifications of 'insecure,' 'hesitant,' and 'assertive,' as defined in the literature. Table 5 provides both absolute and relative values for these results, presented in this manner for the purpose of comparison and accuracy.

Proportionally, male pedestrians exhibit more reckless behaviour than their female counterparts. Additionally, although both genders exhibit a higher degree of assertive behaviour, women tend to display more insecure behaviour than men. When examining age groups, children are found to be the most reckless pedestrians (44.4%), followed by adolescents (37.5%) and adults/elderly individuals (36.1%). Conversely, younger people, including children/teenagers and young adults, tend to demonstrate greater prudence (100% and 75.3%, respectively), as do the elderly (73.2%). Regarding the classifications defined in the literature, 82.3% of pedestrians exhibit assertive behaviour. However, children (33.3%), adults/elderly individuals (22.2%), and the elderly (19.5%) exhibit higher percentages of insecure behaviour. Children and children/adolescents also show the highest rates of hesitant behaviour, at 11.1% and 25.0%, respectively.

Regarding the other behaviours, a comparative summary was presented in Table 6.

Table 5 Age and gender distribution by classification

	Prudent		Reckless		Total	Insecure		Hesitant		Assertive		Total
Gender												
Male	100	65,8%	52	34,2%	**152**	10	6,6%	8	5,3%	134	88,2%	**152**
Female	163	71,8%	64	28,2%	**227**	34	15,0%	15	6,6%	178	78,4%	**227**
Total	**263**	**69,4%**	**116**	**30,6%**	**379**	44	11,6%	23	6,1%	312	82,3%	**379**
Age												
Children	5	55,6%	4	44,4%	**9**	3	33,3%	1	11,1%	5	55,6%	**9**
Children / Teenager	4	100,0%	0	0,0%	**4**	0	0,0%	1	25,0%	3	75,0%	**4**
Teenager	20	62,5%	12	37,5%	**32**	1	3,1%	2	6,3%	29	90,6%	**32**
Young adult	55	75,3%	18	24,7%	**73**	5	6,8%	5	6,8%	63	86,3%	**73**
Adult	96	67,1%	47	32,9%	**143**	11	7,7%	9	6,3%	123	86,0%	**143**
Adult / *Elderly*	23	63,9%	13	36,1%	**36**	8	22,2%	3	8,3%	25	69,4%	**36**
Elderly	60	73,2%	22	26,8%	**82**	16	19,5%	2	2,4%	64	78,0%	**82**
Total	**263**	**69,4%**	**116**	**30,6%**	**379**	**44**	**11,6%**	**23**	**6,1%**	**312**	**82,3%**	**379**

Table 6 Summary of behaviours defined in the literature

	Prudent		Reckless		Total	Insecure		Hesitant		Assertive		Total
Obedient	56	96,6%	2	3,4%	**58**	29	50,0%	0	0,0%	29	50,0%	**58**
Opportunist	13	68,4%	6	31,6%	**19**	2	10,5%	1	5,3%	16	84,2%	**19**
Influenced	8	28,6%	20	71,4%	**28**	3	10,7%	6	21,4%	19	67,9%	**28**
Search for successive gaps	0	0,0%	2	100,0%	**2**	0	0,0%	0	0,0%	2	100,0%	**2**
Crossing diagonally	10	45,5%	12	54,5%	**22**	1	4,5%	0	0,0%	21	95,5%	**22**
Daring	10	17,5%	47	82,5%	**57**	0	0,0%	7	12,3%	50	87,7%	**57**
Out of range due to route	2	20,0%	8	80,0%	**10**	0	0,0%	1	10,0%	9	90,0%	**10**
Pedestrian speed increase	2	66,7%	1	33,3%	**3**	1	33,3%	0	0,0%	2	66,7%	**3**
Search for break in hiking	0	0,0%	0	0,0%	**0**	0	0,0%	0	0,0%	0	0,0%	**0**
Crossing in the crosswalk	162	90,0%	18	10,0%	**180**	8	4,4%	8	4,4%	164	91,1%	**180**
Total	**263**	**69,4%**	**116**	**30,6%**	**379**	**44**	**11,6%**	**23**	**6,1%**	**312**	**82,3%**	**379**

Among the 'obedient' pedestrians, 96.6% were classified as 'prudent,' while 50.0% exhibited 'insecure' behaviour, and the remaining 50.0% displayed 'assertive' behaviour. Insecurity is a recurring factor in obedience, as pedestrians often wait for vehicles to stop before crossing when they don't feel safe, resulting in obedient behaviour. Another interesting comparison emerges from the fact that 90.0% of pedestrians using the crosswalk were classified as 'prudent'; however, 91.1% of them demonstrated 'assertive' behaviour. This occurs because pedestrians, aware of traffic rules, understand that they have the right of way when using the crosswalk and assert this right. Additionally, bold pedestrians (87.7%) are frequently assertive; however, most (82.5%) fall into the 'reckless' category compared to other groups.

Regarding the behaviour of blind pedestrians, the known presence of an electric vehicle creates greater insecurity at the crossing. Despite being safe and monitored, even the most diligent blind people hesitated to cross and feared accidents. The absence of noise related to these vehicles increases the risk, especially in asphalt areas, without the presence of soundtracks or some stones that could indicate the approach of the pedestrian crossing. makes it difficult for those who cannot see and identify these vehicles without noise.

In this study, 30 combinations between behaviours were identified. The most common combination of behaviours is "Prudent, assertive and crosses the zebra crossing", followed by "Prudent, assertive and obedient" and "Prudent, insecure and obedient", with 146, 29 and 27 pedestrians classified in this way respectively. These three behaviours, for the most part, are characterized by pedestrians who respect the traffic rules, know their priority at the zebra crossing, and respect not only the rules but also other road users during the crossing, which have many characteristics in common. The most common age and gender in each of the combined behaviours are women and adults, women and elderly, women and young people, respectively.

Finally, during the observations, it was found that blind pedestrians tend to be more cautious than non-blind pedestrians, that younger and older pedestrians tend to behave more dangerously and less calculatedly than other road users and that differences are more noticeable in age than in gender. Notably, when in groups, especially teenagers, they make more traffic errors. Regarding the absence of noise associated with the electric vehicle, in moments of pedestrian distraction, if the driver is not attentive, the risk of accidents increases.

These results are significant for decision-making, both for experts and society. Experts gain greater awareness of the need to prepare urban spaces and electric vehicles for interaction with the most vulnerable users. Additionally, disseminating these results can raise social awareness of this issue, not only because of blind pedestrians but also due to the increasing number of elderly vulnerable users of urban spaces, characterised by vision and hearing problems. Approaches like this can encourage inclusion and accessibility by supporting vulnerable users and promoting sustainable mobility. The benefits can also be seen from a safety perspective, with the identification of risks and the development of preventive measures, as well as by encouraging technological development through innovations in alert systems and integration with assistive navigation systems,

However, despite the significant results and insights obtained, some limitations remain. The exposure of vulnerable road users, in this case, pedestrians, especially those with some limitations, depends on the support of an institution with available human resources willing to take risks for the sake of the study. Additionally, as an observational study, there is no control over variables, particularly in uncontrolled environments, as was the case in this study. During execution, there may be some

bias, either through subjectivity during data interpretation or an effect caused by the Hawthorne effect (a phenomenon where individuals modify their behaviour in response to being observed or receiving attention from researchers or supervisors). Another challenge associated with observational studies is that, although associations can be established, definitive causal relationships cannot be determined due to the lack of experimental manipulation. Further issues included sample and time limitations, the complexity of analysing observational data due to confounding variables and bias, and the need for guarantees regarding sample representativity since participant selection was not random. Finally, observing participants without their explicit consent raises ethical issues. Because of this, all filming areas in this study had alerts for pedestrians, who became more attentive to their actions, knowing they were being filmed. Nevertheless, as initially stated, the present study can be an essential guide to further studies while electric vehicles are increasingly present in the urban environment.

5 Conclusions

The main objective of this study was to recognise patterns in these interactions by creating profiles based on the literature and comparing these interactions with those of non-blind pedestrians through observing behaviour in uncontrolled environments and everyday interactions. This observation was done to subsequently and potentially develop measures to make this contact safer for pedestrians and drivers of electric vehicles. Differences were identified in the behaviour of blind and non-blind pedestrians at non-signalised crossings, and insights were gathered into the interaction of both groups with electric vehicles to understand behaviours that increase the risk during crossings. Based on the results, the following conclusions can be drawn:

- Pedestrians who rely solely on their sense of hearing to detect electric vehicles often express surprise at the vehicle's approach. Although electric vehicles tend to be quieter than conventional cars, particularly at speeds exceeding 20 km/h, they still produce less noise compared to the ambient noise of urban traffic and other vehicles on the road.
- Children's failure to look before crossing the street underscores the significance of traffic training and education. Furthermore, this early behaviour can affect their future pedestrian behaviour.
- The driver's behaviour is a crucial variable. When drivers responsibly adhere to traffic rules and stop before a pedestrian crossing, it becomes easier to avoid potential accidents, even if a pedestrian exhibits risky behaviour.
- Most pedestrians do not show intention to cross when there are other people already crossing.

It is essential to highlight that the best behaviour to adopt to avoid a potential accident is Prudent, obedient, Assertive, attentive and Obedient pedestrian, which is characterised by a pedestrian who respects the traffic rules, who is concerned about their safety and that of the driver, i.e., wait for the vehicle to stop so that it can begin crossing, and behave pleasantly towards other road users. However, this combination appears rarely and is mainly practised by adult women. Another relevant factor for adopting a particular behaviour is the type of road you are crossing and the risks involved. Pedestrians do not always adopt the same behaviour at different crossings since different characteristics can affect human behaviour.

It is important to note that this study's limitations were presented in the previous chapter. The study was mainly conducted during the COVID-19 pandemic. The small sample of blind and local people is due to the restrictions that the entire world faced during this period. The participation of blind people in this study was voluntary, which makes adherence difficult, especially when it comes to exposure to urban traffic. Recognizing these is crucial for critically and carefully interpreting the results of observational studies. In these cases, limitations help in planning future research that can address and mitigate some limitations through complementary methods, such as controlled experimental studies.

Therefore, this study can be considered useful for what it proposes, being relevant and necessary to consider the characteristics of more scenarios and external effects, outside the control of the study, that may affect the results.

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Author contributions

Anna Oliveira: Conceived and designed the study, conducted experiments, analysed data, performed statistical analysis and interpretation, prepared figures and tables and contributed to manuscript writing and preparation. Ana Bastos: Contributed to the study design and to the field experiment Anabela Ribeiro: Reviewed and edited the manuscript, provided critical feedback, and supervised the research.

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Availability of data and materials
The data and materials used in this study are available upon request. Please contact Anna Beatriz Espíndola de Oliveira at annaoliveira@student.uc.pt for access to the dataset and any other supplementary materials.

Declarations

Competing Interests
The authors declare that they have no competing interests.

Author details
[1]CITTA – Research Centre for Territory, Transports and Environment, Department of Civil Engineering, Faculty of Sciences and Technology, University of Coimbra, Rua Luís Reis dos Santos 290, 3030-790 Coimbra, Portugal.

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