

Article

An Examination of Pedestrian Crossing Behaviors at Signalized Intersections with Bus Priority Routes

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Abstract: Public transport is an integral part of sustainable urban development when its use is promoted by setting bus priority routes (BPRs). BPRs provide clear mobility benefits, but they raise pedestrian safety concerns. In this study, observations were conducted at signalized intersections with two types of BPRs, center-lane and curbside, aiming to characterize pedestrian crossing behaviors, with a particular focus on red-light crossings. We found that at intersections with center-lane BPRs, 30% of pedestrians crossed at least one crosswalk on red, while at another type, 11% crossed on red. Multivariate analyses showed that the risk of crossing on red was substantially higher at intersections with center-lane vs. curbside BPRs; it was also higher among pedestrians crossing to/from the bus stop, males, and young people but lower under the presence of other waiting pedestrians. Furthermore, among pedestrians crossing on red at center-lane BPRs, over 10% did not check the traffic before crossing and another 10% checked the traffic in the wrong direction, thus further increasing the risk. At center-lane BPRs, infrastructure solutions are needed to reduce pedestrian intention to cross on red. Additionally, education and awareness programs for pedestrians should be promoted to emphasize the heightened risk of red-light crossing at intersections with BPRs.

Keywords: bus priority routes; safety; pedestrian behaviors; observations; red-light crossing



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1. Introduction

In light of the growing problem of congestion in urban areas, policies promoting the use of public transportation are encouraged around the world [1–3]. In Europe, public transport is considered as an integral part of sustainable urban development aiming to promote active travel modes, walking, and cycling [4]; in the USA, transit-oriented development is supported, aiming to attain more resilient, healthier, and all-inclusive cities [5]. In Israel, public transport development has become an official priority in the past decade, initially, due to congestion on the road network, particularly at the entrances to major cities, and more recently, following the need for sustainable development of urban areas [6,7].

Policies to promote public transport are particularly reflected in the allocation of transport infrastructure for bus priority routes (BPRs). The latter include bus lanes or routes dedicated to the exclusive or priority running of buses, at selected hours or all day, to provide undisturbed flow for bus traffic [8]. BPRs are commonly established on arterial streets in cities and suburban areas, while the ultimate form of such systems is known as bus rapid transit (BRT) [9,10]. Over the past decades, bus priority systems have been rapidly developing across the world and especially, in South and North American countries, Asia, and Australia [11–13]. Similarly, in Israel, in recent years, re-development of urban

streets to include BPRs has been implemented. For example, in the Haifa metropolitan area, a BRT system was introduced, covering about forty kilometers of bus priority streets and routes [14]. In the city of Tel Aviv, there are tens of kilometers of BPRs, with various bus operators. Currently, as part of the development of public transport services in the country [6], a nation-wide program called “Rapid to the city” is being conducted, including planning and implementation of hundreds of kilometers of BPRs in various cities.

Previous research has shown that bus priority systems and establishing BPRs offer evident mobility benefits, e.g., in terms of savings in bus travel time, increasing commercial bus speeds at peak hours, and enhancing the capacity of existing transport infrastructure [15,16]. In a more general sense, it is expected that congestion in cities will be alleviated by encouraging a shift from private cars to public transportation, with the consequent positive impacts of reducing emissions, enhancing economic opportunities, better accessibility, and increasing active travel [13,17].

Concerning the safety impacts of bus priority systems and BPRs, the situation is more complicated. In general, evaluations conducted in the USA and European countries have shown the safety advantages of using public transportation [17–19]; when considering the extent of casualties and fatalities per passenger kilometer, it is evident that traveling on buses is safer than using a private car. In Israel as well, under various occupancy assumptions, it has been estimated that the risk of being killed or severely injured on a bus is significantly lower than in a private car; for instance, with an occupancy of forty passengers on a bus and four in a private car, the risk of severe injury in the car is four times higher than on the bus [20]. Furthermore, comparative evaluations of North American cities demonstrated a direct link between higher use of public transport in cities and lower numbers of fatalities in road accidents per urban resident [17,21]. Therefore, in the long term, improvements in bus systems and the growth in their use are expected to contribute to a decrease in road traffic injuries in cities.

However, the short-term safety impacts of BPRs can be mixed, as introducing BPRs requires essential infrastructure changes in road layouts, which are typically more complex than traditional urban settings [13,22,23]. Indeed, previous research reported various effects on safety following BPRs’ introduction. For example, the operation of BRT systems in several South American cities and India led to substantial reductions both in injury and fatal accidents [15]. Similarly, the implementation of bus priority lanes in Melbourne, Australia, brought a reduction in total accidents [24,25]. At the same time, US studies showed higher accident rates following the implementation of dedicated bus lanes [26], while a recent evaluation of a BRT system in New Mexico revealed a significant decrease in the frequency of accidents [27]. In Israel, an assessment of the safety implications of a BRT system in Haifa and evaluations in other cities showed that BPR operations were associated with upward trends in accident occurrences, relative to previous periods and controlling for changes on comparison-group roads [14,28].

Moreover, the safety impacts of BPRs may depend on their design and engineering characteristics [12,14,15]. The main forms of BPR configurations, common in international practice and in Israel, are center-lane bus routes and curbside bus lanes [9,12]; see examples in Figure 1. In a center-lane route, the bus lane is a left lane on each carriageway, near the median, while a curbside bus lane is located adjacent to the sidewalk. In this context, again, mixed research findings can be found in the literature, without a clear indication which form is safer. It should be noted that BPRs are typically set on multilane urban arterials with high traffic volume, where pedestrian safety can be attained through separation in space and time from vehicle and bus traffic. Previous research showed [12,15] that on road sections with center-lane bus routes, pedestrian accidents occurred due to uncontrolled pedestrian crossings. Thus, physical fencing is recommended by current design guidelines

to prevent uncontrolled pedestrian crossings and associated accidents along road sections with BPRs.

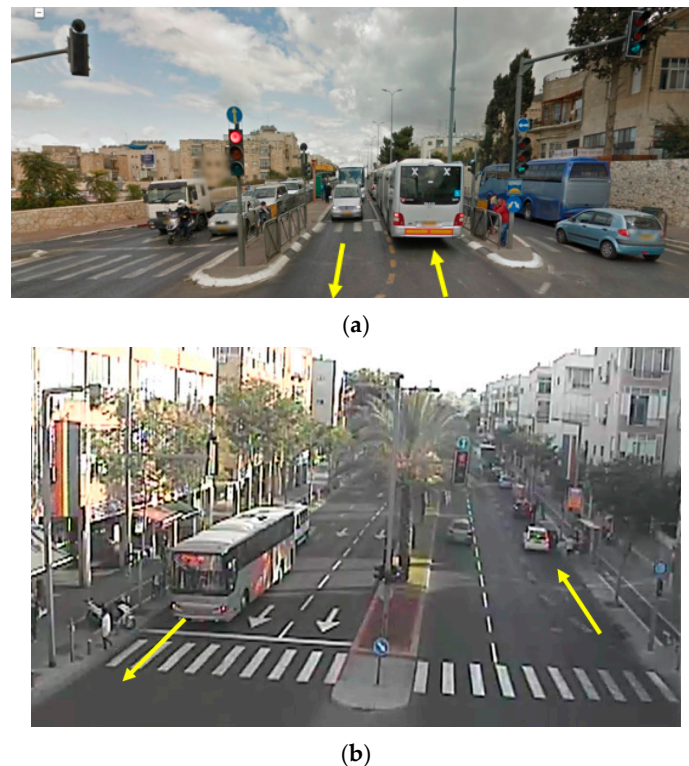


Figure 1. Examples of intersections with bus priority routes: (a) center-lane bus route, (b) curbside bus lane. (Yellow arrows indicate the directions of bus traffic).

Concerning the safety impacts of various BPR configurations, for example, a previous study [22] developed accident models for vehicle and pedestrian accidents in BPR systems in several South American cities, and showed that both center-lane and curbside configurations were safer compared with another (counter-flow) form. Repeated analyses of accident changes following the introduction of such systems in South America and India demonstrated a positive impact of center-lane BPRs on road safety [15]. Concerning the safety impacts of curbside BPRs, in Mexico, a significant increase in both vehicle and pedestrian accidents was found in one city and insignificant changes in another [15]. In New York, a significant increase in total accidents, vehicle collisions, and pedestrian accidents, on road sections, was reported [29], while in Hong Kong, the safety impacts of curbside bus lanes were not statistically significant [30]. In contrast, in Australia, where lower accident rates were found on road sections with BPRs, the latter were mainly in the form of curbside bus lanes [24,25].

Furthermore, previous research has consistently indicated that the weak points of BPR operation lie in pedestrian safety [13,15,22]. For example, a study [15] reported that over half of the fatalities on BPR routes in South America were pedestrians. It was argued [22] that BPR systems are located on main traffic arterials and attract large pedestrian volumes (representing more users of public transport), thus increasing pedestrian exposure and injury risk. In addition, a significant share of pedestrian injuries occurred while crossing streets on their way to bus stops [22]. Similarly, another study [31] found an increase in accidents in the vicinity of stops along BRT corridors in Bogota, which was apparently related to the higher flow of pedestrians. Additionally, US studies reported increases in pedestrian accidents on streets with BPR corridors [27,29].

In Israel, signalized intersections with BPRs were found to be associated with a higher risk of pedestrian accidents compared with similar intersections without BPRs [23]. In gen-

eral, increasing trends in pedestrian accidents at intersections following BPRs' introduction were consistently observed in evaluation studies in Israel [14,28], despite the fact that traffic settings in BPR corridors in the country were designed following the best-practice international recommendations, e.g., distinguishing BPRs by yellow road markings; segregation of center-lane routes by a curb or fencing and a red-color aggregate; signaling all junctions along the bus corridors; placing bus stops adjacent to junctions; etc. [8–10,12].

In local practice, a particular concern was raised regarding center-lane BPRs due to the structure of pedestrian crossings at signalized intersections, which may surprise and confuse pedestrians [23]. A central BPR creates three traffic routes to be crossed by pedestrians, instead of the usual two, thus requiring a change in the rules of pedestrian behavior while crossing the road—the so-called “three-route effect” (Figure 2). Pedestrians need to look left when crossing the first (vehicle) route and look left again when crossing the BPR, instead of looking right as they are used to doing at intersections without BPRs. To continue crossing, pedestrians are expected to then look right (within the BPR) and again right when they reach the third route (for general traffic). In other words, the three-route crossing structure contradicts traditional road-crossing habits, potentially triggering a response to look in the wrong direction, thereby increasing accident risk. For example, a pedestrian crossing the bus route on a red light, based on habit, may look in the opposite direction and fail to notice the approaching bus. Indeed, fatal pedestrian accidents related to this phenomenon have occurred in one Israeli city at intersections with center-lane BPRs, and a ministerial committee was initiated to investigate the safety of this BPR type [32]. In addition, occasional observations of pedestrian behaviors at signalized intersections with center-lane BPRs, which were conducted during the processes of safety auditing, pointed to the presence of the phenomenon: some pedestrians who crossed the BPR checked bus traffic in the wrong direction (e.g., [33]). However, an examination of the previous literature revealed that pedestrian behaviors on streets with bus corridors and particularly, when crossing signalized intersections with BPRs had not previously been explicitly examined.

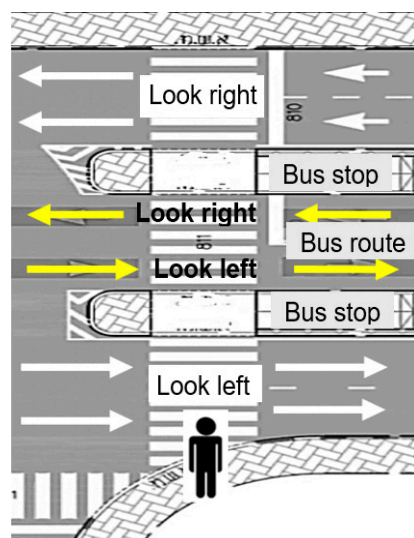


Figure 2. Illustration of the “three-route effect” when crossing an intersection with a CL BPR.

In summary, public transport use in urban areas is associated with potential mobility, safety, and environmental benefits, while current safety concerns regarding BPRs are mainly related to pedestrian injury. The latter stems from increasing pedestrians' exposure and the characteristics of BPR systems, which may impact road users' behaviors in a way that increases accident risks. Previous research on BPR safety has not been extensive and has mostly included accident data analyses and evaluating the general safety effects of such

systems. Given the continuous development of BPRs in Israel, it is important to provide road designers and decision-makers with empirical findings regarding pedestrian behaviors on streets with BPRs, an area where research data are scarce. Therefore, an observational study was initiated to examine pedestrian behaviors at intersections with BPRs, focusing on the two types that are most common in Israel, i.e., center-lane and curbside BPRs. This study aimed to characterize pedestrian behaviors when crossing at urban intersections with BPRs, particularly red-light crossings, and to compare behaviors between the two types of BPRs.

This study contributes to the current literature by providing empirical values of pedestrian crossing behaviors at signalized intersections with common types of bus priority routes; such characteristics have not been reported in previous research. The study examined pedestrians' compliance with the red light along with other possible influential factors and found that the risk of crossing on red was substantially higher at intersections with center-lane versus curbside BPRs. Furthermore, this study showed that such risk was higher among pedestrians crossing to or from the bus stop relative to those crossing from sidewalk to sidewalk at the intersection, among males, and among young people, but the risk was lower under the presence of other waiting pedestrians. In addition, among pedestrians who crossed on red at center-lane BPRs, over a tenth did not check the traffic before crossing and another tenth checked the traffic in the wrong direction, thus further increasing the risk of pedestrian injury. All these findings are new and important for a better understanding of pedestrian crossing behaviors at urban intersections with embedded bus priority routes.

The remainder of this paper is structured as follows. Section 2 provides an overview of factors that affect pedestrian crossing behaviors at signalized intersections. Section 3 describes the study research model, with methods applied for observational data collection and analyses. Section 4 presents the study results. Section 5 provides a discussion on the study findings. Section 6 suggests the main conclusions with implications for planning BPRs.

2. Previous Research on Factors Affecting Pedestrian Behaviors at Signalized Intersections

A significant share of pedestrian accidents is associated with human errors in the interaction between road users and the road environment and/or non-compliance with traffic rules [34,35]. Among the risk factors associated with pedestrian injury at signalized intersections, the literature indicates non-compliance with red lights by crossing pedestrians, ignoring vehicular movement during crossing, insufficient length of green lights for pedestrians to complete the crossing, etc. [15,26,36–38].

Additional risk factors are related to pedestrians' characteristics, such as age and gender. For example, elderly pedestrians experience difficulties in distinguishing approaching vehicles, assessing vehicle speeds, and crossing intersections in a timely manner, due to ageing changes in their mental and motoric abilities [39–41]. Conversely, cognitive immaturity and a lack of necessary skills for safe crossing contribute to child and adolescent pedestrian injury [42–44]. Research suggests that elderly pedestrians delay longer before crossing signalized crosswalks and tend to comply more with traffic laws compared with younger pedestrians [45,46]. Regarding children's crossing patterns, observations at urban intersections in Israel have shown that risk-taking behaviors are higher among adolescents aged 14–17 compared with younger age groups; they cross more on red, without checking traffic, and while distracted [44,47].

Concerning pedestrians' gender, research has consistently indicated that male pedestrians are more likely to cross on red and tend towards higher risk-taking compared with

females [45,48,49]. Similar findings were revealed in observational surveys conducted in Israel [50]. Furthermore, the use of mobile phones while walking, especially for talking, reading, and writing messages, leads to a decrease in environmental awareness and a diversion of attention from the road [51,52].

Regarding crossing on a red light, observational surveys conducted in several countries have shown that a non-negligible share of pedestrians do not comply with traffic lights [38,53,54]. A national observational survey in Israel found that 30% of pedestrians crossed signalized intersections on a red light, and over 10% of those did so without checking whether the traffic conditions allowed for a safe crossing [50].

Moreover, the research literature indicates that a pedestrian's decision to cross on red is influenced by, among other things, infrastructure and environmental factors such as the duration of the red light, the length of the pedestrian crossing, the clearance time between green lights, the location of bus stops at intersections, surrounding land uses, etc. For example, it was shown that the longer the waiting time, the higher the probability of a pedestrian crossing on red [12,55,56]. A study [57] found that signalized crosswalks with a refuge island were associated with a higher frequency of red-light violations compared with crosswalks without refuges. Some pedestrians may perceive such crosswalks as less dangerous, leading them to be less hesitant to cross on red. A divided road may impose on the pedestrian an additional wait for a second green light, potentially encouraging red-light violations, especially if they are in a hurry to catch a bus [23].

The presence and behavior of other pedestrians also play a role in the individual's decision to cross on red. Research has shown that as the number of pedestrians waiting on the sidewalk increases, the probability of crossing on red decreases [38,49,56]. On the other hand, tendency towards social conformity increases the chance of a pedestrian crossing on red if other pedestrians do so [46,58]. Another study [59] analyzed separately the behavior of the first pedestrian and of those who followed, and found that the former had a strong influence on the decision of others to cross on red.

Finally, the destination of the crossing may influence compliance with traffic lights. For example, a study that examined pedestrian behavior in two cities in Poland found that pedestrians rushing to catch the tram were more likely to cross on red than others [58]. However, when traffic lights were coordinated with public transportation, better pedestrian compliance with traffic lights was observed.

3. Materials and Methods

3.1. The Study Framework

The previous literature indicates that unsafe pedestrian behaviors and especially crossing on red are among the main causes of pedestrian accidents at signalized intersections in general and at sites with BPRs in particular. At the same time, empirical data are lacking regarding the extent of red-light crossings at intersections with BPRs. Thus, this research aimed to examine the extent of unsafe pedestrian behaviors at urban intersections with BPRs, with a focus on crossing on red, while accounting for factors that may influence non-compliance with traffic lights (see Section 2). In addition, this study considered other pedestrian behaviors that may increase accident risk at BPR sites, e.g., not checking traffic before crossing or checking the wrong direction [23,32], and non-contextual behaviors such as using distracting devices during crossing [51,52].

Furthermore, as pedestrians' compliance with red lights may characterize the safety level of an intersection [34,36,60,61], this study intended to compare pedestrian behaviors at two types of BPR intersections, i.e., with a center-lane (CL) bus route and a curbside (CS) bus lane. Such examination may contribute to understanding the safety of various BPR settings and can assist in identifying factors that increase the risk.

The data on pedestrian behaviors were collected by means of field observations at the two types of BPR sites, which were selected in cities with operating BPRs. The requirements of the study sites were defined as follows: it should be a signalized intersection, located on a dual-carriageway road with a built median and two general vehicle lanes in each travel direction; the street should include a bi-directional BPR, moderate to high activity of crossing pedestrians, and a speed limit of 50 km/h. Such traffic settings are typical for streets with BPRs in Israel in recent decades, following the design guidelines [62,63]. A full list of intersections with BPRs in urban areas in Israel was received from another study conducted for the Ministry of Transport. This list was then reduced to exclude sites that did not satisfy the predefined requirements.

Furthermore, field surveys and consultations with traffic engineers from municipalities and the National Road Safety Authority were conducted to exclude intersections with specific (site-sensitive) layouts. The final list of intersections for the study observations included ten sites, five of each type, CL and CS, located in seven cities; the cities represented a combination of large-sized (e.g., Tel Aviv, Jerusalem, Rishon Lezion) and medium-sized Israeli cities (e.g., Ram Gan, Bat Yam, Bnei Brak, Kiriath Motzkin). The sites were situated on arterial and collector streets, with mostly mixed land uses in the street environment and in the proximity of commercial centers or other points of pedestrian attraction in the cities. Figure 1 provides examples of intersections of both types that were included in the study observations.

The research model for this study was formulated based on the literature review (see Section 2) to comprise potential explanators for red-light crossing behavior, such as the following:

1. pedestrian characteristics—age group and gender;
2. crossing characteristics—direction of crossing, destination of crossing (to or from the bus stop, or from one side to another side of the intersection), time (hour);
3. intersection characteristics—type of BPR (CL or CS), bus stops' location (on one side or both sides of the intersection), traffic levels (number of crossing pedestrians, number of buses in the BPR per hour), duration of red light;
4. situational variables—presence of other pedestrians (yes, no), presence of a bus at the bus stop (yes, no), use of distracting devices by pedestrians, i.e., mobile phone, earphones (yes, no).

Among pedestrians who crossed on red, additional behaviors were considered including stopping before crossing (yes, no), checking traffic before crossing (yes, no), and looking in the correct direction of approaching traffic (yes, no), to reflect safety rules being kept when violating the red light. Particularly, at intersections with CL BPRs, looking in the wrong direction for traffic may indicate the presence of the “three-route effect” (see Section 1). Regarding the age groups of pedestrians, a subdivision into major age groups was applied: children (below 18), adults (ages 18–64), and elderly (65+), in line with previous observational studies of pedestrians [37,38,50,61].

As introduced in Section 1, in the case of a CL BPR, at the intersection, the crosswalk is divided into three routes separated by raised islands (see Figure 2). To cross from one side of the intersection to the other, a pedestrian needs to pass three crosswalks, including the first vehicle route, the BPR, and the second vehicle route. In the case of a CS BPR, the bus lane is the far right in the direction of traffic, adjacent to the sidewalk; at the intersection, the crosswalk is divided into two parts by a raised median, similar to a common intersection on a divided urban street.

In the case of a CL bus route, the bus stops are located within the BPR. According to the guidelines [63], two types of bus stop location are possible: on one side of the intersection, where the stops are positioned facing each other, meaning that one stop is located before the

intersection, in the direction of travel, and the second after the intersection; or on both sides of the intersection, where the stops are located before the intersection in both directions of travel. For both cases of bus stop locations, in this study, five types of crossing destination were defined: (1) crossing from the sidewalk to a distant stop (includes two crosswalks); (2) crossing from the sidewalk to a nearby stop (one crosswalk); (3) crossing from a distant stop to the sidewalk (two crosswalks); (4) crossing from a nearby stop to the sidewalk (one crosswalk); and (5) crossing to another side of the intersection (three crosswalks). Figure 3 illustrates the definition of crossing destinations in a case with bus stops on one side of the intersection, for one crossing direction. Similar definitions were applied for the opposite crossing direction and for cases with bus stops on both sides of the intersection. In the case of a CS PTR, the bus stops are located on sidewalks and hence, any crossing of the intersection is “from side to side”.

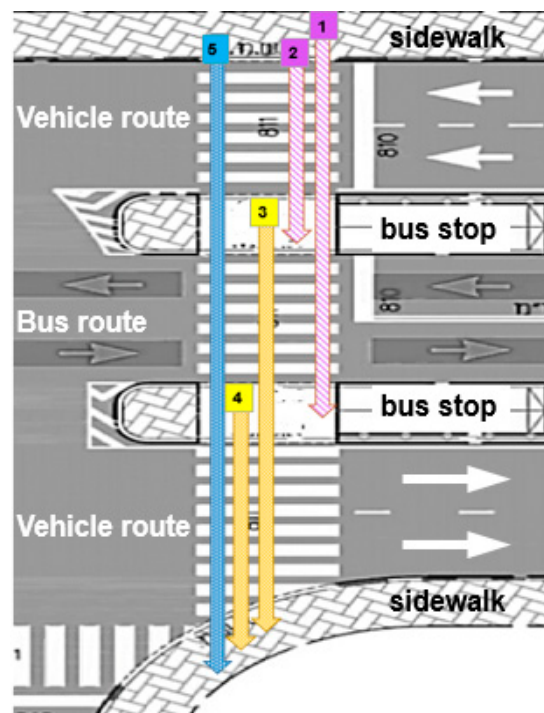


Figure 3. Definition of crossing destinations at intersections with CL BPRs (bus stops located on one side of the intersection). Destinations: 1, 2—from sidewalk to bus stop (two/one crosswalks), 3, 4—from bus stop to sidewalk (two/one crosswalks), 5—from sidewalk to sidewalk (three crosswalks).

3.2. Data Collection and Analyses

The study observations were conducted on weekdays between the hours of 8 a.m.–2 p.m. at the CL sites and 8 a.m.–1 p.m. at the CS sites. At each site, two observers were placed; one recorded pedestrian crossing behaviors, another collected data on pedestrian and bus traffic at the intersection and the duration of the traffic-light cycles. The observers worked according to a predefined protocol with a balanced sample of pedestrians by direction of crossing and crossing destination (at the CL BPR sites) and systematic counting over the hours. The data were recorded using a tablet or a smartphone.

More specifically, at the beginning of the shift, the first observer was positioned on one side of the intersection and monitored pedestrians crossing towards him from the opposite direction. Every hour, the observer switched observation side at the intersection (the crossing directions at each site were predefined by the research team). The observer visually surveyed the behavior of the first pedestrian who arrived at the crosswalk and followed him/her visually until he/she reached the destination. Upon completing the

data for the first pedestrian, the observer surveyed the behavior of the next pedestrian who arrived at the crosswalk, and so on. The observer recorded details of the pedestrian's age and gender, crossing on red over the different crosswalks, checking traffic conditions before crossing, and use of distractions, and also the crossing characteristics—direction, destination, presence of other pedestrians, and presence of buses at the bus stops, in accordance with the study research model. At intersections with a CL BPR, the observers were instructed to sample pedestrians based on the starting point of the crossing—from the sidewalk or from the bus stop, at predefined time intervals each hour.

The second observer conducted pedestrian and bus counts twice per hour, for four minutes each time, using a counter. Pedestrian counts were performed in both crossing directions, for all parts of the crosswalk at the intersection; the bus numbers in the BPR were counted in both travel directions. Measurements of traffic lights' timings (in seconds) were taken twice per hour after completing the traffic counts, using a stopwatch; the observer was instructed to start the stopwatch at the beginning of green until the signal turned red, continue, and measure the time until the next green. Then, red-light durations were estimated for each part of the crosswalk at the intersection.

To consolidate the observation method and duration, pilot observations were conducted at two sites, one of each type included in this study. The pilot showed that in five hours of busy morning–early afternoon traffic, it was possible to collect data on over 100 observed pedestrians per site. The observers were thoroughly trained by the study team in accordance with the observation protocol. The study observations took place in April 2019.

The main behavior indicators estimated in this study were the percentage of pedestrians who crossed on red among those who arrived at the crosswalk on red, for each part of the crosswalk at the intersection and in accordance with the crossing destination. Among those crossing on red, additional behavior indicators were estimated, including the percent of pedestrians who did not stop before crossing, crossed without checking the traffic, or checked the wrong traffic direction. In addition, the rates of pedestrians using distracting devices during the crossing were calculated.

The data analyses included several steps. For each type of site (according to their BPR layout), first, a summary of pedestrian behavior indicators was produced and the influence of various characteristics on red-light crossing was examined, using Pearson's chi-square test for a categorical feature and Student's *t*-test for a continuous one [64]. The difference was judged as significant with $p < 0.05$. To note, the chi-square test and *t*-test are both “goodness of fit” tests which examine a null hypothesis that the data follow the distribution assumed or belong to the same population. In both cases, a test statistic is estimated which shows the probability of obtaining test results at least as extreme as the result actually observed, under the assumption that the null hypothesis is correct. This probability is indicated as a *p*-value. The null hypothesis is rejected if the *p*-value is less than a predefined threshold value, which is referred to as significance level. This threshold is set by researchers before examining the data. In observational studies, it is commonly set to 0.05, though lower levels can be used as well [64,65]. In this study, the significance level was set at 0.05. The Results section shows the actual *p*-values estimated using the study data, which are given as “*p*”.

Second, a multivariate binary logistic regression model was fitted to the probability of crossing on red [65], to identify the most affecting factors. For each type of BPR sites, logistic regression models were adjusted for various crossing situations, for example, crossing on red over the first crosswalk (a vehicle route) or over at least one crosswalk of the intersection, while among potential explanatory variables, the characteristics collected during the observations were considered. Furthermore, a logistic regression model for the

probability of crossing on red was fitted while considering both types of sites together, to examine the impact of the BPR type. In addition, summary values were produced for additional behavior indicators of pedestrians who crossed on red, to explore the existence of the “three route-effect” at CL BPR sites.

The logistic regression models were fitted using a stepwise method. The process of model development lasted as long as adding a variable was associated with a significant difference in the *-2Log Likelihood parameter*. Adequacy of fit for a model was assessed by the significance of the *Omnibus chi-square test* of the model coefficients [66]; in addition, “pseudo R²” indices (e.g., *Nagelkerke R²*) and the percentage of correct predictions were estimated, where higher values of such parameters indicated a better fit. Furthermore, a *McFadden pseudo R²* index was evaluated to reflect the model’s improvement due to the inclusion of explanatory variables versus the initial model with intercept only (the null model) [66]. Using the models, adjusted odds ratios with 95% Wald confidence intervals were estimated to show the impacts of the explanatory variables’ values on the probability of crossing on red. Variables with a significant impact ($p < 0.05$) were counted for the interpretation of results. The regression models were developed using SPSS v.26 software.

4. Results

Table 1 provides descriptive statistics of the study observations. Overall, data on 1122 crossing pedestrians were recorded, of which 592 were at intersections with CL BPRs and 530 at intersections with CS BPRs. The hours covered by the observations included peak and off-peak hours, with a range of bus and pedestrian hourly traffic volumes. Most pedestrians observed at both types of sites were adults (86% and 83%); the percent of child pedestrians (below 18) was similar at both types of sites (8% and 6%, $p = 0.195$), while the share of elderly pedestrians was higher at sites with CS BPRs (11% vs. 6%, $p < 0.01$). Interestingly, at both types of sites, more female than male pedestrians were observed (58–59%). According to the mean hourly estimates, the numbers of crossing pedestrians were higher at the CL BPR sites, while higher bus volumes were observed at the CS BPR sites.

Table 1. Descriptive statistics of the study observations.

Characteristic	At Sites with CL BPRs	At Sites with CS BPRs
No of observations per site	86–137	87–131
Hourly number of crossing pedestrians: mean (s.d.)	239 (106)	179 (66)
Hourly bus volume in BPR: mean (s.d.)	29 (17)	50 (21)
Red light duration for pedestrians, sec: mean (s.d.)	First crosswalk—82.6 (20.1), second crosswalk—63.5 (27.1)	First crosswalk—42.3 (6.8), second crosswalk—30.6 (10.7)
Pedestrian age groups *	Below 18—8%, age 18–64—86%, 65 and over—6%	Below 18—6%, age 18–64—83%, 65 and over—11%
Pedestrian gender *	Males—42%, females—58%	Males—41%, females—59%
Pedestrian crossing destination *	To bus stop—37%, from bus stop—28%, to another sidewalk—35%	To another sidewalk—100%
Use of distracting devices by crossing pedestrians *	Wearing headphones: yes—9%, no—91%; talking on the phone: yes—16%, no—84%; looking at the phone: yes—15%, no—85%	Wearing headphones: yes—12%, no—88%; talking on the phone: yes—9%, no—91%; looking at the phone: yes—10%, no—90%
Percent of pedestrians crossing on red, by crosswalk (No of pedestrians approaching the crosswalk on red)	First crosswalk: yes—19%, no—81% (353); BPR crosswalk: yes—30%, no—70% (188); third crosswalk: yes—28%, no—72% (84)	First crosswalk: yes—6%, no—94% (354); second crosswalk: yes—12%, no—88% (290)
Checking traffic by pedestrians who crossed on red: (1) looking in correct direction, (2) not checking traffic, (3) checking traffic in wrong direction	First crosswalk: (1) 82%, (2) 12%, (3) 6%; BPR crosswalk: (1) 78%, (2) 11%, (3) 11%; third crosswalk: (1) 94%, (2) 6%, (3) 0%	First crosswalk: (1) 65%, (2) 30%, (3) 5%; second crosswalk: (1) 68%, (2) 26%, (3) 6%

* Of the total number of pedestrians recorded: N = 592 at CL BPRs, N = 530 at CS BPRs.

4.1. Pedestrian Behaviors at Intersections with Center-Lane BPRs

Figure 4 presents an overview of the rates of pedestrians crossing on red at the intersections with CL BPRs, according to their crossing destination and the crosswalk part at the intersection. It shows the following:

- Overall, 30% of the pedestrians observed crossed on red, over at least one crosswalk, with a higher rate among pedestrians crossing to a bus stop (33%) or from a bus stop (38%) compared with those who crossed to another side of the intersection—23% ($p < 0.05$).
- At the first crosswalk (a vehicle route), 19% of pedestrians crossed on red, and this rate was higher among those who crossed to a bus stop than those crossing to the other side of the intersection (difference not significant).
- At the middle crosswalk (a bus route), 30% of pedestrians crossed on a red light, and this behavior was more common among pedestrians who went to the bus stop compared with other crossing situations: 44% vs. 24% ($p < 0.05$).
- At the third crosswalk (a vehicle route), 28% of pedestrians crossed on red, while this behavior was more frequent among pedestrians who crossed only one crosswalk on their way from the bus stop compared with those who crossed two crosswalks on their way from the bus stop or crossed to the other side of the intersection: 42%, 28%, and 21%, respectively ($p < 0.05$).

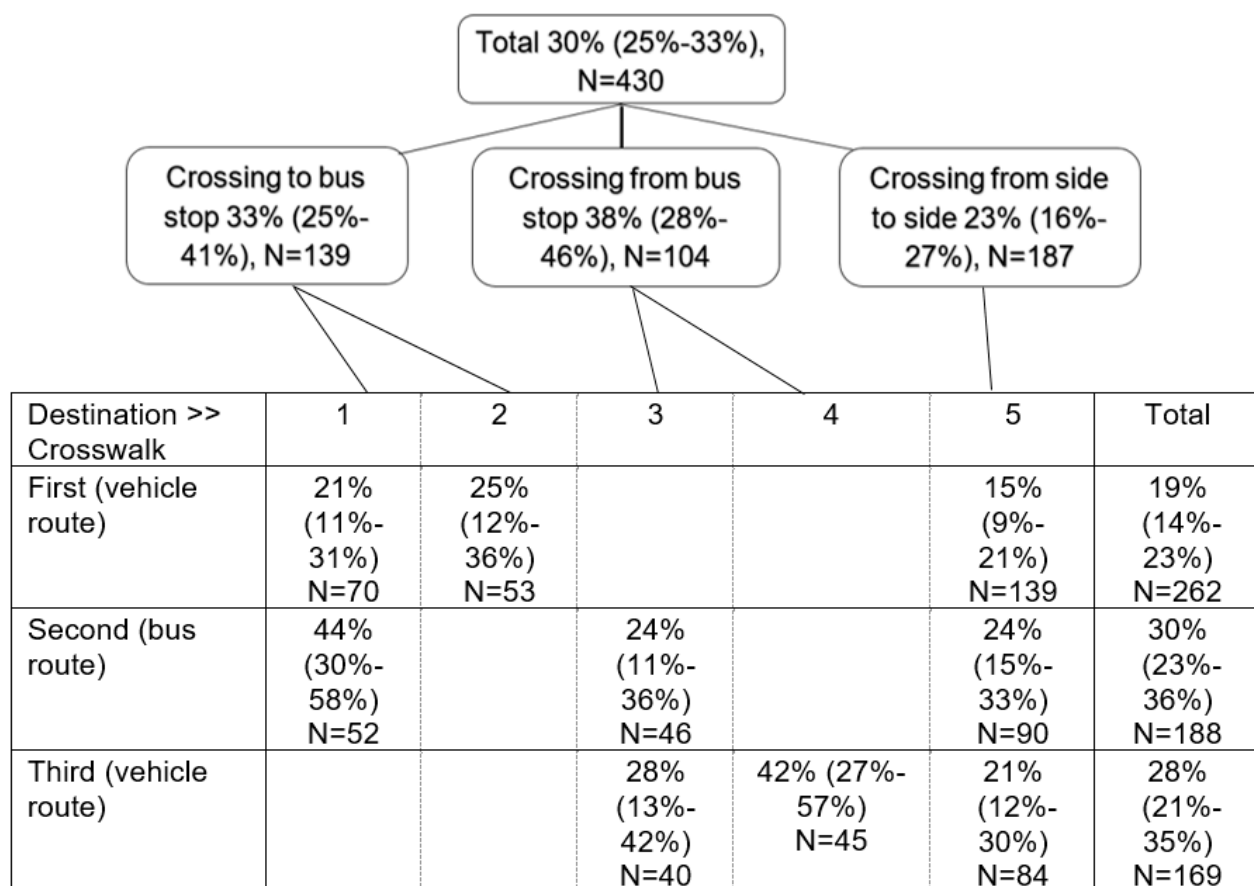


Figure 4. Rates of pedestrians crossing on red, at intersections with CL BPRs. Notes: in parentheses, a 95% confidence interval of the rate is given; N shows a sample size. See destination types (1–5) in Figure 3.

Concerning pedestrian age and gender effects, it was found that male pedestrians crossed on red more frequently compared with females: over at least one crosswalk at the

intersection, 38% vs. 24% ($p < 0.01$); when crossing the BPR, 44% vs. 20% ($p < 0.001$). Elderly pedestrians crossed on red less frequently compared with younger ones; for example, crossing on red in at least one crosswalk of the intersection was observed among 6% of elderly pedestrians vs. 31% and 32% among adult and child age groups ($p < 0.05$).

Further univariate analyses indicated that at the first crosswalk (for all crossing destinations), the red-light crossing rate was lower when other people were waiting while the observed pedestrian arrived compared with cases when the observed pedestrian was alone: 19% vs. 31% ($p < 0.001$). The rate of pedestrians crossing on red at the first crosswalk was not affected by the presence of a bus at the bus stop ($p = 0.21$) or by the duration of the red light ($t(351) = 1.04$, $p = 0.15$) (Student's t -test was used to compare the mean duration of the red light between the groups of pedestrians who crossed on red and those who waited for a green light. The one-sided t -test indicated that the null hypothesis could not be rejected and therefore, there was no significant difference between the two groups of pedestrians).

The rate of red-light crossings over at least one crosswalk of the intersection was higher at the hours of 9 a.m. and 10 a.m. in the morning and 1 p.m. in the afternoon, and lower at other times of observation ($p < 0.05$). A similar trend was observed in the percentage of pedestrians crossing on red at the BPR crosswalk ($p < 0.05$).

Concerning the impact of the bus stop locations (on one side or both sides of the intersection) the results were mixed: the rate of crossings on red in the first crosswalk was higher in the case of one-side bus stops vs. both sides, i.e., 28% vs. 16% ($p < 0.01$). However, the impact of this feature was insignificant when the rate of red crossings over at least one crosswalk of the intersection and the BPR crosswalk was examined.

The extent of using distracting devices while crossing was as follows:

- Overall, about 35% of pedestrians crossed at CL BPR intersections while distracted by using earphones and/or a mobile phone. As expected, the frequency of usage was very low among elderly pedestrians compared with other age groups: 3% vs. about a third ($p < 0.001$).
- This behavior was more common among pedestrians who crossed to the other side of the intersection compared with those crossing to or from a bus stop: 43% vs. 16% ($p < 0.05$).

Furthermore, multivariate logistic regression models were adjusted to the probability of crossing on red at CL BPR sites in three situations: (a) at the first crosswalk, (b) at the BPR crosswalk, and (c) over at least one crosswalk of the intersection (Table 2). The models showed that the probability of crossing on red was higher among male pedestrians and those crossing to a bus stop compared with pedestrians crossing to the other side of intersection (in models *b* and *c*). In addition, the probability was higher among pedestrians crossing from the bus stop than among those crossing to the other side of the intersection (in models *a* and *c*). Moreover, in the model for the first crosswalk, the probability was higher at sites with a bus stop located on one side of the intersection vs. both sides (close to significant, $p < 0.1$) and for later hours of observation. Conversely, the probability was lower under the presence of other pedestrians waiting for the green light (in models *a* and *c*) and when pedestrians were using distracting devices (in model *b*, close to significant, $p < 0.1$). For other characteristics examined, such as direction of crossing and the presence of a bus at the bus stop, insignificant impacts were found in all the models. It should be noted that pedestrian age groups were not considered in these models due to the small samples of young and elderly pedestrians in the data subsets, while the addition of red-light duration and the site (specific locations) did not improve the model fits.

Table 2. Binary logistic regression models for the probability of crossing on red at intersections with CL BPRs.

a—At the first crosswalk							
Variables	B	S.E.	Wald	Sig.	Exp(B)	95% C.I. for Exp(B)	
						Lower	Upper
Males vs. females	0.272	0.272	0.997	0.318	1.313	0.770	2.238
Using distracting devices vs. not	−0.244	0.316	0.594	0.441	0.784	0.422	1.457
Crossing to bus stop vs. from side to side	0.381	0.348	1.202	0.273	1.464	0.741	2.894
Crossing from bus stop vs. from side to side	0.915	0.359	6.502	0.011	2.497 *	1.236	5.047
Direction of crossing	−0.236	0.280	0.710	0.400	0.790	0.456	1.368
Presence of other pedestrians vs. alone	−0.733	0.293	6.272	0.012	0.480 *	0.271	0.853
Bus present at bus stop vs. not	−0.268	0.274	0.959	0.327	0.765	0.447	1.308
Bus stops' location on one side vs. both sides	0.543	0.326	2.780	0.095	1.721 #	0.909	3.258
Hour of observation	0.194	0.091	4.555	0.033	1.214 *	1.016	1.451
Constant	−3.292	1.033	10.151	0.001	0.037		
b—At the BPR crosswalk							
Variables	B	S.E.	Wald	Sig.	Exp(B)	95% C.I. for Exp(B)	
						Lower	Upper
Males vs. females	1.059	0.347	9.304	0.002	2.883 **	1.460	5.693
Using distracting devices vs. not	−0.750	0.397	3.560	0.059	0.472 #	0.217	1.029
Crossing to bus stop vs. from side to side	0.957	0.411	5.429	0.020	2.603 *	1.164	5.819
Crossing from bus stop vs. from side to side	0.096	0.462	0.043	0.836	1.100	0.445	2.723
Direction of crossing	0.045	0.390	0.013	0.908	1.046	0.487	2.248
Presence of other pedestrians vs. alone	−0.130	0.411	0.100	0.752	0.878	0.392	1.965
Bus present at bus stop vs. not	0.333	0.374	0.791	0.374	1.395	0.670	2.903
Bus stops' location on one side vs. both sides	0.174	0.410	0.181	0.670	1.191	0.533	2.658
Hour of observation	0.128	0.121	1.122	0.289	1.137	0.897	1.442
Constant	−3.019	1.398	4.663	0.031	0.049		
c—Over at least one crosswalk							
Variables	B	S.E.	Wald	Sig.	Exp(B)	95% C.I. for Exp(B)	
						Lower	Upper
Males vs. females	0.664	0.222	8.941	0.003	1.943 **	1.257	3.003
Using distracting devices vs. not	−0.211	0.247	0.726	0.394	0.810	0.499	1.315
Crossing to bus stop vs. from side to side	0.522	0.269	3.759	0.053	1.686 #	0.994	2.858
Crossing from bus stop vs. from side to side	0.764	0.290	6.927	0.008	2.146 **	1.215	3.789
Direction of crossing	−0.238	0.229	1.072	0.301	0.789	0.503	1.236
Presence of other pedestrians vs. alone	−0.515	0.248	4.333	0.037	0.597 *	0.368	0.970
Bus present at bus stop vs. not	−0.279	0.225	1.539	0.215	0.756	0.487	1.176
Bus stops' location on one side vs. both sides	0.213	0.254	0.701	0.402	1.237	0.752	2.034
Hour of observation	0.080	0.073	1.199	0.273	1.083	0.939	1.249
Constant	−1.770	0.824	4.613	0.032	0.170		

Model statistics: (a) N = 353; Nagelkerke R² = 0.121, correct prediction = 77.6%, McFadden pseudo R² = 0.08. (b) N = 188; Nagelkerke R² = 0.171, correct prediction = 75.5%, McFadden pseudo R² = 0.11. (c) N = 430; Nagelkerke R² = 0.094, correct prediction = 70.2%, McFadden pseudo R² = 0.06. Significant variables: * $p < 0.05$, ** $p < 0.01$, # $p < 0.1$.

4.2. Pedestrian Behaviors at Intersections with Curbside BPRs

The univariate analyses of pedestrian behaviors when crossing the intersections with CS BPRs indicated the following:

- Overall, 11% of pedestrians crossed on red over at least one crosswalk of the intersection (95% confidence interval, CI: 3–8%); on average, 6% crossed on red at the first crosswalk (CI: 8–15%) and 12% at the second crosswalk (CI: 8–13%).
- Similar to findings for the CL BPRs, males crossed on red more frequently than females: over at least one crosswalk, 16% vs. 8% ($p < 0.01$); at the second crosswalk, 18% vs. 8% ($p < 0.05$). Unlike the results for CL BPRs, differences between the age groups were insignificant.
- Similar to the behaviors observed at the CL BPR sites, the rate of crossing on red was higher when the pedestrian was alone compared with cases when other pedestrians were waiting on the sidewalk: 19% vs. 3% ($p < 0.001$). The rate of pedestrians crossing on red at the first crosswalk was not affected by the duration of the red light ($t(352) = -0.85$, $p = 0.20$), the presence of a bus at the bus stop, or the bus stop location.
- The rate of red-light crossings over at least one crosswalk of the intersection was higher between the hours of 8 a.m. and 10 a.m. than at the other observation times ($p < 0.05$).

- Overall, about a quarter of pedestrians crossed the CS BPR sites while using distracting devices. Similar to findings at the CL sites, the frequency of using distracting devices was lower among elderly pedestrians compared with other age groups: 3% vs. 25% ($p < 0.01$).

Multivariate logistic regression models were fitted to the probability of crossing on red at CS BPR sites in two situations: (a) at the first crosswalk and (b) over at least one crosswalk of the intersection (Table 3). The models showed that in both cases, the probability was lower when other pedestrians were present on the sidewalk. In addition, in model *b*, a higher probability was found for male pedestrians. Regarding other characteristics examined including pedestrian age group, use of distracting devices, direction of crossing, and hour, insignificant impacts were found in both models. Other site characteristics, e.g., bus stops' location, duration of red lights, and the site (as a specific location) were not included in the final models due to their negligible contribution to the model fit.

Table 3. Binary logistic regression models for the probability of crossing on red at intersections with CS BPRs.

a—At the first crosswalk							
Variables	B	S.E.	Wald	Sig.	Exp(B)	95% C.I. for Exp(B) Lower	Upper
Males vs. females	0.617	0.500	1.523	0.217	1.853	0.696	4.936
Young vs. elderly	−0.135	0.968	0.019	0.889	0.874	0.131	5.824
Adults vs. elderly	−0.972	0.660	2.172	0.141	0.378	0.104	1.378
Using distracting devices vs. not	0.447	0.574	0.606	0.436	1.563	0.508	4.815
Direction of crossing	−0.088	0.530	0.028	0.868	0.916	0.324	2.589
Presence of other pedestrians vs. alone	−1.820	0.501	13.196	<0.001	0.162 **	0.061	0.433
Hour of observation	−0.121	0.192	0.396	0.529	0.886	0.609	1.291
Constant	0.042	2.229	0.000	0.985	1.043		
b—Over at least one crosswalk							
Variables	B	S.E.	Wald	Sig.	Exp(B)	95% C.I. for Exp(B) Lower	Upper
Males vs. females	0.677	0.303	4.979	0.026	1.968 *	1.086	3.568
Young vs. elderly	0.535	0.671	0.636	0.425	1.707	0.458	6.359
Adults vs. elderly	0.097	0.475	0.042	0.837	1.102	0.435	2.796
Using distracting devices vs. not	−0.668	0.411	2.635	0.105	0.513	0.229	1.148
Direction of crossing	0.212	0.353	0.361	0.548	1.236	0.619	2.470
Presence of other pedestrians vs. alone	−0.741	0.337	4.825	0.028	0.477 *	0.246	0.923
Hour of observation	−0.137	0.114	1.430	0.232	0.872	0.697	1.091
Constant	−0.626	1.346	0.216	0.642	0.535		

Model statistics: (a) $N = 354$; Nagelkerke $R^2 = 0.158$, correct prediction = 94.4%, McFadden pseudo $R^2 = 0.13$. (b) $N = 477$; Nagelkerke $R^2 = 0.073$, correct prediction = 88.9%, McFadden pseudo $R^2 = 0.05$. Significant variables: * $p < 0.05$, ** $p < 0.001$.

4.3. A Combined Model for Both Types of Sites

Following a separate examination of the two types of sites, a combined logistic regression model was developed for the probability of crossing on red while considering both types of sites together. The model was fitted for crossing on red over the first crosswalk—a vehicle route—which was present in both types of intersections with BPRs. This model aimed to examine the impact of the BPR type, having controlled for other pedestrian and site characteristics. The model was adjusted in two steps; initially, it included the characteristics that were available for both types of sites, including pedestrians' age and gender, use of distracting devices, direction of crossing, presence of other pedestrians, red-light duration, and hour; on the second step, the BPR type was added to the model.

The combined model showed (Table 4) that at the intersections with CL BPRs, the probability of crossing on red was substantially higher compared to the CS BPR type. The BPR type had the strongest impact on red-crossing behavior related to other explanatory variables, while its addition improved the model's fit (McFadden pseudo R^2 increased from 0.09 to 0.12). Besides, the combined model indicated that young and adult pedestrians crossed more on red than elderly pedestrians and that, overall, in later morning hours a

higher risk of crossing on red is expected. Conversely, presence of other waiting pedestrians has a mitigating effect on the probability of crossing on red. For pedestrian gender, using distracting devices, direction of crossing and duration of red-lights no significant impact was found.

Table 4. Combined model: binary logistic regression model for the probability of crossing on red, in the first crosswalk, at intersections with CL and CS BPRs, together.

Variables	B	S.E.	Wald	Sig.	Exp(B)	95% C.I. for Exp(B)	
						Lower	Upper
Males vs. females	0.352	0.232	2.311	0.129	1.422	0.903	2.240
Young vs. elderly	1.317	0.639	4.242	0.039	3.732 *	1.066	13.070
Adults vs. elderly	0.831	0.500	2.761	0.097	2.295 #	0.862	6.115
Using distracting devices vs. not	−0.186	0.274	0.462	0.496	0.830	0.486	1.419
Direction of crossing	−0.095	0.232	0.169	0.681	0.909	0.577	1.432
Presence of other pedestrians vs. alone	−0.940	0.246	14.603	0.000	0.391 **	0.241	0.633
Hour of observation	0.193	0.087	4.967	0.026	1.213 *	1.024	1.438
Duration of red light	−0.009	0.007	1.517	0.218	0.991	0.978	1.005
Type of BPR: CL vs. CS	1.721	0.379	20.666	0.000	5.589 **	2.662	11.737
Constant	−4.500	1.051	18.343	0.000	0.011		

Model statistics: N = 707; Nagelkerke R² = 0.173, correct prediction = 86.4%, McFadden pseudo R² = 0.12. Significant variables: * $p < 0.05$, ** $p < 0.001$, # $p < 0.1$.

4.4. Other Pedestrian Behaviors When Crossing on Red at Intersections with BPRs

As explained in Section 3, for pedestrians who crossed on red, additional behaviors were recorded, regarding following safety rules, e.g., stopping before crossing, checking vehicle traffic before crossing, and looking in the correct direction of approaching traffic. At sites with CL BPRs, particular attention was given to looking in the wrong direction, potentially characterizing the existence of the “three-route effect”.

Figure 5 illustrates the rates of unsafe behaviors observed among pedestrians who crossed on red over the first crosswalk and the BPR crosswalk at intersections with CL BPRs. One can see that the rates of pedestrians who did not stop and did not check the traffic before crossing were similar in both cases: 38–39% and 11–12%, respectively, while the rate of pedestrians who looked in the wrong direction tended to be higher across the bus route: 11% vs. 6%; however, the differences between the two crosswalks were not statistically significant.

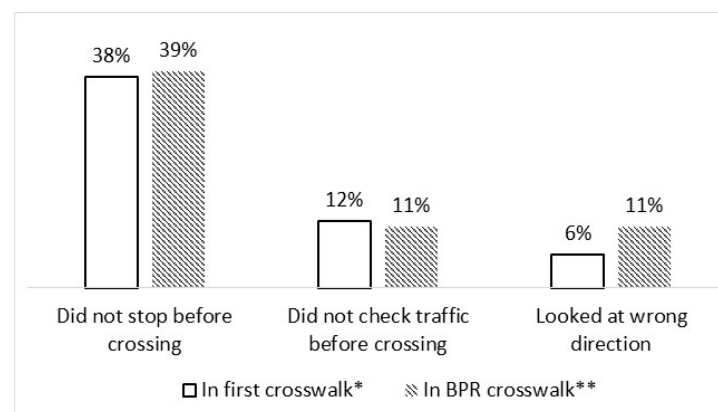


Figure 5. Additional unsafe behaviors among pedestrians who crossed on red at intersections with CL BPRs (* N = 79, ** N = 56).

Furthermore, the observations showed that at intersections with CS BPRs, among pedestrians who crossed on red in the first crosswalk, 30% did not check the traffic before crossing and 5% looked in the wrong direction, while at the second crosswalk, these rates were 26% and 6%, respectively (see Table 1). A comparison revealed that for both behaviors, the differences between the two types of sites (CL vs. CS) were not statistically significant.

(at a 0.05 level). (It should be noted that the number of pedestrians who looked in the wrong direction at the CS BPR sites was very small, three cases in total.)

A detailed examination of cases at the CL BPR sites indicated that the behaviors of not checking traffic and looking in the wrong direction when crossing on red were observed mainly among pedestrians who crossed to/from the bus stop, and they did not appear among pedestrians who crossed from one to another sidewalk of the intersection. This difference was significant at both the first crosswalk ($p < 0.05$) and the BPR crosswalk ($p < 0.05$).

The “three-route effect” manifests in checking the wrong direction of bus/vehicle traffic and is mainly expected at the second crosswalk, e.g., when a pedestrian crosses a bus route after crossing the vehicle route or when they cross the vehicle route after crossing the BPR. Figure 6 provides an overview of cases observed at the CL BPR sites when pedestrians crossed on red and used at least two consecutive crosswalks; the cases are subdivided according to the part of the crossing, the destination, and the checking of vehicle traffic by pedestrians. In total, 12 pedestrians were observed who checked traffic in the wrong direction (10%), which mostly occurred in two scenarios: when crossing the bus route on the way to the bus stop and when crossing a vehicle route on the way from the bus stop. In addition, in 15 cases (13%), pedestrians did not check traffic conditions; these cases occurred during crossings to or from the bus stop. In contrast, neither of these types of pedestrian error were observed among pedestrians who crossed from side to side of the intersection.

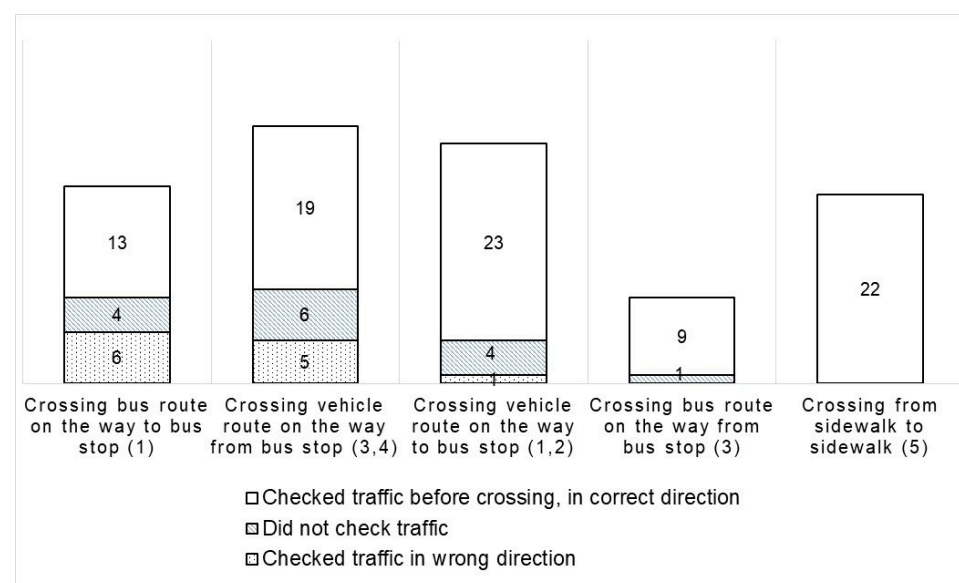


Figure 6. Subdivision of pedestrians who crossed on red at CL BPRs, by crossing part, destination, and checking traffic before crossing (N = 113; destination types 1–5 are indicated in parentheses).

5. Discussion

In this study, observations of pedestrian behaviors at signalized intersections with bus priority routes were performed aiming to characterize pedestrians’ red-light crossings and to compare the two common types of BPRs in this context: a center lane and a curbside lane. Previous research has indicated that pedestrian injury is one of the current safety concerns in relation to BPR operation [13–15,22,28], while unsafe pedestrian behaviors and particularly, crossing on red appear among the main causes of pedestrian accidents at signalized intersections [12,34,35,38]. Moreover, previous research regarding BPR corridors provided mixed findings concerning accident changes associated with various BPR configurations, while behavior research on the topic has been scarce. Thus, the current

study aspired to reduce this gap by conducting observations of pedestrian behaviors at typical intersections with BPRs. Furthermore, this study considered a wide range of factors that may influence pedestrians' non-compliance with traffic lights, according to the literature [12,36,38,41,45,49], including pedestrian characteristics, crossing conditions, and the characteristics of infrastructure settings and traffic at the sites observed. Pedestrian behaviors were analyzed in relation to the intersection structure and crossing destination, aiming to contribute to insights into traffic arrangements.

This study found that non-compliance with traffic lights at intersections with center-lane BPRs was a common phenomenon; on average, 30% of pedestrians crossed on red at one or more of these intersection crosswalks. At intersections with curbside BPRs, pedestrians' non-compliance with red lights was lower, at 11% on average. For comparison, a national observational survey of pedestrian behaviors in Israel revealed [50] that 30% of pedestrians crossed on red at signalized intersections. Therefore, the prevalence of red crossings at intersections with CL BPRs was similar to the national average, while intersections with CS BPRs were associated with a lower risk of crossing on red.

Concerning the factors affecting pedestrian compliance with traffic lights, the current study findings indicated that, similar to previous research [45,46,48,49], male pedestrians crossed on red more often than females, elderly pedestrians were more obedient to red lights, while young pedestrians tended to cross on red more frequently than other age groups. In addition, in line with other studies [38,56], it was observed that the presence of other pedestrians increased the level of compliance with red lights, and this effect was consistent and significant for both types of BPR sites and across various study models.

Similar to earlier research [23,56,58], this study found that the level of pedestrian compliance with red lights was affected by the road infrastructure setting. Regarding the impacts of bus stops' location at the intersection (on one or both sides) and the duration of the red light, this study did not yield significant findings, which may be related to the limitations of the data collected. The strongest finding of this research was that, controlling for other explanatory variables, the probability of crossing on red was substantially higher at the intersections with CL BPRs compared with the CS BPR type. Yet, it should be noted that the combined model examined the probability of red crossing over the first crosswalk, which represented a vehicle route with two lanes at the CL BPR sites, and included two general traffic lanes and a bus lane at the CS BPR sites. This meant that in the latter case, there was a longer crossing distance, which might have had an enduring effect on pedestrians' tendency to cross on red. At the same time, the detailed findings on red crossings at the intersections with CL BPRs showed a higher intention to cross on red over the second and third parts of the crosswalks (the bus route and a second vehicle route), indicating the higher risk associated with CL BPRs.

Additional explanations of a higher frequency of red-light crossings at CL BPR intersections may be related to a higher presence of refuge islands in these crosswalk settings [57]; such crosswalks may be perceived as less dangerous by pedestrians, thus leading them to be less hesitant to cross on red, or the need for an additional wait for a second (and third) green may potentially encourage red-light violations [23]. In general, red-light durations were longer at the CL BPR than at the CS BPR intersections in the current study, which might have increased the probability of pedestrians crossing on red [12,55,56], yet, a direct impact of this feature was not found in the current study.

This study showed that at intersections with CL BPRs, non-compliance with red lights was more prominent among pedestrians crossing to or from the bus stop relative to those who crossed to another side of the intersection, thus supporting the expectation that crossing destination influences compliance with traffic lights, in line with previous findings [58].

Concerning the effects of the use of distracting devices by crossing pedestrians, the direction of crossing, the presence of a bus at the bus stop, and the hour of observation, mostly insignificant impacts were found in the current study analyses, although some models indicated that in the later morning hours, a higher risk of crossing on red could be expected.

Recent research literature has drawn attention to the increasing use of mobile phones by pedestrians [51,52], that leads to a decrease in environmental awareness and potential violation of traffic rules. The current study findings showed that 35% of pedestrians at the CL BPR sites and 25% at the CS BPR sites crossed a road while being distracted (using a mobile phone and/or earphones). While the general rate of use was substantial, the study found that, as expected, the frequency of using distracting devices was lower among elderly pedestrians compared with other age groups, at both types of sites. At the CL BPR sites, this behavior was more common among pedestrians who crossed to the other side of the intersection compared with those crossing to or from a bus stop. However, it was not associated with a significant change in the probability of crossing on red, actually indicating a decreasing trend.

Among pedestrians who crossed on red at the intersections with CL BPRs, about 40% did not stop before crossing, and over 10% did not check the traffic before crossing. The latter rate was comparable with findings of a national observational survey of pedestrian behaviors at signalized intersections [50]. At the intersections with CS BPRs, among pedestrians crossing on red, the observed rates of not checking the traffic were higher but the differences related to the CL BPR sites were not statistically significant, due to the small data samples for red crossings.

Regarding the “three-route effect” at intersections with CL BPRs, which may increase accident risk due to looking in the wrong traffic direction by pedestrians who cross on red [23,32], the current research provided an empirical estimate that this occurred in 10% of cases (when pedestrians crossed on red at the CL BPR sites). However, pedestrian errors in checking the direction of traffic were mainly observed in situations where pedestrians crossed to or from the bus stops, and not when crossing the entire width of the road from sidewalk to sidewalk. This finding suggests that the occurrence of such errors may also be influenced by other factors not measured in the current study, such as being in a hurry to reach the bus stop on time, the pedestrian’s familiarity with the intersection, etc. In addition, regarding this behavior, a statistically significant difference between the two types of BPRs (CL vs. CS) was not ascertained; hence, the presence of the “three-route effect” at intersections with CL BPRs still needs to be proven. Evidently, further research is needed to understand this behavior more comprehensively.

In summary, the current study has demonstrated that signalized intersections with CL BPRs impose increased safety risks, as pedestrian non-compliance with red lights at such sites was significantly higher compared with intersections with CS BPRs. At the same time, while comparing the safety performance of the two types of BPRs, one cannot ignore the findings of previous studies that analyzed accident data and found that, under certain conditions, center-lane BPRs were associated with lower accident rates compared with other BPR forms [12,15,28]. Furthermore, current global and local knowledge summaries on BPR design promote the use of both types of BPRs [9,10,12,13,63].

In a more general sense, it should be noted that current policies of urban development promote traffic calming measures in urban areas to improve the safety of vulnerable road users and to exhibit changing priorities in town planning [67–69]. However, this issue has hardly been explored in the context of BPR design. For example, an Israeli study [28] found that streets with center-lane BPRs adjacent to a single traffic lane had better safety performance than similar streets with more traffic lanes, thereby pointing to a positive

safety effect of reducing the number of lanes on streets with BPRs. A recent US study [70] reported on speed reductions observed following changes in road layouts due to setting BRT corridors in a city in New Mexico, suggesting that BPR infrastructure changes may have traffic-calming effects with associated injury prevention. It seems that combining BPR planning with traffic-calming considerations may be a promising approach for creating a safer urban environment, particularly when focusing on pedestrian safety in the vicinity of BPRs. In this context, more empirical research is required to support effective design solutions to meet public transport priorities in combination with pedestrian safety needs.

This study's limitations lie in the relatively small samples of pedestrians crossing on red that were collected in the observations, which restricted the ability to ascertain the effects of some factors examined in the study. The explanatory power of multivariate models fitted in the current study was relatively low, indicating the possibility that other factors rather than those measured in the study might also affect the behavior considered. The data collection in this study was performed by trained observers, enabling coverage of characteristics related to pedestrian behaviors and crossing conditions across various parts of the observation sites. However, this method is constrained by the hours of data collection and the extent of details that can be documented at a given time. This study examined a predefined list of variables that, based on previous research, were expected to affect pedestrian behaviors at signalized intersections. The current study observed pedestrian behaviors in the morning to early afternoon hours; to examine the differences in pedestrian behaviors at other hours of the day vs. those covered by the current study more observational studies would be useful. Among other potentially influential variables that were not measured in this study, the following can be mentioned: general vehicle traffic volumes, bus arrival times, pedestrian waiting times, environmental characteristics of intersections, etc. Further observational research is needed to explore the effects of additional factors on risky pedestrian behaviors at signalized intersections with BPRs. To explore socio-cultural factors, the personal habits of pedestrians, their familiarity with the intersection, and other background factors among potential explanators for pedestrian crossing behaviors, questionnaire surveys are required, as such factors cannot be collected through observational research.

6. Conclusions

In this study, in light of the growing development of bus priority routes in urban areas and associated safety concerns, pedestrian crossing behaviors were examined at intersections in Israel with two common types of BPRs. The study found that center-lane BPR intersections were characterized by a higher safety risk, in terms of non-compliance with red lights by pedestrians, relative to intersections with curbside BPRs. Furthermore, the tendency to cross on red was higher among pedestrians crossing to or from the bus stop, males, and young pedestrians but lower under the presence of other waiting pedestrians. Among pedestrians who crossed on red at intersections with center-lane BPRs, non-negligible shares did not stop before crossing, did not check the traffic, or checked the traffic in the wrong direction, thus further increasing the risk. Overall, this observational study provides useful insights regarding the human factor's involvement in creating safety risks at BPR sites, which may assist road designers and decision-makers in future planning of BPRs.

Practical implications of this study may involve considering infrastructure solutions that might reduce the intention to cross on red, thereby improving pedestrian safety at intersections with CL BPRs. Such solutions may include, for example, implementing a green wave for crossing pedestrians and reducing waiting times, or improving intersection design by arranging crosswalks consisting of two parts instead of three by removing one of

the refuge islands. However, each solution should undergo an evaluation of impacts on pedestrian behaviors and the safety performance of intersections with BPRs. In addition, recognizing the rapid expansion of BPRs in the country, education and awareness programs for pedestrians should be promoted to emphasize the heightened risk of crossing on red at intersections with bus priority routes.

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