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Exploring patterns of child pedestrian behaviors at urban intersections

Victoria Gitelman[a,*], Sharon Levi[b], Roby Carmel[a], Anna Korchatov[a], Shalom Hakkert[a]

[a] Transportation Research Institute, Technion - Israel Institute of Technology, Haifa, Israel
[b] Beterem - Safe Kids Israel, Petach Tiqwa, Israel

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ABSTRACT

Children are more vulnerable as pedestrians due to their cognitive, physical and behavioral traits. However, walking is one of the main forms of travel for children, particularly during leisure hours. Child pedestrian injury primarily occurs in urban areas, with a significant share at crosswalks. This study observed child pedestrian behaviors at crosswalks of urban intersections aiming to characterize their behavior patterns and identify risk factors that may lead to injury. Crossing behaviors of children and adolescents up to age 18, during leisure hours, were video-recorded at 29 crosswalks, on signalized and un-signalized intersections situated on collector roads. Some children used pedestrian crosswalks while riding a bicycle or other non-motorized means; they were also included in the sample. Behaviors of 2930 young road users were encoded and compared by age groups. Multivariate logistic regression models were adjusted to identify factors associated with crossing on red and with non-checking vehicle traffic at un-signalized crosswalks. The findings pointed to different behavior patterns for the various child age groups. Risk-taking behaviors are higher for older children; adolescents aged 14–17 cross more on red, without checking traffic, outside crosswalk boundaries and while distracted. At all types of sites, a fifth of children over the age of 9 crossed by riding, the probability of crossing on red and of non-checking traffic prior to crossing at an un-signalized crosswalk was higher for children riding an electric bicycle or kick-scooter. The non-checking of traffic was also higher when a child is distracted by a mobile phone or other electronic gadget, or carries a big object. Children under age 9 were usually accompanied by adults but still exhibited risk-taking behaviors that apparently mirrored those of the adults. Risk-taking behaviors of young road users should be taken into account in the development of injury prevention programs focusing on child and parent education and training, and by adapting the urban environment to better meet their needs.

1. Introduction

Road crashes are a leading cause of unintentional injuries in children worldwide and the leading cause of injury-related death in children aged 1–17 in Israel (Peden, 2008; Nir et al., 2017). Research worldwide found that children are injured as pedestrians at higher rates than other transport modes: about 38% of child mortality in road crashes is as pedestrians (WHO, 2015).

Children are vulnerable road users in urban areas, in particular as pedestrians, traveling to and from schools, community centers, parks, and other neighborhood and city destinations. An analysis of pedestrian crash data in Israeli municipalities, in 2009–2012, revealed that the share of severe injuries among children was consistently higher than among adults, by 1.25 times, on average (Levi et al., 2015). Children comprise, on average, 31% of the total severe pedestrian injuries in urban areas in Israel. The data also showed that most cases of child and adolescent injuries as pedestrians took place in the afternoon and evening (about 56%), with the highest concentration of injury incidents between 1:00 and 7:00 pm (Levi et al., 2015). In a previous study on child travel patterns in Israel, these hours were identified as the time involving the majority of child travel for leisure purposes of all types (Levi et al., 2013). The findings also indicated that Israeli children are active and independent travelers, from the age of six through adolescence, along various routes throughout the day and making considerable use of walking.

Studies reveal that children and adolescents are particularly vulnerable because of their cognitive traits, physical and behavioral characteristics (Schwebel et al., 2012; Schieber and Thompson, 1996; AAP, 2009; WHO, 2013; Meir et al., 2015). Lack of maturity in cognitive, behavioral, and physical abilities limit their capacity to evaluate risk and make them more susceptible to injuries. In particular, young children below 13, have difficulties in judging vehicle speeds, travel

* Corresponding author.
E-mail addresses: trivica@technion.ac.il (V. Gitelman), sharonl@beterem.org (S. Levi), robyc@technion.ac.il (R. Carmel), grabarn@technion.ac.il (A. Korchatov), hakkert@technion.ac.il (S. Hakkert).

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direction and vehicle distance from the crosswalk that impair their ability in selecting crossing gaps (Connely et al., 1998; Foot et al., 1999; MacGregor et al., 1999; Morrongiello et al., 2015). Additionally, young children experience difficulties in orientation in the urban environment and in identification of potential hazards in road-crossing reality (Leden et al., 2006; Meir et al., 2015). Previous research has indicated that children's impulsive behavior places them at a higher risk for road traffic injury than adults (Schwebel et al., 2012). Similarly, crash data in Israel point to higher rates of child pedestrians "darting out" suddenly in the middle of the road or from a hidden point as opposed to adults (Levi et al., 2015).

As children approach adolescence, their abilities begin to be more similar to those of adults; however, the development of necessary skills varies as to age and individual. Even past age 14 there is some concern that teens are not yet as skilled as adults, possibly due to more limited experience (Plumert and Kearney, 2014; O'Neal et al., 2018). Risk-taking behavior, common for both younger children and adolescents, may be deliberate, due to a lack of knowledge, or because of peer pressure (Schieber and Thompson, 1996; Schwebel et al., 2012). In addition, risk-taking among adolescent pedestrians may be further influenced by gender, with higher levels of risk-taking by male teens, and may increase with age, due to a lower perception of dangers in the road environment (Granié, 2009). One of the potential risk-taking behaviors more common among adolescent pedestrians is use of mobile devices. There is initial evidence that distraction due to this type of secondary task may be dangerous for both child and adolescent pedestrians (Stavrinos et al., 2009; Tapiro et al., 2016).

Beyond the inherent vulnerability of child pedestrians due to their personal cognitive, physical and behavioral development, the urban environment is often not designed for safe travel of children. Many roads are characterized by high speeds, heavy traffic volumes, and presence of obstacles that reduce visibility and increase risk of child injury (Schieber and Thompson, 1996; Schieber and Vegega, 2002; Schwebel et al., 2012). The location of schools or other attractions for children and adolescents may contribute to increased risk of pedestrian injury (Schwebel et al., 2012). Moreover, design of pedestrian facilities in urban areas frequently does not account for the limitations and needs of child pedestrians (Leden et al., 2006; Johansson and Leden, 2010; Johansson et al., 2011). Traffic calming measures such as speed humps, elevated crossings, and road narrowing were shown to be effective in providing safer crossing conditions for young pedestrians. Following installation of such measures, drivers ceded the right of way to child pedestrians at a higher rate (Johansson and Leden, 2007).

Parental supervision has the potential to contribute to pedestrian safety for children both by modeling good behaviors and by providing appropriate instructions (Barton and Schwebel, 2007; Morrongiello and Barton, 2009; Morrongiello and Corbett, 2015). However, parents may not provide the necessary skills for safe pedestrian behavior (Rosenbloom et al., 2008; Morrongiello and Barton, 2009; Morrongiello and Corbett, 2015). In addition, parents and other adults tend to overestimate a child's ability and skills proffering less supervision than necessary (Dunne et al., 1992; MacGregor et al., 1999; Morrongiello and Corbett, 2015).

In general, pedestrian behaviors is one of the road safety topics that has been extensively researched in the literature. As a result, common knowledge on the general pedestrian population is often applied to child pedestrian behaviors, limitations and needs. Further empirical findings targeting child pedestrians are required for better understanding of the phenomenon and in order to tailor appropriate injury prevention measures, with a particular focus on the detailed characteristics of crossing pedestrians and urban site conditions.

Field observational studies have been utilized to explore child pedestrian behaviors in various types of urban environment and traffic composition (Zeedyk and Kelly, 2003; Leden et al., 2006; Johansson and Leden, 2007; Rosenbloom et al., 2008; Mendoza et al., 2010). Additional forms include self-reports (e.g. Koekemoer et al., 2017) and simulation studies (e.g. Meir et al., 2015; Morrongiello and Corbett, 2015; Tapiro et al., 2016). However, previous research with observational surveys frequently used a limited scope of data on child pedestrian behaviors. Some larger scale observational studies considered the impacts on child crossing behaviors of specific infrastructure measures such as speed cushions before pedestrian crossings (Johansson et al., 2011) or count-down pedestrian signals at signalized intersections (Fu and Zou, 2016). Recently, video-based data collection has been applied for a limited number of observational child pedestrian studies (Johansson and Leden, 2007; Morrongiello and Barton, 2009; Johansson et al., 2011; Fu and Zou, 2016).

This study intended to add to existing research on observations of child and adolescent pedestrian behaviors in real-time conditions, by conducting data collection at a variety of typical urban settings where children are most likely to be observed and where higher rates of child pedestrian injuries occur. The study aimed to characterize the behavior patterns of young pedestrians at crosswalks of different types of urban intersections and identify risk factors that may lead to road injury. In the current study, video-based data were captured on a substantial sample of children, allowing for more detailed investigation of various safety related behaviors, including interactions with the environment and other road users. An additional motivation of this study was the collection and analysis of local data on child pedestrian behaviors for planning safety interventions. It should be noted that the study observations revealed that some children used pedestrian crosswalks while riding a bicycle or other non-motorized means. Such cases were included in the study analyses as they characterize the actual use of pedestrian crosswalks by children.

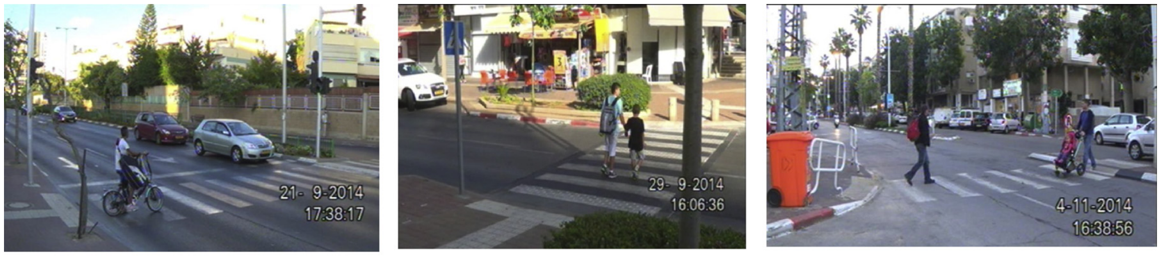
2. Methodology

2.1. Study sites

Following previous analyses of pedestrian crashes in urban areas and child travel activities (Levi et al., 2013, 2015), this study focused on crossing behaviors of pedestrians under age 18, during leisure hours. In Israel, the traffic laws require that drivers slow down at crosswalks and stop if the pedestrian shows intent to cross; this includes standing near the crossing and preparation for crossing as well as actually stepping onto the crosswalk. Pedestrians and particularly children at schools, are instructed to stop prior to crossing a road and check for vehicles. Road safety messaging and education publicize that child pedestrians may not cross roads independently until age nine. In addition, the traffic laws prohibit using pedestrian facilities for cycling. A cyclist is required to get off the bicycle and walk across the crosswalk while wheeling the bicycle. The regulations also limit the use of electric bicycles to children above the age of 14 (at the time of observations; since May 2016 - above 16).

The data were collected through field observations, by means of video-recording. To select observational sites we sought pedestrian crosswalks at urban intersections, with a higher potential to observe children and teenagers, in the afternoon and evening hours. Such sites were selected on collector roads situated at the boundaries of neighborhoods or in city centers close to attractions such as community centers, public parks and shopping malls. The study focused on collector roads, characterized by substantial traffic volumes and higher pedestrian activities. Previous research indicated that such streets are associated with higher concentrations of pedestrian crashes in urban areas in Israel (Gitelman et al., 2012).

The study sites were chosen from the typical urban road settings in Israel, including: (1) signalized intersections, with a divided road layout in the junction area (two or more lanes per travel direction and a built median); (2) un-signalized intersections on undivided roads (with one traffic lane in each direction, no median), and (3) un-signalized intersections on divided roads (with two lanes in each travel direction and a built median). The sites were selected in three cities representing



a – A signalized intersection b – An un-signalized intersection on an undivided road c – An un-signalized intersection on a divided road

Fig. 1. Examples of observational sites in the study.

different types of urban environments in the country, as follows:

(1) Rishon Lezion - a big city, not densely-populated, with a medium socio-economic level;
(2) Givatayim – a medium-sized city, densely-populated, with a high socio-economic level;
(3) Yehud - a small town, not densely-populated, with a high socio-economic level.

In line with the national observational surveys in the country (e.g., Gitelman et al., 2013), a big city was defined with a population of over 200,000 inhabitants, a small town – below 60,000 inhabitants, a medium city – with an intermediate size. The socio-economic levels of the towns were defined based on estimates of the Central Bureau of Statistics (CBS). The CBS method divides towns into ten clusters accounting for such characteristics as the average income per capita, motorization level, unemployment rate, dependence rate (a ratio of the number of children and older people to working ages), etc. (CBS, 2011). In this study, high socio-economic level included clusters 7–10, medium level – clusters 4–6.

The study sites were chosen based on maps and field visits, in every city, and following a consultation with the local authorities. In total, 29 observation sites were selected, of which 16 are signalized intersections, 9 - un-signalized intersections on undivided roads and 4 - un-signalized intersections on divided roads. Each site is a pedestrian crosswalk between the two sidewalks, on an undivided street, or between a sidewalk on one side and a built median on the other side, on a divided street. Each crosswalk typically included two traffic lanes to be crossed: in opposing travel directions, on undivided streets, or in the same travel direction, on divided streets (at three signalized intersections, there were three lanes to be crossed).

Signalized intersections in Israel utilize a traditional tri-color traffic light for vehicles, and two colors for pedestrians, red and green, which are combined with images of standing or walking pedestrians, respectively. Vehicle and pedestrian movements are usually separated, turning vehicle movement on red (known as permissible or unrestricted turning) is not allowed. Sometimes, a shared green is applied in Israel for right turning vehicles and crossing pedestrians on the nearby crosswalk (the crosswalk situated at the intersection in the direction of the destination of the turning vehicle). The study sites did not include intersections with a shared green for vehicles and pedestrians.

All the crosswalks had a basic zebra-marking (sign 811 according to Israeli traffic regulations) and ramped sidewalks. Some un-signalized crosswalks had side or overhead squared blue signs with a picture of crossing pedestrian (sign 306). None of the sites had additional high visibility components, e.g. a raised crossing or road narrowing, as such solutions are not applied at intersections situated on collector roads in Israel. To note, such measures on similar intersections are not yet frequent in the international practice as well (Zegeer and Bushell, 2012; WHO, 2013; Stoker et al., 2015). All the study sites had 50 km/h speed limits as is common for collector roads in Israel.

A consideration of crash history at the study sites indicated that in the years 2010–2012 (background years to the study performance), crashes with child pedestrians (below age 18) occurred at three sites, one crash at an un-signalized intersection on an undivided road and two crashes at signalized intersections; in the years 2013–2014, no child pedestrian crashes occurred at all study sites. The total numbers of pedestrian crashes (for all ages) at the study sites, in the years 2010–2012, were: zero at 22 sites, one at five sites, two at two sites. In the same period, in reviewing pedestrian crashes for each of the cities for all roads, the numbers of pedestrian crashes at urban intersections were: 161 in Rishon Lezion (a big city), 26 in Givatayim (a medium city), 8 in Yehud (a small city); the number of pedestrian crashes per intersection in these cities ranged between 0–3. As evident, the study sites were characterized by low pedestrian crash frequencies.

2.2. Data collection

Video-recording of pedestrian crosswalks was conducted on working days, in autumn, with non-rainy weather, and in daylight hours between 15:30 and 19. At each site, an unobtrusive location was designated for positioning the video-camera to prevent pedestrian attention. Fig. 1, provides examples of the observational sites, from the video-recordings, with crossing pedestrians. The observations showed that, in spite of the law, some children used pedestrian crosswalks while riding a bicycle (regular or electric) or other non-motorized means (e.g. a kick-scooter). Such cases were included in the study sample and in the study analyses as they represent a common phenomenon in the use of pedestrian crosswalks by children in Israel.

The video-recordings were coded manually, using the rules and forms defined for each site type, to document the characteristics and behaviors of each child or teenager that crossed the road. For each young pedestrian (or rider) observed, the following data were coded:

- Composition of crossing pedestrians: a child alone, a group of children (children that crossed together and thus assumed to be traveling together), a child and adults (cases where a child arrived at the intersection at the same time as an adult and crossed alongside, but did not appear to be actively accompanied by an adult), and child accompanied by an adult. In the case of a child and adults the child was coded; in a group of children, the first child entering the crosswalk was coded to represent the entire group;
- Gender and age group of the child;
- Pedestrian observance of safe crossing rules:
  - Stopping and checking the traffic before the crossing (at un-signalized crosswalks);
  - Obeying the red light (at signalized crosswalks);
- Place of crossing by the pedestrian (inside/outside the crosswalk boundaries);
- Vehicle provision of right-of-way to the pedestrian, on the nearside and far-side lanes (at un-signalized crosswalks);
- Conflict occurrence between the pedestrian and vehicles during the crossing;
- Presence of distractions while crossing (secondary tasks), e.g.

talking on a mobile phone, playing a gadget, etc.;
- Carrying or pushing a big object while crossing, e.g. a stroller, a bicycle or other (that might hamper the crossing action);
- Crossing while riding instead of walking, including a regular bicycle, an electric bicycle (electric-powered with pedal assistance, also called e-bike, pedelec), or a kick-scooter (non-motorized).

The range of characteristics and behaviors of child pedestrians collected by the study was composed based on previous experience of pedestrian observational studies (Rosenbloom et al., 2008; Havard and Willis, 2012; Gitelman et al., 2017a). We divided the observations into three age groups of children: up to 9, 9–13, 14–17, relying on the current knowledge on the level of maturity and independence in behaviors of children of various ages and, also, accounting for common safety recommendation in Israel (e.g. to accompany a child pedestrian until the age of 9). A vehicle-pedestrian conflict was defined as an abrupt change of course or speed by one of the actors, in order to avoid a collision, similarly to encounters used by other studies (Ewing and Dumbaugh, 2009; Gitelman et al., 2017a). The study also took into account risk-taking behaviors that may be on the rise including the use of mobile phones (Stavrinos et al., 2009; Tapiro et al., 2016) and bicycle riding on pedestrian facilities.

Coding was conducted by trained university students, who viewed the films, and encoded the information required in the study database. The age group and other features were estimated visually based on sample photos provided during training. The supervisor checked the first 20 records of each student to verify accurateness of coding before proceeding with the rest. In addition, for each site, vehicle traffic volumes and total pedestrian crossing volumes were counted, for each hour, and converted into average hourly values, to provide background traffic estimates for the sites.

2.3. Data analyses

Statistical analyses were undertaken, aiming to characterize behavior patterns of young pedestrians, on various junctions, and by different age groups. Descriptive statistics were provided for each of the three types of sites followed by additional analyses, which are:

(1) A comparative analysis of child behavior characteristics by age groups: up to 9, 9–13, 14–17, with a focus on more risky behaviors. The behavior indicators were estimated as a percentage of certain (usually, unsafe) behaviors out of the total sample of pedestrians observed. To examine the significance of differences between the behavior indicators among the age groups a Pearson chi-square test was applied (the difference is significant with $p < 0.05$). When relevant, pair comparisons between certain age groups were conducted using a z-test for proportions.
(2) An identification of factors influencing the most dangerous behaviors, such as crossing on red (at signalized crosswalks) and non-checking vehicle traffic before crossing (on un-signalized crosswalks). For this, a multivariate binary logistic regression model was fitted to (the log odds of) the probability of undertaking each unsafe behavior (Fleiss et al., 2013). The models were obtained using a *stepwise* method. For each dependent behavior, the influence of characteristics was examined such as the age group and gender of the child, the composition of crossing pedestrians, presence of distractions, crossing while riding, type of city and traffic estimates of the site. The latter were subdivided into 3–4 categories, for each site type, based on the empirical data and aiming to reflect various levels of traffic. The model for crossing on red used the sample of children who arrived during the red light. The model for non-checking traffic before crossing was fitted to each type of un-signalized crosswalk, using the whole sample of children observed.

The model parameters were adjusted using the maximum likelihood estimates, by the Logistic procedure of SAS. The process of the model development lasted as long as a variable adding was associated with a significant difference in the *-2Log Likelihood* parameter. The *Hosmer and Lemeshow* test was applied to examine the quality of the model fit. In addition, the *max-rescaled R-square* and the percentage of correct prediction were estimated, where higher values of both parameters were judged as better. The explanatory variables with a significant impact ($p < 0.05$) were counted for the interpretation of results.

In addition, to enable a comparison of child behaviors with adults, relevant data were extracted from the national observational survey of pedestrian behaviors at urban crosswalks (Gitelman et al., 2013) and processed for the study purposes. The national survey covers six types of locations of pedestrian crosswalks, including those examined by the current study, and applies a stratified sampling of sites based on the population size and types of Israeli towns. It examines a range of pedestrian behaviors including crossing on red; non-stopping and non-checking vehicle traffic prior to crossing; crossing outside the crosswalk boundaries; pedestrian-vehicle conflicts during the crossing; and using distractions (earphones, mobile phones) by pedestrians. Due to similarity of frameworks of both observational surveys (in the current study and the national one), the comparisons were possible. Thus, the data on adult pedestrian behaviors were extracted from the national survey for three location types: signalized junctions on divided roads, un-signalized junctions on undivided roads and un-signalized junctions on divided roads. Adult behavior indicators were evaluated for each type of sites and then compared with the values of similar indicators of child pedestrian behaviors estimated in this study.

Furthermore, to re-examine the factors that influence the behaviors of crossing on red (at signalized crosswalks) and of non-checking vehicle traffic before crossing (on un-signalized crosswalks), a re-modelling the probability of undertaking each unsafe behavior was performed using a combined data set of child and adult pedestrians. A multivariate binary logistic regression model was adjusted for each behavior, when as potential explanatory variables were examined those characteristics which are common to both surveys, such as the age group and gender of the pedestrian, type of city (big, medium, small) and presence of distractions. To satisfy the demands for the model quality (insignificance of the *Hosmer and Lemeshow* test of goodness-of-fit), a possibility of interaction between the explanatory variables was allowed in the combined models.

3. Results

3.1. General observations

A total sample of 2930 young crossing pedestrians (and riders) was observed, including 1763 at signalized junctions, 852 at un-signalized junctions on undivided roads and 315 at un-signalized junctions on divided roads. Table 1 presents descriptive statistics for pedestrian characteristics and behaviors, according to the site types. Children from the various age groups were observed at all site types, with a slightly higher share of males (54%–61%) than females.

At signalized junctions, about 10% of children did not cross completely within the crosswalk boundaries. Some 8% of children crossed with a distraction and about 8% crossed while carrying or pushing a big object. Most children walked across the roadway, yet, a significant share 19%, crossed while riding a bicycle or a kick-scooter. Out of the total number of children observed at signalized junctions, 46% arrived at the crosswalk on green and crossed on green, about 42% arrived on red and waited for a green light, and 12% arrived on red and crossed on red. While crossing on red, in 26% of cases, the child did not check the vehicle traffic. However, a really dangerous situation, when the child while crossing on red did not check the traffic and there was an incoming vehicle on the road, was rare and observed in 3% only of the cases of crossing on red. As a result, the conflict rate observed in this subsample was relatively low, about 2%.

Table 1
Descriptive statistics for child pedestrian characteristics and behaviors, at the study sites.

Pedestrian characteristics	At signalized junctions (N = 1763, 16 sites)	At un-signalized junctions on undivided roads (N = 852, 9 sites)	At un-signalized junctions on divided roads (N = 315, 4 sites)
Composition of pedestrians: (1) child alone, (2) group of children, (3) child and adults, (4) child accompanied by adult	(1) 33.8%, (2) 19.3%, (3) 15.9%, (4) 36.9%	(1) 38.4%, (2) 29.5%, (3) 0.4%, (4) 31.8%	(1) 29.2%, (2) 15.3%, (3) 4.4%, (4) 51.1%
Gender	Males - 54.1%	Males - 55.9%	Males - 60.9%
Age groups: (1) Up to age 9, (2) 9-13, (3) 14-17	(1) 24%, (2) 36%, (3) 39%	(1) 26%, (2) 46%, (3) 28%	(1) 48%, (2) 27%, (3) 25%
Crossed outside the crosswalk boundaries: (1) fully, (2) partly	(1) 1.3%, (2) 8.4%	(1) 1.4%, (2) 7.9%	(1) 0.6%, (2) 6.0%
Crossed with a distraction: (1) talking on the phone, (2) earphones/other, (3) playing on a gadget	(1) 3.7%, (2) 1.4%, (3) 2.7%	(1) 2.9%, (2) 0.1%, (3) 2.6%	(1) 1.9%, (2) 1.3%, (3) 1.9%
Crossed carrying or pushing: (1) a stroller, (2) a bicycle, (3) other	(1) 6.1%, (2) 0.9%, (3) 0.6%	(1) 2.1%, (2) 3.3%, (3) 1.7%	(1) 1.9%, (2) 0.6%, (3) 4.4%
Crossed while riding: (1) electric bicycle, (2) regular bicycle, (3) kick-scooter	(1) 7.0%, (2) 8.6%, (3) 3.1%	(1) 5.4%, (2) 6.7%, (3) 2.8%	(1) 5.7%, (2) 12.1%, (3) 3.5%
Arrived at crosswalk on: (1) green light, (2) red light and stopped, (3) red light and crossed	(1) 46.1%, (2) 41.7%, (3) 12.2%	—	—
Vehicle-pedestrian conflicts in groups of those who arrived on: (1) green light, (2) red light and stopped, (3) red light and crossed	(1) 0%, (2) 0.4%, (3) 1.9%	—	—
Did not stop before crossing	—	51.2%	57.5%
Did not check traffic before crossing	—	12.4%	18.1%
Given right-of-way by vehicles: (1) on the near lane, (2) on the far lane	—	(1) 71.8%, (2) 51.8%	(1) 78.8%, (2) 47.3%
Vehicle-pedestrian conflicts: (1) on the near lane, (2) on the far lane	—	(1) 3.8%, (2) 2.4%	(1) 2.9%, (2) 7.5%
Average hourly vehicle traffic (sd)	551 (357)	446 (188)	768 (208)
Average hourly crossing pedestrians (sd)	418 (264)	235 (152)	197 (61)

At un-signalized junctions on undivided roads, in half the cases the child did not stop before the crosswalk and 12% did not check the traffic before crossing. In cases where the child intended to cross and there was a vehicle on the road, the vehicle gave the right-of-way to the child in 72% of cases on the near lane and in 52% of cases on the far lane. A conflict between a young pedestrian and a vehicle was observed in 2%–4% of cases when a vehicle-pedestrian interaction occurred. In general, over 9% of children did not perform a full crossing within the crosswalk boundaries. In total, relatively few children (6%–7%) crossed with a distraction or a disturbance but a higher rate (15%) crossed while riding instead of walking.

At un-signalized junctions on divided roads, in most cases (57%) the child did not stop before the crosswalk and in 18% of cases did not check the traffic before crossing. In cases of interaction between the child and a vehicle, the vehicle gave the right-of-way to the child in 79% of cases on the near lane and in 47% of cases on the far lane. Conflicts between a child and an incoming vehicle were observed in 3% of cases on the near lane and in about 8% of cases on the far lane. Only about 7% of children did not perform a full crossing in the crosswalk area. At this type of site, a higher rate of children (21%) crossed by riding a bicycle or a kick-scooter.

3.2. Comparisons between the age groups

Table 2, a–c, presents the comparisons between crossing behaviors of various child age groups, at the three types of sites. In addition, the values of similar adult behavior indicators are presented, when available, based on the national observational survey of pedestrian behaviors at crosswalks. From the national survey, a sample of 2572 adult pedestrians (over age 18) was extracted, including 1022 pedestrians observed at signalized junctions (11 sites), 584 at un-signalized junctions on undivided roads (6 sites) and 966 at un-signalized junctions on divided roads (12 sites).

The results show that at signalized junctions, behaviors were different across the age groups of children (Table 2, a). In particular:

- For children up to age 9, related to other age groups, no salient risky behaviors were identified. Two phenomena worth mentioning as associated with a higher risk: first, 20% of the children crossed the road while pushing a stroller (that might hinder attention and hamper movement); second, about 8% of children that arrived on red crossed on red (they were all accompanied by adults).
- Most children aged 9–13 crossed alone or in a group of children. Among salient risky behaviors in this age group were crossing on red (17%) and riding while crossing (25%). Moreover, over 40% of children who crossed on red were riding and not walking.
- Adolescents aged 14–17 usually crossed alone or in a group. In this age group related to other age groups, a number of risky behaviors were observed, including crossing on red (36%), riding while crossing (23% in total and 24% while crossing on red), crossing outside the crosswalk area (12%), and crossing with a distraction (14%). In both older child age groups (over age 9), in 11% of crossings on red there was a vehicle approaching the crosswalk area, thus increasing a crash risk.

The behaviors of adult pedestrians at signalized junctions were different from all child age groups: fewer adults (1% only) crossed outside the crosswalk boundaries, however more adults (15%) talked on a mobile phone while crossing (differences significant, $p < 0.01$, related to each child age group). The share of adults who crossed on red (10%) was lower related to both older child age groups ($p < 0.01$).

At un-signalized junctions on undivided roads, differences between the age groups were found in most behaviors (Table 2, b), as follows:

- For children up to age 9, a frequent risky behavior was not stopping before the crossing (56%); most of these children were accompanied by adults who, apparently, did not stop before the crossing. A few additional unsafe behaviors were observed (6%–7% of the sample), such as not checking vehicle traffic before crossing, crossing outside the crosswalk boundaries, and crossing while carrying or pushing an object (e.g. a stroller).

- For children aged 9–13, salient risky behaviors included: not stopping prior to crossing (42%); not checking traffic before crossing (12%); riding while crossing (16%). To a smaller extent (5%–8%), other risky behaviors were observed: crossing outside the crosswalk area, crossing with a distraction or while carrying or pushing an object.

- Among adolescents aged 14–17, higher rates of most risky behaviors were observed. In most cases (61%) they did not stop before crossing and 19% did not check the traffic prior to crossing. In these behaviors, the adolescents were mostly close to adults, which exhibited 70% of not stopping and 26% of not checking traffic before crossing (yet, the differences between the adult and adolescent groups were significant, $p < 0.05$). Additionally, 15% of teenagers did not fully cross in the crosswalk area, 11% had a distraction while crossing, and 22% crossed by riding.

Table 2
Comparisons between crossing behaviors of various child age groups, at three types of sites, in the current study, and similar adult behavior indicators from the national observational survey.

a – At signalized junctions (16 sites in the current study, 11 sites in the national survey)

Behaviors	Ages up to 9	Ages 9-13	Ages 14-17	Comparison between child age groups (χ^2)	Adult behavior indicators
Sample size	N = 430	N = 641	N = 692		N = 1022
Composition of pedestrians: (1) child alone, (2) group of children, (3) child and adults, (4) child accompanied by adult	(1) 2.1%, (2) 1.2%, (3) 0.7%, (4) 96.1%	(1) 30.9%, (2) 27.3%, (3) 12.8%, (4) 29.0%	(1) 41.2%, (2) 24.4%, (3) 26.8%, (4) 7.5%	952.2*	—
Crossed outside the crosswalk boundaries (fully or partly)	4.7%	10.1%	12.4%	18.5*	1.1%
Crossed with a distraction: (1) talking on the phone, (2) earphones, (3) playing on a gadget	(1) 1.6%, (2) 0.5%, (3) 0%	(1) 2.5%, (2) 0.5%, (3) 2.3%	(1) 6.2%, (2) 2.9%, (3) 4.8%	63.9*	(1) 14.9%, (2) 2.7%
Crossed carrying or pushing: (1) a stroller, (2) a bicycle, (3) other	(1) 20.2%, (2) 0.2%, (3) 0.5%	(1) 3.0%, (2) 1.9%, (3) 0.8%	(1) 0.3%, (2) 0.4%, (3) 0.6%	211.0*	—
Crossing mode: riding (1) electric bicycle, (2) regular bicycle, (3) kick-scooter; (4) walking	(1) 0.2%, (2) 1%, (3) 1%, (4) 98%	(1) 7.5%, (2) 12%, (3) 6%, (4) 74.4%	(1) 11%, (2) 11%, (3) 1.6%, (4) 76.5%	133.0*	—[&]
Crossed on red [among those who arrived on red]	7.9% [227]	16.7% [335]	36.2% [389]	72.8*	10.4% [546]
Crossed on red while: (1) walking, (2) running, (3) riding	(1) 55.6%, (2) 44.4%, (3) 0%	(1) 44.6%, (2) 14.3%, (3) 41.1%	(1) 68.1%, (2) 7.8%, (3) 24.1%	30.5*	—

b– At un-signalized junctions on undivided roads (9 sites in the current study, 6 sites in the national survey)

Behaviors	Ages up to 9	Ages 9-13	Ages 14-17	Comparison between child age groups (χ^2)	Adult behavior indicators
Sample size	N = 220	N = 392	N = 240		N = 584
Composition of pedestrians: (1) child alone, (2) group of children, (3) child and adults, (4) child accompanied by adult	(1) 5%, (2) 6.4%, (3) 0%, (4) 88.6%	(1) 39.8%, (2) 41.6%, (3) 0.5%, (4) 18.1%	(1) 66.7%, (2) 30.8%, (3) 0.4%, (4) 2.1%	487.9*	—
Crossed outside the crosswalk boundaries (fully or partly)	6.8%	7.4%	14.6%	11.3**	5.7%
Crossed with a distraction: (1) talking on the phone, (2) earphones, (3) playing on a gadget	(1) 0.9%, (2) 0%, (3) 0%	(1) 3.1%, (2) 0.3%, (3) 1.8%	(1) 4.6%, (2) 0%, (3) 6.3%	26.9*	(1) 11.8%, (2) 3.1%
Crossed carrying or pushing: (1) a stroller, (2) a bicycle, (3) other	(1) 7.3%, (2) 0.9%, (3) 0.9%	(1) 0.5%, (2) 4.8%, (3) 2.3%	(1) 0%, (2) 2.9%, (3) 1.3%	46.6*	—
Crossing mode: riding (1) electric bicycle, (2) regular bicycle, (3) kick-scooter; (4) walking	(1) 0.5%, (2) 2.7%, (3) 0.9%, (4) 96%	(1) 3.8%, (2) 7.4%, (3) 4.8%, (4) 84%	(1) 12.1%, (2) 9.2%, (3) 1.3%, (4) 77.5%	55.3*	—[&]
Did not stop before crossing	56.4%	42.1%	61.3%	25.1*	70.2%
Did not check traffic before crossing	5.9%	12.0%	19.2%	18.7*	26.2%
Given right-of-way by vehicles: (1) on the near lane, (2) on the far lane	(1) 77.1%, (2) 64.0%	(1) 69.3%, (2) 54.8%	(1) 70.1%, (2) 35.9%	(1) 1.9, (2) 9.9**	—
Vehicle-pedestrian conflicts: (1) on the near lane, (2) on the far lane	(1) 3.2%, (2) 0%	(1) 3.3%, (2) 3.7%	(1) 6.1%, (3) 1.6%	(1) 1.1, (2) 2.4	3.4% (any lane)

c – At un-signalized junctions on divided roads (4 sites in the current study, 12 sites in the national survey)

Behaviors	Ages up to 9	Ages 9-13	Ages 14-17	Comparison between child age groups (χ^2)	Adult behavior indicators
Sample size	N = 151	N = 85	N = 79		N = 966
Composition of pedestrians: (1) child alone, (2) group of children, (3) child and adults, (4) child accompanied by adult	(1) 2.6%, (2) 9.9%, (3) 0.7%, (4) 86.8%	(1) 35.3%, (2) 22.4%, (3) 7.1%, (4) 35.3%	(1) 73.4%, (2) 17.7%, (3) 8.9%, (4) 0%	188.0*	—
Crossed outside the crosswalk boundaries (fully or partly)	1.3%	8.2%	15.2%	16.5*	9.9%
Crossed with a distraction: (1) talking on the phone, (2) earphones/other[1], (3) playing on a gadget	(1) 0%, (2) 1.3%, (3) 0.7%	(1) 0%, (2) 0%, (3) 3.5%	(1) 7.6%, (2) 2.5%, (3) 2.5%	23.2*	(1) 20.9%, (2) 3.1%
Crossed carrying or pushing: (1) a stroller, (2) a bicycle, (3) other	(1) 2.6%, (2) 0%, (3) 4.6%	(1) 2.4%, (2) 2.4%, (3) 3.5%	(1) 0%, (2) 0%, (3) 5.1%	7.7	—
Crossing mode: riding (1) electric bicycle, (2) regular bicycle, (3) kick-scooter; (4) walking	(1) 0.7%, (2) 4.6%, (3) 4.6%, (4) 90%	(1) 8%, (2) 17.6%, (3) 5%, (4) 69.4%	(1) 13%, (2) 20%, (3) 0%, (4) 67%	36.3*	—[&]
Did not stop before crossing	54.3%	51.8%	69.6%	6.5[#]	43.8%
Did not check traffic before crossing	23.8%	10.6%	15.2%	7.0[#]	14.7%
Given right-of-way by vehicles: (1) on the near lane, (2) on the far lane	(1) 79.7%, (2) 43.8%	(1) 77.6%, (2) 50.0%	(1) 78.6%, (2) 52.6%	(1) 0.1, (2) 0.5	—
Vehicle-pedestrian conflicts: (1) on the near lane, (2) on the far lane	(1) 1.3%, (2) 6.3%	(1) 2.0%, (2) 11.5%	(1) 7.1%, (3) 5.3%	(1) 3.5, (2) 0.9	4.0% (any lane)

Notes to Table 2: Percentages of unsafe behaviors out of the sample of pedestrians observed (N) are shown. [1]On sites *c*: playing a ball. Significant difference with *$p < 0.001$, **$p < 0.01$, [#]$p < 0.05$. [&] In the national survey, only walking pedestrians were included.

At un-signalized junctions on undivided roads, more adults than children of any age group talked on a mobile phone while crossing (p < 0.01). The share of adults that crossed outside the crosswalk boundaries was not statistically different from the younger age groups of children, below 13, but was lower than the value observed for adolescents (p < 0.01).

In addition, at this type of sites, in a substantial portion of cases, vehicles did not give right-of-way to the child who intended to cross in the marked crosswalk, for all age groups. The difference between the child age groups was not significant for provision of right-of-way to pedestrians on the near lane (with 70%–77% of child pedestrians ignored by vehicles in all age groups) but was significant on the far-side lane (due to a higher rate of ignoring younger pedestrians, below age 9 – in 64% of cases). The level of vehicle-pedestrian conflicts in the crosswalk area was similar for the various child age groups (2%–6% of cases) and for adults.

At un-signalized junctions on divided roads, similarly to the previous site types, significant differences between the age groups were found for most behaviors (Table 2, c), as follows:

- For children up to age 9, the most salient risky behaviors were not stopping before the crossing (54%) and not checking the traffic (24%). Most children at this age were accompanied by adults; hence, both risky behaviors likely reflect the adult habits.
- Among children aged 9–13, the most salient risky behavior was not stopping before the crossing (52%), that is particularly worrying, because the majority of children crossed unaccompanied by adults. In addition, 11% of children did not check the traffic before the crossing and 31% crossed while riding a bicycle or kick-scooter.
- Among adolescents aged 14–17, a higher rate of dangerous behaviors was found, compared to other child age groups, including not stopping before the crossing (70%), not checking the traffic (15%), crossing by riding (33%), crossing with distractions (13%), and crossing outside of the crosswalk area (15%). Related to adult pedestrians, the share of adolescents who crossed outside the dedicated area and did not check the traffic before the crossing was not statistically different, whereas the share of adolescents that did not stop before the crossing was higher (p < 0.01). Adult pedestrians exhibited a higher rate of crossing with a distraction than for any child group as 21% of adults talked on a mobile phone while crossing.

For all child age groups, in many cases, vehicles did not give theright-of-way to a young pedestrian. As a result, more pedestrian-vehicle conflicts were observed, particularly, on the far lane (in 5%–11% of cases) than for adults. Regarding these behaviors the differences were not significant between the age groups, where for all child ages the findings indicated a higher pedestrian risk associated with a multi-lane crosswalk.

3.3. Factors associated with unsafe children behaviors

Table 3 presents an explanatory model adjusted to the probability that a child that arrived on red will cross on red. Based on the *Type 3 analysis of effects*, in this model, the impacts of child age group, pedestrian composition, riding, vehicle and pedestrian traffic was significant (with p < 0.01) and the impact of city type was close to significant (p = 0.06). According to the odds ratio estimates of the model it follows that the probability of crossing on red is higher for older children (over age 9) and, particularly, for adolescents aged 14–17; if a child crosses while riding an electric bicycle (versus walking) and when the traffic volume at the site is lower (less than 500 vehicles per hour). The probability of crossing on red is also higher at sites in the big city compared to a medium city. In addition, the chance of crossing on red is higher when the child rides a regular bicycle or a kick-scooter, related to walking, but the effects are not significant. On the other hand, the probability of crossing on red is lower for all categories of pedestrian composition related to a child alone and, particularly, when a child is accompanied by an adult, and when the number of crossing pedestrians at the site is lower (especially, when the volume is below 200 pedestrians per hour). Variables such as gender of child, presence of distractions or crossing with a big object, were not found to affect the probability of crossing on red.

Table 4, a–b, presents explanatory models for the probability of not checking vehicle traffic by a child before the crossing, at un-signalized junctions. In the model for undivided roads (Table 4, a), significant impacts were found for the variables of child age group, presence of distraction, riding, vehicle traffic and city type (p < 0.05). It shows that at un-signalized junctions on undivided roads, the probability of not checking traffic before crossing is higher as the age of the child increases (as compared to the up to 9 age group), when the child crosses with distractions (talking on a mobile phone or playing with a gadget), and when the child crosses by riding instead of walking (particularly, when riding an electric bicycle or a kick-scooter). The probability is also higher at sites in big or medium-sized cities compared to a small city. Conversely, the probability of not checking traffic is lower when the traffic volume is higher (over 200 vehicles per hour). In this context, no effect was found for the composition of crossing pedestrians, child gender, walking with an object and the volume of crossing pedestrians at the site.

In the model for divided roads (Table 4, b), significant impacts were found for the variables of child age group, carrying an object, riding and

Table 3
Explanatory model for the probability of crossing on red by a child, at signalized junctions.

Variables	Estimate	S.E.	Wald Chi-Square	Pr > ChiSq	Odds ratio	95% Wald confidence limits	
Intercept	−1.425	0.200	50.954	< .001			
Age: 14-17 vs up to 9	0.600	0.168	12.837	< .001	2.679	1.270	5.653
Age: 9-13 vs up to 9	−0.215	0.155	1.928	0.165	1.186	0.581	2.422
Composition: group of children vs child alone	−0.319	0.181	3.111	0.078	0.252	0.144	0.441
Composition: child with adults vs child alone	−0.012	0.176	0.004	0.948	0.342	0.199	0.588
Composition: accompanied child vs child alone	−0.732	0.228	10.292	0.001	0.166	0.083	0.334
Riding electric bicycles vs walking	0.649	0.252	6.630	0.010	2.894	1.586	5.280
Riding regular bicycles vs walking	−0.298	0.286	1.087	0.297	1.123	0.557	2.266
Riding scooter vs walking	0.064	0.380	0.028	0.867	1.613	0.593	4.388
Vehicle traffic, per hour: < 200 vs over 900	0.511	0.175	8.519	0.004	4.379	2.749	6.974
Vehicle traffic, per hour: 200-500 vs over 900	0.522	0.211	6.144	0.013	4.426	2.162	9.063
Vehicle traffic, per hour: 500-900 vs over 900	−0.068	0.223	0.094	0.760	2.452	1.167	5.153
Crossing pedestrians, per hour: < 200 vs over 400	−1.044	0.197	28.130	< .001	0.130	0.066	0.258
Crossing pedestrians, per hour: 200-400 vs over 400	0.050	0.299	0.028	0.867	0.389	0.140	1.084
City: big vs medium	0.484	0.254	3.633	0.057	2.630	0.973	7.108

Model statistics: max-rescaled R-square 0.341; correct prediction 80.6%; Hosmer and Lemeshow test p = 0.57.

Table 4
Explanatory models for the probability of not checking vehicle traffic by a child before the crossing.

a - At un-signalized junctions on undivided roads[a]

Variables	Estimate	S.E.	Wald Chi-Square	Pr > ChiSq	Odds ratio	95% Wald confidence limits	
Intercept	−1.960	0.516	14.437	< .001			
Age: 14-17 vs up to 9	0.905	0.357	6.442	0.011	2.471	1.229	4.971
Age: 9-13 vs up to 9	0.614	0.346	3.155	0.076	1.849	0.938	3.642
Talking by phone vs no distraction	0.466	0.509	0.838	0.360	1.594	0.588	4.322
Playing a gadget vs no distraction	1.261	0.498	6.410	0.011	3.530	1.330	9.374
Riding electric bicycles vs walking	1.428	0.372	14.759	< .001	4.168	2.012	8.634
Riding regular bicycles vs walking	0.210	0.421	0.247	0.619	1.233	0.540	2.816
Riding scooter vs walking	1.015	0.518	3.829	0.050	2.758	0.998	7.618
Vehicle traffic, per hour: 200-500 vs < 200	−2.901	0.858	11.424	< .001	0.055	0.010	0.296
Vehicle traffic, per hour: over 500 vs < 200	−3.288	0.896	13.459	< .001	0.037	0.006	0.216
City: big vs small	2.938	0.743	15.624	< .001	18.881	4.399	81.045
City: medium vs small	2.027	0.744	7.417	0.007	7.591	1.765	32.644

b - At un-signalized junctions on divided roads[b]

Variables	Estimate	S.E.	Wald Chi-Square	Pr > ChiSq	Odds ratio	95% Wald confidence limits	
Intercept	−0.361	0.264	1.863	0.172			
Age: 14-17 vs up to 9	−1.403	0.486	8.339	0.004	0.246	0.095	0.637
Age: 9-13 vs up to 9	−1.396	0.502	7.737	0.005	0.248	0.093	0.662
Talking on the phone vs no distraction	2.382	1.034	5.307	0.021	10.824	1.427	82.118
Playing with a gadget vs no distraction	1.736	1.124	2.384	0.123	5.674	0.627	51.395
Other distraction vs no distraction	0.123	1.651	0.006	0.941	1.130	0.044	28.722
Crossed with an object vs no	1.406	0.638	4.852	0.028	4.080	1.168	14.255
Riding electric bicycles vs walking	2.429	0.720	11.385	0.001	11.341	2.767	46.483
Riding regular bicycles vs walking	0.661	0.608	1.182	0.277	1.937	0.588	6.377
Riding kick-scooter vs walking	2.094	1.003	4.364	0.037	8.119	1.138	57.912
Vehicle traffic, per hour: 600-800 vs < 600	−3.009	0.668	20.259	< .001	0.049	0.013	0.183
Vehicle traffic, per hour: over 800 vs < 600	−1.950	0.435	20.146	< .001	0.142	0.061	0.333

[a] Model statistics: max-rescaled R-square 0.176; correct prediction 73.6%; Hosmer and Lemeshow test p = 0.19.
[b] Model statistics: max-rescaled R-square 0.367; correct prediction 86.1%; Hosmer and Lemeshow test p = 0.18.

vehicle traffic ($p < 0.05$) and close to significant impact for presence of distraction ($p = 0.06$). The impact of city type was examined but found very insignificant and, hence, this variable was removed from the model. At un-signalized junctions on divided roads, the probability of not checking vehicle traffic before the crossing raises when the child crosses with distractions, particularly, when he/she talks by phone, crosses by riding (especially, when riding an electric bicycle or a kick-scooter) or carries an object while crossing (a dog, a ball, a skateboard, etc.). The probability is lower when the traffic volume is higher, similar to the previous model, and when a child is older, over the age of 9, in contrast to the previous model. No effect was found for the composition of crossing pedestrians and child gender. (The level of pedestrian traffic volume was similar for all sites, and thus was not included in the model).

The difference between the two models in Table 4 with regards the impact of child age on the probability of non-checking vehicle traffic before the crossing needed a clarification. A detailed consideration of the four sites on divided roads revealed that one site was associated with an extremely high share of non-checking the traffic related to other sites, especially in the ages below 9: 64% versus 2% in other sites. Excluding this site from the sample would provide lower values of the indicator such as: 2.0%, 5.8% and 12.7% of non-checking traffic for the ages of below 9, 9–13 and 14–17, respectively, thus, indicating an increasing trend with increase in the age of the child (similarly to the results for undivided roads). Due to the fact that only four sites at un-signalized junctions on divided roads were observed in the current study, the results for this type of sites are site-sensitive and should be treated with caution.

3.4. Re-examination of factors on a combined set of child and adult pedestrians

As mentioned in Sec.2.3, using a combined set of observations of child and adult pedestrians, at similar sites, re-modelling the

Table 5
Explanatory model for the probability of crossing on red by a pedestrian, at signalized junctions (based on a combined set of child and adult pedestrian observations).

Variables	Estimate	S.E.	Wald Chi-Square	Pr > ChiSq	Odds ratio	95% Wald confidence limits	
Intercept	−1.099	0.402	7.467	0.006			
City: big vs small	−1.374	0.309	19.805	< .0001	0.25	0.14	0.46
City: medium vs small	−2.333	0.332	49.537	< .0001	0.10	0.05	0.19
Gender: male vs female	0.805	0.152	28.048	< .0001	2.24	1.66	3.01
Age: adult vs up to 9	−0.618	0.352	3.085	0.079	0.54	0.27	1.07
Age: 14-17 vs up to 9	1.876	0.275	46.601	< .0001	6.53	3.81	11.18
Age: 9-13 vs up to 9	0.833	0.291	8.192	0.004	2.30	1.30	4.07
Presence of distraction: yes vs no	−0.207	0.253	0.666	0.415	0.81	0.50	1.34

Model statistics: max-rescaled R-square 0.216; correct prediction 74.4%; Hosmer and Lemeshow test p = 0.28.

Table 6
Explanatory models for the probability of not checking vehicle traffic by a pedestrian before the crossing (based on a combined set of child and adult pedestrian observations).

a - At un-signalized junctions on undivided roads[a]

Variables	Estimate	S.E.	Wald Chi-Square	Pr > ChiSq	Odds ratio
Intercept	−2.749	0.601	20.919	< .0001	
City: big vs small	1.065	0.769	1.916	0.166	
City: medium vs small	−0.540	0.750	0.518	0.472	
Gender: male vs female	−0.005	0.145	0.001	0.974	1.00
Age: adult vs up to 9	1.515	0.613	6.107	0.014	
Age: 14-17 vs up to 9	−0.805	1.178	0.467	0.494	
Age: 9-13 vs up to 9	0.039	0.789	0.002	0.961	
Presence of distraction: yes vs no	0.536	0.207	6.703	0.010	1.71
Big city and adult	−1.370	0.866	2.502	0.114	3.35[#]
Big city and age 14-17	1.621	1.302	1.552	0.213	6.56[#]
Big city and age 9-13	0.391	0.963	0.164	0.685	4.46[#]
Medium city and adult	0.847	0.775	1.195	0.274	6.19[#]
Medium city and age 14-17	2.471	1.283	3.711	0.054	3.08[#]
Medium city and age 9-13	0.997	0.936	1.134	0.287	1.64[#]

b - At un-signalized junctions on divided roads[b]

Variables	Estimate	S.E.	Wald Chi-Square	Pr > ChiSq	Odds ratio	95% Wald confidence limits	
Intercept	−3.592	0.755	22.608	< .0001			
City: big vs small	0.244	0.214	1.304	0.254	1.28	0.84	1.94
City: medium vs small	−0.436	0.243	3.215	0.073	0.65	0.40	1.04
Gender: male vs female	0.22	0.176	1.553	0.213	1.25	0.88	1.76
Age: adult vs up to 9	1.603	0.737	4.734	0.030	4.97	1.17	21.06
Age: 14-17 vs up to 9	1.711	0.813	4.43	0.035	5.53	1.13	27.22
Age: 9-13 vs up to 9	1.007	0.882	1.304	0.254	2.74	0.49	15.41
Presence of distraction: yes vs no	0.736	0.228	10.443	0.001	2.09	1.34	3.26

[a] Model statistics: max-rescaled R-square 0.115; correct prediction 66.8%; Hosmer and Lemeshow test p = 0.96.
[b] Model statistics: max-rescaled R-square 0.063; correct prediction 59.5%; Hosmer and Lemeshow test p = 0.91.
[#] Final estimate.

probability of undertaking unsafe behaviors was performed. The remodelling considered the characteristics available in all observations, i.e. the age group and gender of the pedestrian, type of city (big, medium, small) and presence of any pedestrian distraction (talking by phone or using earphones for adults, all kinds of distractions for children).

Table 5 presents an explanatory model adjusted to the probability that a pedestrian that arrived on red will cross on red. In this model, the impacts of age group, gender and city type were significant ($p < 0.001$); the impact of presence of distraction was insignificant but improved the overall model quality and, thus, was kept in the model. The model shows that the probability of crossing on red is higher for adolescents and children aged 9–13 compared to young children below age 9 and is lower for adults. This probability is also higher for males compared to females and is lower at sites in big and medium cities related to small cities. Concerning the impact of distraction, the model indicates a negative relation with the probability of crossing on red that is counter-intuitive but this variable is insignificant and apparently reflects the remainder of impacts having controlled for other characteristics. The combined model strengthens the message noticed in the raw values in Table 2 (see Sec.3.2) that the probability of crossing on red is higher for older children and adolescents.

Table 6, a, shows a model for the probability of not checking vehicle traffic by a pedestrian before the crossing, at un-signalized junctions on undivided roads. In this model, the impacts of age group, presence of distraction and an interaction of city type and age group were significant ($p < 0.01$); the impact of city type was close to significant ($p = 0.053$). To exhibit the impacts of various characteristics, odds ratio estimates are shown in the last column of Table 6, a; for city and age variables that interacted in the model final estimates are provided (accounting for both separate effects and interaction effects). The results show that the probability of not checking traffic by a pedestrian before crossing is higher in big cities and if a distraction is present. The probability is higher for adults, adolescents and children aged 9–13 compared to young children below age 9, both in big and in medium-sized cities. In big cities, this probability is highest for adolescents, in medium cities - for adults. It can be noted that regarding the relation between the behavior of not checking vehicle traffic and pedestrian age, the model provided a more detailed insight compared to the raw values presented in Table 2. For gender, the model showed no impact on the behavior examined.

Table 6, b, presents a model for the probability of not checking vehicle traffic before the crossing, at un-signalized junctions on divided roads. Fitting this model, the data of one site with an exceptional share of non-checking traffic by children (see Sec.3.3) were excluded (85 observations). In this model, significant impacts were found for city type and presence of distraction ($p < 0.05$), while impacts of gender and age group were insignificant ($p = 0.112$ for the age group' variable). The model indicates that the probability of not checking traffic by a pedestrian before crossing is higher in big cities compared to small and is lower in medium-sized cities. The probability is higher for adults, adolescents and children aged 9–13 compared to young children below age 9, when a distraction is present and for male pedestrians. Concerning the relation between the behavior examined and age, the model strengthens the messages that were originally noticed in the raw data (see Table 2).

4. Discussion

This study focused on naturalistic behaviors for a large population of child and adolescent pedestrians at a variety of typical urban settings. The results exhibited many risky behaviors of children at pedestrian crosswalks. The observations showed that a significant percent of walking trips among children over the age of 9 were without adult supervision. At signalized intersections, a substantial number of children (12% in total) were observed crossing on red and a quarter of them, while crossing on red, entered the crosswalk without checking the vehicle traffic. Similarly, at un-signalized junctions, a substantial share of children did not follow the safe crossing rules: over half did not stop before the crosswalk and 10%–20% did not check the traffic before crossing. These findings are in line with previous research pointing to difficulties children have in making safe decisions regarding the pedestrian environment and adoption of appropriate crossing behavior, due to their cognitive, behavioral and emotional immaturity (Schieber and Thompson, 1996; Schwebel et al., 2012; Meir et al., 2015).

The share of children who crossed on red at signalized intersections is particularly worrying as the values observed in this study for children aged over 9 and, especially, for adolescents, were higher compared to similar behavior indicators estimated for adult pedestrians based on the national observational survey (Gitelman et al., 2013). At un-signalized intersections, the shares of children who did not follow safe crossing rules were substantial, as indicated above, but generally similar to or lower than values estimated for adult pedestrians.

The probability of crossing on red by a child was higher when the traffic volume at the site is lower. Similarly, at un-signalized junctions, the probability of not checking for traffic was higher when the traffic volume is lower. Child pedestrians may have made these choices as a way to better adapt to the traffic conditions at each site. This is despite the fact that they may not yet have acquired the advanced perceptual development required to recognize oncoming traffic, judge vehicle speed and acceleration, and cross the road safely (Schieber and Thompson, 1996; MacGregor et al., 1999; te Velde et al., 2005; Dukehart et al., 2007; Schwebel et al., 2012; Morrongiello et al., 2015). As a result, the decision-making by a child as to when to cross on red or not check for traffic may not be based on the sufficient judgement. For example, at intersections with low traffic volume drivers may be less likely to anticipate pedestrians and develop higher speeds, therefore, extra caution may be necessary prior to crossing.

At un-signalized crosswalks, vehicle drivers often did not give children the right-of-way: 20%–30% of children were ignored by approaching vehicles on the near lane, half or more on the far lane. This finding is not surprising as low level of yielding to pedestrians is common for zebra crossings without additional safety measures (Mead et al., 2014; Gitelman et al., 2017a). In this sense, the differences were generally not significant between the child age groups. This problem was most evident in the far lane of divided crosswalks (with two travel lanes in the same direction), where less than half of the vehicles stopped to allow the child to cross and more vehicle-pedestrian conflicts occurred. A “multiple-threat” phenomenon can be relevant in this case, that is frequently observed on multi-lane roads and may be especially dangerous for a crossing child (Leden et al., 2006). In general, children are less likely to successfully judge the appropriate time to cross, leaving a potential for conflicts between the crossing child and passing vehicles (te Velde et al., 2005; Morrongiello et al., 2015), as was also indicated by this study.

At all types of sites together, a fifth of children over the age of 9 crossed by riding (a regular bicycle, an electric bicycle, or a kick-scooter), while across various types of sites the range was between a sixth to a third of older children and adolescents. Riding while crossing the road was found to be more dangerous than walking, as it was associated with crossing without checking traffic at non-signalized junctions and with crossing on red at signalized intersections, particularly while riding an electric bicycle. Use of an electric bicycle was conspicuous in the 9–13 age group, despite the regulations in Israel, which limit the use of this mode of transportation to children above the age of 14 (at the time of observations; since May 2016 - above 16). Previous research pointed to higher rates of risk-taking among child bicyclists in this age group due to inadequate perception of gaps while crossing intersections with a continuous traffic flow (Plumert and Kearney, 2014).

The study findings showed consistently that presence of distraction in the form of talking on a mobile phone, using earphones or playing with a gadget, was associated with a higher probability of not checking vehicle traffic before the crossing at un-signalized intersections, both for child and adult pedestrians. A potential danger of pedestrian distraction due to secondary tasks was indicated by previous research (Stavrinos et al., 2009; Tapiro et al., 2016). The share of mobile phone use was higher for adult pedestrians than for children, at all types of sites. For child pedestrians, an additional distraction was observed, carrying objects (a dog, a ball, etc.), also associated with a higher probability of not checking vehicle traffic before the crossing.

The study models indicated that the probabilities of crossing on red or not checking vehicle traffic at un-signalized intersections, by child pedestrians, are higher in big cities. For the combined sets of child and adult pedestrians, the impacts of city size were mixed indicating a lower tendency to cross on red, in big and medium cities compared to small, but a higher tendency of not checking vehicle traffic before the crossing at un-signalized intersections, in big cities. Since urban infrastructure arrangements are similar across the country, this finding may be related to pedestrian exposure, i.e. possibly higher numbers of crossing pedestrians near pedestrian attractions and on the streets of big cities, in general, compared to smaller cities that may lead to a higher degree of pedestrians disregarding (some) traffic rules. This issue needs further research to better understand factors contributing to the differences found.

The study findings clearly indicated that risk-taking behaviors are higher as the child age increases. The models showed that the probability of unsafe behaviors at all crossing types was higher for children over the age of nine. Adolescents aged 14–17 exhibited an extensive array of risk-taking behaviors, at all types of crosswalks, as opposed to younger age groups. They are less likely to stop before crossing, less likely to check for oncoming traffic and more likely to cross on red or outside the crosswalk boundaries. This is in line with previous research, which found that with the increase of age, adolescents, in particular, males, are less likely to internalize pedestrian rules and report higher levels of risk-taking behaviors (Granie, 2009). Additionally, adolescents observed in this study were more likely to cross by riding and far more likely to use a mobile phone or other gadget during the crossing, where both factors increase the potential of unsafe crossing behaviors. Similar types of risk-taking behavior among teen pedestrians were identified in the international literature (Schwebel et al., 2012).

The current study results indicated that some behaviors of adolescent pedestrians were close to adults but other were different, with sometimes higher and sometimes lower values of unsafe behaviors compared to adults. This suggests that adolescent pedestrians do not behave like adults and should be treated as a separate risk group. Previously expressed concerns that teens are not as skilled as adults, due to more limited experience (Plumert and Kearney, 2014; O’Neal et al., 2018), or incline to risk-taking behavior due to a lack of knowledge or because of peer pressure (Schieber and Thompson, 1996; Schwebel et al., 2012), may be relevant here.

Children under age 9 were usually accompanied by an adult but still exhibited risk-taking behaviors, such as crossing on red and non-checking traffic prior to crossing, which apparently mirrored those of the adults. In addition, based on the explanatory models fitted, adult traveling companions were not found to be related to a higher probability of safe behaviors at un-signalized junctions. While this finding may relate to adaptive behaviors on the part of the adult pedestrians, it is worrying that children may not be provided with examples of safer crossing techniques while walking with adults. This finding supports other studies that pointed to a lack of sufficient pedestrian safety instruction and safe behavior modeling by adults (Rosenbloom et al., 2008; Morrongiello and Barton, 2009).

Concerning pedestrian-vehicle conflicts observed at the study sites it should be noted, they were not observed at the sites where child pedestrian crashes occurred in the previous years. The total number of conflicts recognized based on the analysis of about 100 h of observations was not high: 7 at signalized junctions, 18 at un-signalized junctions on undivided roads, 12 at un-signalized junctions on divided roads. Moreover, the majority of them can be classified as not serious, based on the analysis of time gaps to a (potential) collision and actual vehicles speeds (by using, for example, a Dutch traffic conflict technique, see e.g. Van der Horst et al., 2014; Gitelman et al., 2017b). Due to small crash and conflict data, a combined analysis of both was not possible. Such a result is common for observational studies (e.g. Buch and Jensen, 2017; Madsen and Lahrmann, 2017; Gitelman et al., 2017b) leaving the question of verification of surrogate behavior measures as substitutes to injury numbers, for future research.

The study considered child pedestrian behaviors at intersections situated on collector urban roads, which by definition have tangible traffic volumes and are associated with higher complexity of traffic settings. The difficulties experienced by crossing children in such urban environment may increase, thus generating more frequent risky situations and consequent injury. More simple and visible crosswalks, with a reduced number of vehicle approaches and additional speed-reducing devices, are expected to improve child safety (Leden et al., 2006, 2018). In contrast, multi-lane intersection approaches create “multiple-threat” situations for crossing pedestrians and particularly for children, this was reflected also in the current study, for example, in the lower rates of ceding right-of-way to child pedestrians by vehicles and in higher conflict rates, in the far-side lanes of crosswalks.

Collector roads are associated with a major pedestrian safety problem in urban areas in Israel (Gitelman et al., 2012). Such roads are common for most cities and, particularly, for city centers and areas with mixed land-uses, many pedestrian attractions and, thus, higher pedestrian activities. International experience suggests various infrastructure-related measures for improving pedestrian safety, with a main focus on calming vehicle speeds, shortening crossing distances and enhancing pedestrian visibility (Zegeer and Bushell, 2012; WHO, 2013; Mead et al., 2014; Stoker et al., 2015). However, the application of such measures on collectors is not common yet in the international practice while consistent evidence on the efficiency of pedestrian-related measures implemented on busy urban roads is still lacking. It seems that, in a broader sense, to promote pedestrian safety in the city, a change of the concept of city streets is required (Stoker et al., 2015). Wider application of traffic calming measures on busy urban roads, where pedestrians were traditionally left out of consideration, would create a healthier and safer urban environment for walking, in particular for child pedestrians.

This study provided important insights into naturalistic child and adolescent pedestrian behaviors at typical urban locations. At the same time, being an observational study the findings are descriptive and do not denote causality as in a laboratory or other controlled setting. In this study, video-based data were captured for a fairly large sample of children at three different cities, however all are located in the center of the country. Future research should include additional variation in observation sites across a broader geographic area. With regard to the intersection types considered by the study, a more detailed examination of traffic conditions such as actual travel speeds while approaching a crosswalk, types of vehicle movements (turning versus direct), vehicle platooning, and their impacts on pedestrian behavior and vehicle-pedestrian interactions, would be useful in the future. In particular, further examination of child pedestrian behaviors at a larger number unsignalized junctions on divided roads would be useful in order to consider possible differences in crossing populations and location features. A detailed examination of differences in child pedestrian behaviors in reaction to various traffic settings would be helpful as a basis for the development of safer crosswalks for children. Future research that incorporates naturalistic data on child and adolescent pedestrian behaviors with information on trip purpose, destination, and companions is required as the additional information may reveal further influences on risk-taking and safety.

5. Conclusions

This study demonstrated a wide range of risky behaviors of children and adolescents who walked or rode at pedestrian crosswalks of urban intersections, in Israel. Development of injury prevention programs focusing on children and parent education and training should take these findings into account. A meta-analysis of behavioral interventions to improve child pedestrian safety, found that programs that were designed to target prevention of “dash-out” behavior or the selection of safe routes across intersections were generally found to be effective (Schwebel et al., 2014). Young children training in virtual reality can serve as an additional form for enhancing hazard perception skills while crossing an urban road (Meir et al., 2015; Morrongiello and Corbett, 2015). Inclusion of directed instruction for parents to promote interactive guidance as well as appropriate modeling while walking with young children is recommended (AAP, 2009; WHO, 2013, 2015). Specific guidance regarding the necessary skills for independent crossing will allow parents to serve as better models as well as improve their judgement of readiness for independent walking and crossing (Morrongiello and Corbett, 2015).

There has been evidence that a combination of measures may improve child pedestrian safety (Zegeer and Bushell, 2012). Public education measures should emphasize the presence of children in the urban environment and driver compliance with pedestrian right-of-way (Schwebel et al., 2012; Schneider and Sanders, 2015; WHO, 2013, 2015). Targeted enforcement may be useful to reduce conflicts between vehicles and child pedestrians at urban crosswalks (Zegeer and Bushell, 2012; Van Houten et al., 2013, 2017). Recent improvements to bicycling regulations and increased enforcement may help to diminish risky riding behaviors (particularly, of teenagers).

Improvements to the built environment to better suit pedestrian needs are required, in particular, enhanced traffic calming measures in the vicinity of pedestrian attractions such as roundabouts, narrowed streets, speed humps, raised crosswalks, sidewalk extensions, etc. (Schwebel et al., 2012; Mead et al., 2014; WHO, 2013, 2015; Stoker et al., 2015). Infrastructure measures that were proven to be effective for improving pedestrian safety on local streets and in residential areas should be further distributed to collectors streets and city centers. Further development of urban traffic settings, which are focused on safer child pedestrian crossing conditions, is also encouraged (Leden et al., 2018).

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