



Evaluating Impacts of a Leading Pedestrian Signal on Pedestrian Crossing Conditions at Signalized Urban Intersections: A Field Study

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Signalized intersections appear among urban locations with a high frequency of pedestrian injury. Due to the need to move large traffic volumes, a shared vehicle-pedestrian green phase is generally applied for turning vehicles and crossing pedestrians at intersections on busy urban roads. The shared green relies on a driver's ability to yield to crossing pedestrians which, if it fails, may increase the risk of pedestrian injury. A solution suggested for improving pedestrian safety in such situations is to provide a leading pedestrian signal, i.e., the pedestrian green appears earlier than the vehicle green, forcing vehicles to give priority to the pedestrians already on the crossing. A field-study was conducted at two intersections in Tel-Aviv, Israel, to examine the impact of such a measure on pedestrian crossing conditions. The pedestrian green phase was brought forward by 3 s. The study analyzed changes in road user behaviors, in the crosswalk area, in the after period when the measure was activated compared to the before period. The results showed that following the measure's application, the percentage of traffic lights' cycles with giving-right-of-way to all pedestrians, at the beginning of green, increased to 97–100% for pedestrians crossing from the sidewalk and to 94–99% for those who crossed from the road median. In addition, improvements were observed in the provision of pedestrian right-of-way during the whole green phase. The measure did not affect the rate of vehicle-pedestrian conflicts due to low conflict occurrence at the study sites. Overall, the findings indicated positive changes in pedestrian crossing conditions, following the introduction of a leading pedestrian green. The increase in giving-right-of-way to pedestrians by turning vehicles is expected to contribute to improved pedestrian safety while crossing at signalized intersections.

Keywords: pedestrian safety, signalized intersection, shared vehicle-pedestrian green, leading pedestrian signal, field observations, giving-right-of-way

INTRODUCTION

Walking is a basic mode of urban transport in various societies, with well-established health and environmental benefits stemming from increased physical activity and reduced air pollution [World Health Organisation (WHO), 2010, 2013]. As urban density increases in many countries [International Association of Public Transport (UITP), 2015], a growing number of authorities have begun to implement policies to stimulate walking as an essential component of sustainable

urban development. However, pedestrian injury is still one of major safety problems throughout the world, where pedestrians account for 23% of the total fatalities in road crashes in the world [World Health Organisation (WHO), 2018], and represent 40% of total fatalities and 25% of serious injuries on urban roads in Europe [European Transport Safety Council (ETSC), 2019].

In Israel, pedestrian injury is one of the leading road safety problems over the last decades, since pedestrians usually present about a third of the annual fatalities and serious injuries in the country (Gitelman et al., 2012; Sharon, 2017). Most pedestrians (87%) are killed or seriously injured on urban roads (Sharon, 2017). The scope and constancy of the pedestrian safety problem, in Israel, strengthen the need for efforts to promote interventions to improve pedestrian safety. Moreover, the plans of sustainable urban development that discourage private car use and encourage walking (as well as public transport use and cycling) raise additional safety concerns since the existing urban environment is not ready yet for safe walking [Stoker et al., 2015; European Transport Safety Council (ETSC), 2019].

International experience emphasizes the role of infrastructure-related measures for reducing pedestrian injury because such measures provide an immediate and long-term effect [Huang and Cynecki, 2001; Ewing and Dumbaugh, 2009; Zegeer and Bushell, 2012; World Health Organisation (WHO), 2013; Mead et al., 2014]. Among other measures, providing signalized pedestrian crosswalks was reported to be effective in increasing pedestrian safety (Harkey and Zegeer, 2004; Elvik et al., 2009).

Signalized crosswalks, including those at signalized intersections, are supposed to serve as a safe place for pedestrians to cross, since they implement a principle of time-separation between vehicle and pedestrian movements. However, signalized intersections appear to be among urban locations with a high frequency of pedestrian crashes. According to recent estimates, on urban roads in Israel, seven percent of the fatal or serious pedestrian injuries occurred on signalized crosswalks (Sharon, 2017). Gitelman et al. (2012) examined infrastructure characteristics at urban locations with a higher frequency of pedestrian crashes, in Israel, and found that pedestrian crossings at signalized intersections represented the largest group, over a fifth of the sites examined. The vast majority of such intersections were situated on busy urban streets, with heavy traffic volumes and pedestrian activities. Due to the need to move large traffic volumes through the intersection, on an urban road, a shared vehicle-pedestrian green phase is generally applied for turning vehicles and crossing pedestrians. This feature was overrepresented at the signalized intersections with pedestrian crashes in the cities (Gitelman et al., 2012). It should be noted in this context that among other reasons for pedestrian-involving crashes at signalized intersections can be non-compliance with red lights by crossing pedestrians, insufficient length of green signals for completing the road crossing by pedestrians, etc. (Harkey and Zegeer, 2004; Elvik et al., 2009; Koh et al., 2014; Duduta et al., 2015).

According to the design guidelines for traffic signals (Guidelines, 1981), a right turn can be planned as a common green light for the turning vehicles and for pedestrians who cross the road at the adjacent crosswalk—**Figure 1**. In this case, both

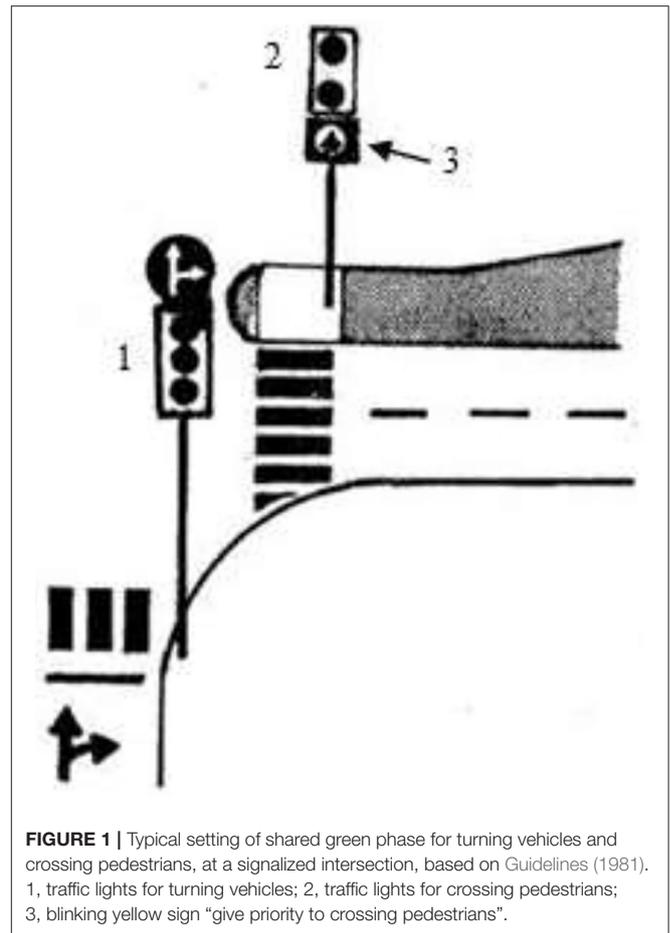


FIGURE 1 | Typical setting of shared green phase for turning vehicles and crossing pedestrians, at a signalized intersection, based on Guidelines (1981). 1, traffic lights for turning vehicles; 2, traffic lights for crossing pedestrians; 3, blinking yellow sign “give priority to crossing pedestrians”.

vehicles turning right and crossing pedestrians simultaneously receive green lights, while a blinking yellow sign indicates that the drivers should give priority to crossing pedestrians. The need for using shared green light is related to the traffic aspects of the intersection and typically refers to the lack of possibility to provide a separate green phase for pedestrians due to capacity constraints. A shared green light for turns at intersections can also be met in other countries (e.g., Koh et al., 2014).

The shared green light relies on a driver’s ability to notice and yield to the crossing pedestrians which, if it fails, may increase the risk of pedestrian injury. A solution suggested in the professional literature for improving pedestrian safety in this situation is to provide a leading pedestrian signal, i.e., the pedestrian green appears earlier than the vehicle green, enabling pedestrians to begin crossing in advance of right turning vehicles and hence forcing vehicles to give priority to the crossing pedestrians [Harkey and Zegeer, 2004; National Cooperative Highway Research Program (NCHRP), 2004; Gitelman et al., 2012].

Literature findings with regard to the safety impacts of shared pedestrian green with right-turning vehicles at intersections are not numerous. Elvik et al. (2009) summarized the international experience regarding the safety impacts of various changes in the traffic lights at intersections and found that the shared

green for pedestrians and vehicles was associated with an 8% increase in pedestrian-involving crashes and a 12% decrease in the vehicle-only crashes (both changes are close to significant). Conversely, the separate pedestrian green was associated with a significant decrease in both pedestrian and vehicle crashes, at 30 and 18%, respectively (Elvik et al., 2009). Concerning an earlier appearance of pedestrian green light in the shared situation, no crash estimates were reported.

Previous research in the USA indicated that a leading pedestrian signal in the shared green with turning vehicles has a potential to improve pedestrian safety, which is reflected in reduced vehicle-pedestrian conflicts and better giving-way to pedestrians by vehicles in the crosswalk area. For example, Van Houten et al. (2000) reported on a study conducted at three urban intersections, when the pedestrian green was changed to start 3 s earlier than the turning vehicles' green. They found a 95% reduction in the odds of vehicle-pedestrian conflicts for pedestrians who started crossing at the beginning of their green, while the odds of the incidence of pedestrians yielding the right-of-way to turning vehicles decreased by 60%. Harkey and Zegeer (2004) described field studies conducted at one intersection in Orlando and at three intersections in Petersburg, Florida, where pedestrian green was changed to appear four or 3 s earlier than the right-turning vehicles' green. In both cases, in after-before comparisons, a decrease in the number of vehicle-pedestrian conflicts was observed.

Being aware of a high presence of signalized intersections in Israeli cities and associated pedestrian safety problems, a field study was initiated aiming to explore the impacts of a leading pedestrian signal, on pedestrian crossing conditions at signalized intersections. As indicated above, previous research on the subject was scarce but generally reported a positive safety potential of the measure. In addition, international experience shows [Ekman and Hyden, 1999; Harkey and Zegeer, 2004; World Health Organisation (WHO), 2013; Mead et al., 2014] that safety-related impacts of an infrastructure measure may vary depending on the local conditions. Thus, the examination of impacts of a leading pedestrian signal was undertaken aiming to contribute both to the local practice of planning traffic lights at urban intersections and to the international knowledge with regard to the safety impacts of this infrastructure measure.

METHODS

This section is divided into two parts to explain the study framework and selecting the study sites, and data collection and analysis' methods, respectively.

The Study Framework and Selection of the Study Sites

The measure considered in this study was the introduction of a leading pedestrian signal—an earlier appearance of pedestrian green signal in shared green for right-turning vehicles and crossing pedestrians, at an urban intersection (see **Figure 1**). The pedestrian green was brought forward by 3 s relative to the co-occurring green light for the turning vehicles. After the initial

3 s of pedestrian green only, there was a shared green both for vehicles and pedestrians. The selection of 3 s for a leading pedestrian signal in this study was based on the experience of previous studies on the topic (Van Houten et al., 2000; Harkey and Zegeer, 2004) and also accounting for the fact that the longer the advanced time the more harmful it can be for the intersection capacity. In addition, Van Houten et al. (2000) indicated that 3 s are appropriate as a start-up time for crossing pedestrians of any age.

The purpose of the study was to examine the influence of the measure on pedestrian crossing conditions, whereas the later are estimated in terms of road user behaviors related to pedestrian safety. An after-before design was applied, where behavior indicators were estimated and compared at the study sites, in the after period when the measure was activated with the same indicators in the before period. Such a design is common in observational studies for estimating safety-related impacts of road infrastructure measures, including those with a focus on pedestrian safety (Van Houten et al., 1999, 2000; Harkey and Zegeer, 2004; Ewing and Dumbaugh, 2009; Gitelman et al., 2017).

The selection of road user behaviors for the current study was based on the experience of previous studies on the topic (Van Houten et al., 2000; Harkey and Zegeer, 2004) and also on the studies which examined pedestrian behaviors at signalized intersections, in general (Gitelman, 2014; Koh et al., 2014; Dommes et al., 2015). The road user behaviors examined in the current study included: giving-right-of-way to pedestrians by turning vehicles during the shared green, vehicle-pedestrian conflicts' occurrence in the crossing area, and crossing on red by pedestrians.

Road user behaviors were to be collected by means of field observations. At each site, three rounds of observations were planned: *before*—prior to application of the measure; *after1*—a week after the activation of the measure to examine its immediate impact; *after2*—about 2 months after the activation, to examine the behavior changes in the long term. The two rounds of after observations were applied to examine the effect of the measure immediately after its activation and after a certain “adaptation” period of the road users to the new situation.

The study intended to examine the measure in a large city with a common use of shared vehicle-pedestrian green for right-turning vehicle movements at signalized intersections. An agreement for co-operation was attained with the traffic engineering department of the Tel Aviv-Yafo municipality. Tel Aviv-Yafo is one of the biggest Israeli cities, with about 450,000 inhabitants and a high concentration of employment centers, including business, administrative, industrial and commercial activities. Due to heavy commuter traffic which enters the city daily, both by car and by public transport, “the active population” of the city is more than twice as high as the number of its inhabitants (Troitsky, 2018).

The requirements for the study sites were defined as follows: (1) It should be a signalized intersection with a signalized pedestrian crossing having a shared green light for pedestrians and turning vehicles, and situated in the city center; (2) The traffic volumes for turning vehicles in the shared green should not be high, about 200 vehicles per hour (in non-rush hours);

(3) The volumes of crossing pedestrians at the crosswalk with shared green should be medium-high, with at least 30 crossings per hour in the daytime. The requirements were based on the characteristics of the city and also accounted for the local guidelines of planning traffic lights, i.e., avoiding the use of shared green at sites with high volumes of turning vehicles. The third requirement related to the need to observe crossing pedestrians at the study sites (i.e., not to select sites with rare crossing pedestrians). Similar boundaries for the intensity of pedestrian activity were applied in other local studies, e.g., Gitelman et al. (2017).

A list of intersections with shared green lights was received from the city traffic department and consequently examined by the study team through preliminary field surveys. The introduction of the advanced pedestrian signal required a refitting of the traffic lights' program at the intersection that should be performed by a traffic engineer. Due to logistic and budget constraints, it was agreed among all the bodies involved (the municipality, the study commissioner and the study team) to apply the change at two sites. Thus, two intersections were selected for the study, both situated in the heart of employment activities of the city and in the proximity to public transport routes. The study sites were:

Site 1 (Levinsky—Lavander) is a four-legged intersection between a dual-carriageway collector road and a single-carriageway secondary road, situated in the vicinity of the central bus station and on a walking route that connects a railway station and the central bus station. A shared vehicle-pedestrian green was found and the advanced pedestrian signal was consequently applied on one leg of the intersection. **Figure 2, a** presents the crosswalk included in the study;

Site 2 (Hamager—Ben Avigdor) is a three-legged intersection, on a dual-carriageway collector road, which crosses the old industrial area of the city having multiple business, administrative and commercial activities and a variety of bus routes. A shared vehicle-pedestrian green was found for vehicles turning right from the secondary to the main road and the advanced pedestrian signal was applied on this leg. **Figure 2, b** presents the crosswalk included in the study, in this site.

Due to the diversity of traffic arrangements at the city intersections and an overload of city streets with various signs (e.g., business and property signs, advertisements, traffic signs), additional signs concerning the change in the traffic lights were not installed at the study sites.

Data Collection and Analysis

At each site, road user behaviors were collected using video-recordings of the crosswalk area, where the camera view covered the crosswalk, the sidewalk and the median next to the crosswalk, the turning vehicles near the crosswalk and the traffic lights for vehicles and for pedestrians. The duration of video-recording, in each period of observations, was about 10 h in a weekday (mostly, between 11 a.m. and 9 p.m.), including 6–7 h of daytime and 2–4 h of evening hours. This way, the observations included hours with both higher and lower vehicle traffic and with more pedestrian activities. The video-recordings were conducted on July 28, 2011 (before), November 24, 2011 (after1) and February

2, 2012 (after2), at both study sites. All days were with sunny and clear weather.

Using the video-records, the data were coded manually, using pre-defined forms and rules. First, hourly traffic volumes of the turning vehicles were produced by means of vehicle counting for each quarter of an hour and converting the values into average hourly estimates. Second, each traffic lights' cycle was identified by the beginning of pedestrian green, and for each cycle were documented: the cycle start time (hour-minutes-seconds); the numbers of pedestrians who started to cross from the sidewalk and from the median; whether there was a vehicle near the stop line for turning right. Third, if at the beginning of the green (in the first 3 s) there were a turning vehicle and at least one crossing pedestrian, then for that cycle it was indicated whether the first vehicle gave priority to all pedestrians coming from the sidewalk (yes/no) and to all pedestrians coming from the median (yes/no). In addition, the amount of pedestrians who started to cross in the first 3 s was counted, including their subdivision according to gender and major age groups (children, adults, elderly).

Further, concerning each traffic lights' cycle were documented: the duration of the whole green (in seconds); the number of pedestrians who crossed on green from the sidewalk, of them those who did not receive priority from the vehicles and those who experienced a conflict with the vehicle; similar numbers were counted for pedestrians who crossed on green from the median; the duration of the red light (in seconds) and the number of pedestrians who started crossing on red. A conflict was defined as a sudden change in the speed and/or the direction of walking by a pedestrian or of travel by the vehicle in order to avoid a collision. Such a definition is common in observational studies of pedestrian-vehicle interactions at crossing facilities (Van Houten et al., 1999; Ewing and Dumbaugh, 2009; Gitelman et al., 2017).

Using the total data records produced for a site, a set of behavioral indicators was estimated, for each period of observations, including: (1) Percent of cycles with giving-right-of-way by the turning vehicles, to all pedestrians who crossed from the sidewalk, in the first 3 s of green; (2) Percent of cycles with giving-right-of-way by the turning vehicles, to all pedestrians who crossed from the median, in the first 3 s of green; (3) Percent of pedestrians who were yielded by turning vehicles, during the whole green light, among the pedestrians who crossed from the sidewalk; (4) Percent of pedestrians who were yielded by turning vehicles, during the whole green light, among the pedestrians who crossed from the median; (5) Percent of conflicts between pedestrians and vehicles in the crosswalk area, during the whole green light, among the pedestrians who crossed from the sidewalk; (6) Percent of vehicle-pedestrian conflicts in the crosswalk area, during the whole green light, among the pedestrians who crossed from the median; (7) Average number of pedestrians who crossed on red, per a traffic lights' cycle.

The behavior indicators were estimated separately for daytime and evening hours. In addition, to characterize the extent of relevance of the topic examined, we estimated the percent of cases when there was a vehicle turning right at the intersection, out of the total number of traffic light cycles observed.

The significance of differences between the behavior indicators in the periods after the activation of advanced



pedestrian signal vs. the before period was examined using a *z*-test for proportions and a *t*-test for average values (Jekel et al., 2007). The difference was judged as significant when $p < 0.05$ was obtained. In addition, odds ratios and their 95% confidence intervals were estimated for the indicators of giving-right-of-way to pedestrians by turning vehicles when the advanced pedestrian signal is present.

Furthermore, binary logistic regression models were developed to explain the main behavior indicators—the probability of giving-right-of-way to all crossing pedestrians by turning vehicles, in the first 3 s of green. Four explanatory models were fitted—separate models for both sites and for pedestrians who crossed from the sidewalk and from the median. Among the explanatory variables in the models were examined: the study period (before, after1, after2); the number of crossing pedestrians at the beginning of green which were divided into three categories (1, 2-3 or more than 3 pedestrians), and the time period (day or evening hours). Weather conditions were not included in the data since all observations took place in nice weather conditions (sunny days, no rain). The observation units in the model datasets were traffic lights' cycles when both turning vehicles and crossing pedestrians were present at the beginning of the pedestrian green. The models were fitted using the Logistic procedure of Statistical Analysis Software (SAS 9.4). In the models' development, the need for interactions of the third and second order, between the explanatory variables, was examined but found not significant and thus the models were fitted without interactions between the variables. Each model fit was examined using a convergence criterion, Likelihood Ratio, Score and Wald criteria (which should be significant, $p < 0.05$); a Max-rescaled R-Square value was estimated for each model which indicates the amount of information gained when including the predictors into the model in comparison with the "null" model. Type 3 tests of effects showed the significance of the model variables ($p < 0.05$ indicates a significant impact). Using the models, adjusted odds ratios (OR), with 95% Wald confidence intervals, were estimated to show the impacts of the explanatory variables' values on the response variable.

RESULTS

In this section we present the background characteristics of the study sites and the detailed results of observations at both sites, during daytime hours. Explanatory models for the probability of giving-right-of-way to crossing pedestrians by turning vehicles, at the beginning of green, are also presented. The next section will discuss the summary changes in behavior indicators, at the study sites.

Background Characteristics of the Study Sites

Table 1 provides estimates of vehicle traffic and pedestrian volumes, at the study sites, in terms of the mean and standard deviation of the hourly volume of turning vehicles and the mean number of crossing pedestrians, per traffic light cycle, in various study periods. (To note, the traffic lights' cycle length was 90 s at site 1 and about 125 s at site 2). It can be seen that, across various periods of observations, the level of vehicle traffic was relatively stable at the study sites in daytime hours but was more variable in evening hours. The average numbers of crossing pedestrians were quite consistent, both in day and evening hours. The percent of cycles with presence of turning vehicles was slightly over half at site 1 and more substantial at site 2. In most cases, the average hourly numbers of turning vehicles were around 200 which corresponds to a low level of traffic volumes on urban roads. The amount of crossing pedestrians was high at site 1 and suited to a medium level at site 2. Given both lower numbers of turning vehicles and fewer crossing pedestrians in evening hours at site 2, some observational samples were small thus limiting the after-before comparisons.

The majority of pedestrians observed were adults (aged 19–64) while the shares of children (up to the age of 18) and elderly people (aged 65+) were minor, <10% each. Such a result was expected since both sites belong to industrial and business areas of the city. The share of female pedestrians was less than half at site 1 and close to half at site 2. In general, the study sites reflected various conditions with regard to the volume and the composition of crossing pedestrians.

TABLE 1 | Study sites, with estimates of vehicle and pedestrian volumes, in various study periods, and characteristics of crossing pedestrians.

a—Vehicle traffic.						
Study site	Average number of turning vehicles, per hour (standard deviation)			% of traffic light cycles with turning vehicles (total number of cycles observed)		
	Before	After1	After2	Before	After1	After2
Site 1, day hours	219 (34)	196 (35)	198 (48)	62% (285)	52% (208)	54% (247)
Site 1, evening hours	144 (36)	195 (35)	207 (68)	52% (126)	51% (163)	54% (176)
Site 2, day hours	234 (25)	272 (42)	233 (25)	96% (220)	64% (150)	80% (184)
Site 2, evening hours	170 (35)	110 (25)	202 (48)	82% (72)	67% (84)	87% (124)

b—Pedestrian traffic.										
Study site	Among pedestrians crossing from the sidewalk			Among pedestrians crossing from the median						
	No of cycles when crossing pedestrians and turning vehicles were present [#] (average number of crossing pedestrians per cycle)			Gender: % of males	Age: % of adults	No of cycles when crossing pedestrians and turning vehicles were present [#] (average number of crossing pedestrians per cycle)			Gender: % of males	Age: % of adults
	Before	After1	After2	*	*	Before	After1	After2	*	*
Site 1, day hours	164 (4.5)	98 (4.3)	121 (3.8)	57–67%	87–96%	172 (7.1)	104 (7.4)	129 (7.3)	53–65%	87–98%
Site 1, evening hours	55 (3.6)	80 (6.1)	88 (5.0)	64–67%	87–98%	63 (6.1)	82 (7.3)	89 (7.2)	61–63%	86–99%
Site 2, day hours	119 (1.8)	46 (1.7)	96 (1.6)	51–63%	87–92%	153 (2.8)	57 (2.8)	117 (2.3)	53–63%	84–96%
Site 2, evening hours	10** (1.3)	8** (1.3)	33 (1.6)	46–54%	70–98%	9** (2.1)	18 (2.3)	48 (2.1)	47–56%	95–100%

[#]At the beginning of pedestrian green. *Range, across the three periods.
^{**}Small sample: up to 10 cycles observed with both movements.

Behavior Changes at Site 1, in Day Hours

Table 2 shows the behavior indicators estimated for site 1, in day hours, in each period of observations, including the results of statistical comparisons between the periods. The activation of advanced pedestrian signal was associated with a significant increase in the share of cases when the turning vehicle gave priority to all pedestrians who crossed at the beginning of green, both from the sidewalk and from the median. The percent of cycles where all pedestrians who started crossing in the first 3 s received the right-of-way increased from 89 to 99% for those who crossed from the sidewalk, and from 86 to 98% for those who crossed from the median. This means that giving-right-of-way to pedestrians at the beginning of green was improved substantially while the frequency of the situation when a crossing pedestrian is interrupted by a turning vehicle was minimized to 1–2%.

However, among the pedestrians who crossed during the entire green, the percentage of those who received priority from the turning vehicles did not change consistently: for pedestrians who crossed from the sidewalk, the share of those who received the right-of-way increased by 4% immediately after the introduction of the advanced green but reduced to the previous level after 2 months. For pedestrians crossing from the median, a general increase in the percent of giving-right-of-way was observed following the measure’s activation, by 4–6%, but the improvement was moderated after 2 months.

Conflicts between pedestrians and vehicles in the crossing area were rare (between 0 and 3 events per round of observations), both before and after the application of change in the traffic lights; the changes in conflict occurrence were insignificant. Similarly, the average number of pedestrians crossing on red did not change substantially between the periods: it was and remained about 1 pedestrian, per cycle.

Behavior Changes at Site 2, in Day Hours

Table 3 presents the behavior indicators observed, in various periods, at site 2 and the results of their comparisons. The impacts of the advanced pedestrian signal were more positive and consistent at this site indicating a substantial increase in giving the priority to crossing pedestrians at the beginning of green, by 16–23%, with no moderation in the effect after 2 months of activation. The frequency of cases when a crossing pedestrian was not respected by a turning vehicle was minimized to 2–4%. In addition, in the longer after period, an improvement was observed in the share of giving-right-of-way to pedestrians during the whole green phase, both for those crossing from the sidewalk and from the median. The increase was remarkable for pedestrians crossing from the median, by 19%.

Similar to site 1, vehicle-pedestrian conflicts in the crosswalk area were rare (between 0 and 2 events per round of observations), and their frequency did not change significantly between the study periods. The average number of pedestrians

TABLE 2 | Behavior indicators at site 1, day hours, in each observation period, and the results of statistical comparisons between the periods.

Behavior Indicator	Behavior indicator values (No of observations)			Statistical differences between periods		
	Before	After1	After2	After1 vs. Before	After2 vs. Before	After2 vs. After1
% of giving-right-of-way by the turning vehicles to all pedestrians who crossed from the sidewalk, in the first 3 s of green	89% (164 ^a)	99% (98)	99% (121)	I, $p < 0.001$, OR 12.0, CI 1.6–91.1	I, $p < 0.001$, OR 14.8, CI 1.9–112.4	ns, $p = 0.88$, OR 1.2, CI 0.1–20.0
% of giving-right-of-way by the turning vehicles to all pedestrians who crossed from the median, in the first 3 s of green	86% (172 ^a)	99% (104)	98% (129)	I, $p < 0.001$, OR 16.7, CI 2.2–125.4	I, $p < 0.001$, OR 10.3, CI 2.4–44.4	ns, $p = 0.68$, OR 0.6, CI 0.1–6.9
% of giving-right-of-way to pedestrians, during the whole green, among the pedestrians who crossed from the sidewalk	90% (1597 ^b)	94% (1055)	88% (1234)	I, $p < 0.001$, OR 1.8, CI 1.3–2.4	ns, $p = 0.26$, OR 0.9, CI 0.7–1.1	D, $p < 0.001$, OR 0.5, CI 0.4–0.7
% of giving-right-of-way to pedestrians, during the whole green, among the pedestrians who crossed from the median	93% (1676 ^b)	99% (1091)	97% (1270)	I, $p < 0.001$, OR 7.1, CI 3.9–12.9	I, $p < 0.001$, OR 2.9, CI 2.0–4.2	D, $p < 0.01$, OR 0.4, CI 0.2–0.8
% of conflicts between pedestrians and vehicles in the crossing area, during the whole green, among the pedestrians who crossed from the sidewalk	0.13% (1597 ^b)	0.28% (1055)	0.16% (1234)	ns, $p = 0.39$	ns, $p = 0.80$	ns, $p = 0.54$
% of conflicts between pedestrians and vehicles in the crossing area, during the whole green, among the pedestrians who crossed from the median	0% (1676 ^b)	0.18% (1091)	0.08% (1270)	ns, $p = 0.16$	ns, $p = 0.32$	ns, $p = 0.49$
Average number of pedestrians who crossed on red, per traffic lights' cycle, \pm sd	0.91 \pm 0.86 (285 ^c)	1.05 \pm 0.51 (208)	0.98 \pm 0.52 (247)	I, $p < 0.05$	ns, $p = 0.28$	ns, $p = 0.13$

^aNumber of traffic light cycles with turning vehicles and crossing pedestrians.

^bTotal number of pedestrians who crossed on green. ^cTotal number of traffic light cycles. I, increase; D, decrease; ns, no change; OR, odds ratio; CI, 95% confidence interval.

crossing on red was low, about 1 pedestrian per two traffic light cycles, and generally did not change after the activation of advanced pedestrian signal.

Explanatory Models

Table 4 shows results of the explanatory models fitted to the probability of giving-right-of-way to all crossing pedestrians at the beginning of green, accounting for the study period (before or after the activation of advanced pedestrian signal), the number of crossing pedestrians at the beginning of the green light and the time of day. All four models converged and were significant; the Max-rescaled R-Square values were 0.22–0.28 for models of site 1, and 0.14–0.16 for models of site 2. In all the models, a significant impact of advanced pedestrian signal was found. The adjusted OR for the probability of giving-right-of-way to crossing pedestrians at the beginning of green, after 2 months of the activation of the signal change compared to before period, was 23.7 for pedestrians crossing from the sidewalk and 10.3 for those crossing from the median, at site 1, and 8.7 and 8.5, respectively, at site 2. The time of day (day vs. evening hours) did not have a significant impact on the behavior examined, in all models. The number of crossing pedestrians did not have a significant impact on the response variable in the models, except for the case of pedestrians crossing from the median at site 1, where a lower

number of crossing pedestrians (one or 2–3 only) was associated with a lower probability of giving-right-of-way by turning vehicles compared to 3+ crossing pedestrians (OR of 0.11 and 0.32, respectively).

DISCUSSION

Table 5 presents a summary of changes observed in road user behaviors following the application of an advanced pedestrian signal at the study sites, both in day and evening hours, with a focus on the impacts in a long-term. At both sites, there was a consistent improvement in giving-right-of-way to pedestrians by the vehicles, in first 3 s of their green, both in day and evening hours and for crossing from both sides of the road. Following the activation of the advanced pedestrian green, the percentage of cycles where all pedestrians received priority at the beginning of the green increased to 97–100% for those who crossed from the sidewalks and to 94–99% for those who crossed from the median; the increase was significant in most cases (except for the case of evening hours at site 2 where the number of cycles with crossing pedestrians was small in the before period). The general regression models for both sites found a significant increase in giving-right-of-way to pedestrians at the beginning of green, following the measure's application, for pedestrians

TABLE 3 | Behavior indicators at site 2, day hours, in each observation period, and the results of statistical comparisons between the periods.

Behavior Indicator	Behavior indicator values (No of observations)			Statistical differences between periods		
	Before	After1	After2	After1 vs. Before	After2 vs. Before	After2 vs. After1
% of giving-right-of-way by the turning vehicles to all pedestrians who crossed from the sidewalk, in the first 3 s of green	82% (119 ^a)	96% (46)	98% (96)	I, $p < 0.01$, OR 4.7, CI 1.1–21.0	I, $p < 0.001$, OR 10.1, CI 2.3–44.1	ns, $p = 0.50$, OR 2.1, CI 0.3–15.7
% of giving-right-of-way by the turning vehicles to all pedestrians who crossed from the median, in the first 3 s of green	73% (153 ^a)	91% (57)	96% (117)	I, $p < 0.01$, OR 3.8, CI 1.4–10.2	I, $p < 0.001$, OR 8.2, CI 3.1–21.5	ns, $p = 0.28$, OR 2.1, CI 0.6–7.8
% of giving-right-of-way to pedestrians, during the whole green, among the pedestrians who crossed from the sidewalk	88% (285 ^b)	93% (68)	94% (319)	ns, $p = 0.18$, OR 1.8, CI 0.7–4.7	I, $p < 0.01$, OR 2.3, CI 1.3–4.2	ns, $p = 0.62$, OR 1.3, CI 0.5–3.7
% of giving-right-of-way to pedestrians, during the whole green, among the pedestrians who crossed from the median	76% (445 ^b)	100% (41)	95% (336)	I, $p < 0.001^*$	I, $p < 0.001$, OR 6.2, CI 3.6–10.7	D, $p < 0.001^*$
% of conflicts between pedestrians and vehicles in the crossing area, during the whole green, among the pedestrians who crossed from the sidewalk	0.70% (285 ^b)	2.9% (68)	0.63% (319)	ns, $p = 0.29$	ns, $p = 0.91$	ns, $p = 0.27$
% of conflicts between pedestrians and vehicles in the crossing area, during the whole green, among the pedestrians who crossed from the median	0.22% (445 ^b)	0% (41)	0.30% (336)	ns, $p = 0.32$	ns, $p = 0.85$	ns, $p = 0.32$
Average number of pedestrians who crossed on red, per traffic lights' cycle, \pm sd	0.55 \pm 1.13 (220 ^c)	0.35 \pm 0.84 (150)	0.62 \pm 1.01 (184)	ns, $p = 0.07$	ns, $p = 0.52$	I, $p < 0.05$

^aNumber of traffic light cycles with turning vehicles and crossing pedestrians.

^bTotal number of pedestrians who crossed on green. ^cTotal number of traffic light cycles.

I, increase; D, decrease; ns, no change; OR, odds ratio; CI, 95% confidence interval.

*OR is not applicable due to 100% of giving-right-of-way to pedestrians in after1 period.

crossing from any side of the crosswalk, both in day and evening hours. The impact of the measure was substantial, with the adjusted odds ratios (in a long-term) over 10 at site 1 and over 8 at site 2.

Concerning the giving-right-of-way to pedestrians during the whole green, following the activation of the measure, the changes were inconsistent for pedestrians who crossed from sidewalks, while for pedestrians crossing from the median, a consistent improvement was observed. Such a difference in the effect can be related to a lower conspicuity of pedestrians coming from the sidewalks, for turning vehicles. The level of yielding to pedestrians by the vehicles, in the after period, was 90% and greater, at all sites, which is comparable with the rates reported in the US study (Van Houten et al., 2000).

The effect of the advanced pedestrian green on giving priority to crossing pedestrians was stronger at site 2, where medium volumes of crossing pedestrians were observed compared to high volumes at site 1. Based on the observations at site 2, it can be stated that fewer crossing pedestrians are associated with lower initial rates of giving them the right-of-way during the shared green, both at the beginning of the green light

and during the whole green phase. The introduction of an advanced pedestrian signal enables pedestrians to start walking while vehicles are still waiting thus providing actual priority for crossing pedestrians, which is particularly important for single pedestrians compared to groups because the former are more frequently disregarded by the vehicles (Dommes et al., 2015). Similarly, in the current study, one of the models for predicting giving-right-of-way for pedestrians at the beginning of green found a lower probability of yielding to single pedestrians or small groups compared to a larger number of pedestrians.

The rate of conflicts was close to zero before the application of the measure and remained similar after the application. Unlike previous studies (Van Houten et al., 2000; Harkey and Zegeer, 2004), the current study could not show an effect of the advanced pedestrian green on conflict occurrence in the crossing area due to the scarcity of this problem at the observational sites. For example, Van Houten et al. (2000) reported the average conflict rates of 2.1–3.3 per 100 pedestrians in baseline conditions and of 0.1–0.2 per 100 pedestrians after the introduction of a leading pedestrian green. The current study values were between the above boundaries. The higher frequency of conflicts in the

TABLE 4 | Logistic regression models for the probability of giving-right-of-way to crossing pedestrians by turning vehicles, in the first 3 s of green.**a–At site 1, for pedestrians crossing from the sidewalk.**

Variable	Variable category	Estimate	Standard error	Pr > ChiSq	Odds ratio	95% Wald Confidence Limits	
Intercept		2.79	0.55	<.0001			
Study period*	After1	2.91	1.03	0.0047	18.38	2.44	138.32
	After2	3.17	1.03	0.0021	23.70	3.15	178.04
	Before	0	.	.	Ref.		
No of crossing pedestrians	1	−0.97	0.56	0.0805	0.38	0.13	1.13
	2–3	−0.23	0.49	0.6342	0.79	0.31	2.06
	over 3	0	.	.	Ref.		
Time of day	Day hours	−0.52	0.53	0.3283	0.60	0.21	1.68
	Evening hours	0	.	.	Ref.		

b–At site 1, for pedestrians crossing from the median.

Intercept		2.73	0.44	<.0001			
Study period*	After1	3.27	1.03	0.0014	26.32	3.52	196.80
	After2	2.32	0.62	0.0002	10.13	3.01	34.16
	Before	0	.	.	Ref.		
No of crossing pedestrians*	1	−2.22	0.49	<.0001	0.11	0.04	0.29
	2-3	−1.14	0.43	0.0081	0.32	0.14	0.74
	over 3	0	.	.	Ref.		
Time of day	Day hours	−0.35	0.43	0.4089	0.70	0.30	1.63
	Evening hours	0	.	.	Ref.		

c–At site 2, for pedestrians crossing from the sidewalk.

Intercept		1.59	1.02	0.1195			
Study period*	After1	1.25	0.64	0.0519	3.48	0.99	12.24
	After2	2.16	0.64	0.0007	8.70	2.48	30.52
	Before	0	.	.	Ref.		
No of crossing pedestrians	1	−0.17	0.81	0.8354	0.85	0.17	4.14
	2-3	0.25	0.85	0.7719	1.28	0.24	6.84
	over 3	0	.	.	Ref.		
Time of day	Day hours	0.01	0.67	0.9903	1.01	0.27	3.73
	Evening hours	0	.	.	Ref.		

d–At site 2, for pedestrians crossing from the median.

Intercept		0.78	0.54	0.1521			
Study period*	After1	1.25	0.43	0.0036	3.50	1.51	8.15
	After2	2.14	0.43	<.0001	8.47	3.65	19.63
	Before	0	.	.	Ref.		
No of crossing pedestrians	1	−0.12	0.43	0.7822	0.89	0.38	2.07
	2-3	−0.49	0.38	0.1963	0.61	0.29	1.29
	over 3	0	.	.	Ref.		
Time of day	Day hours	0.51	0.44	0.2497	1.67	0.70	3.97
	Evening hours	0	.	.	Ref.		

(a) N = 606. Max-rescaled R-Square=0.218. *Significant variable, $p < 0.001$.

(b) N = 639. Max-rescaled R-Square = 0.284. *Significant variable, $p < 0.0001$.

(c) N = 312. Max-rescaled R-Square = 0.136. *Significant variable, $p < 0.01$.

(d) N = 402. Max-rescaled R-Square = 0.157. *Significant variable, $p < 0.0001$.

TABLE 5 | Summary of changes in behavior indicators at the study sites, following the application of advanced pedestrian green.

Behavior Indicator	Site 1, day hours	Site 1, evening hours	Site 2, day hours	Site 2, evening hours
% of giving-right-of-way to pedestrians crossing from the sidewalk, in the first 3 s of green	I, from 89 to 99%	I, from 91 to 100%	I, from 82 to 98%	ns*, from 90 to 97%
% of giving-right-of-way to pedestrians crossing from the median, in the first 3 s of green	I, from 86 to 98%	I, from 87 to 99%	I, from 73 to 96%	ns*, from 67 to 94%
% of giving-right-of-way to pedestrians crossing from the sidewalk, during the whole green	ns, 88–90%	D, from 91 to 85%	I, from 88 to 94%	ns*, 94–95%
% of giving-right-of-way to pedestrians crossing from the median, during the whole green	I, from 93 to 97%	I, from 96 to 99%	I, from 76 to 95%	ns*, from 81 to 89%
% of conflicts between vehicles and pedestrians crossing from the sidewalk, during the whole green	ns, 0.1–0.2%	ns, 0–0.1%	ns, 0.6–0.7%	ns*, 0%
% of conflicts between vehicles and pedestrians crossing from the median, during the whole green	ns, 0–0.1%	ns, 0–0.2%	ns, 0.2–0.3%	ns*, 0%
Average number of pedestrians who crossed on red, per cycle	ns, 0.9–1	I, from 0.6 to 0.9	ns, 0.6	I, from 0.4 to 0.8

*I, increase; D, decrease. Results reported in this table are based on the comparison of after2 vs. before periods. I/D indicates a statistically significant change, with $p < 0.05$; ns, not significant. *Small sample in before period ($N < 30$).*

initial conditions in the US study can be related to the higher number of lanes at the pedestrian crosswalks examined (four compared to two in the current study) and also to the fact that both left- and right-vehicle turns were allowed concurrently with pedestrian green while in the current study the shared green was for right-turning vehicles only. In spite of the lack of impact on vehicle-pedestrian conflicts, the consistent and significant increases in giving-right-of-way to pedestrians, in the current study sites, definitely support the improvement in pedestrian crossing conditions, following the introduction of advanced pedestrian green.

Despite the improvement of pedestrian crossing conditions during the green light, the number of pedestrians who crossed on red did not decrease and even an increase was observed in evening hours, at both sites (see **Table 5**). The phenomenon of pedestrians crossing on red at signalized intersections is well known in the road safety literature (Gitelman, 2014; Koh et al., 2014; Dommes et al., 2015). The intention to cross on red typically increases with a longer waiting time for pedestrians (Duduta et al., 2015) and, in particular, when sufficient gaps appear in the vehicle traffic on the road. Both explanations are relevant to the current study intersections. The gaps in vehicle traffic are more expected in the evening hours; indeed, a slight increase in the rate of pedestrians crossing on red was observed in evening hours in this study. In general, the study findings indicated that advanced pedestrian green probably cannot contribute to improving the compliance with red lights by crossing pedestrians.

Overall, the changes observed in road user behaviors following the activation of an advanced pedestrian signal in shared vehicle-pedestrian green were positive, particularly with regard to giving-right-of-way to pedestrians, and hence, they can be associated with a safety improvement of pedestrian crossing conditions at the signalized intersections. This measure may provide safety benefits in busy urban areas where, due to the need to move high

volumes of vehicle traffic at signalized intersections, shared green light was applied for turning vehicles and crossing pedestrians. The study demonstrated the benefits of the measure under the conditions of relatively low volumes of turning vehicles (about 200 vehicles per hour) and medium to high volumes of crossing pedestrians.

The limitations of the current study are related to the limited number of sites where the measure was applied that led to small observational samples in some cases. Further follow-up studies of the measure at intersections with different combinations of vehicle and pedestrian volumes and various urban environment conditions would contribute to a better understanding of its effects on pedestrian safety. Possible impacts of demographic and socio-economic characteristics of crossing pedestrians and of various vehicle types should be also considered in this context.

The definition of conflict adopted in the current study—an abrupt vehicle braking and pedestrian stop or taking an evasive action to avoid a collision, followed the experience of previous research on the topic (Van Houten et al., 1999, 2000; Ewing and Dumbaugh, 2009). However, it was based on a visual recognition by an observer and thus may suffer from a subjective interpretation. Due to small numbers of conflicts observed in this study, a formal conflict analysis technique with measures like time-to-collision and post-encroachment time (e.g., Laureshyn et al., 2010) was not applied. Future research with automated video-analysis and formal traffic conflict analysis techniques would be useful for better understanding of conflict occurrences at signalized intersections, including a quantification of the effect of advanced pedestrian green on conflict occurrence under Israeli conditions. As evident from the results of the current study and Van Houten et al. (2000), substantial samples of crossing pedestrians should be observed in order to pronounce the impact of the measure on conflict rates.

CONCLUSION

This study examined the impacts of a leading pedestrian signal—an earlier appearance of the pedestrian green signal in shared green for right-turning vehicles and crossing pedestrians—on pedestrian crossing conditions at urban intersections. The findings indicated the increase in giving-right-of-way to pedestrians by turning vehicles which is expected to contribute to improved pedestrian safety while crossing at signalized intersections. The effect of the measure may be stronger at intersections with a lower initial level of giving-the-right-of-way to pedestrians and higher rates of vehicle-pedestrian conflicts, during the shared green.

Being aware of pedestrian safety problems in urban areas and in line with sustainable urban development, infrastructure measures which improve pedestrian safety should be promoted throughout the cities (Stoker et al., 2015; European Transport Safety Council (ETSC), 2019). At busy signalized intersections, when separate pedestrian green is inapplicable due to capacity reasons, the application of advance pedestrian signal should be considered as a rule. To promote safe walking in the cities, accounting for pedestrian needs should become one of the basic principles in planning traffic lights at signalized intersections, especially in areas with high pedestrian presence.

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DATA AVAILABILITY STATEMENT

The datasets generated for this study are available on request to the corresponding author.

AUTHOR CONTRIBUTIONS

VG: study conception and design. RC: coordination with external bodies, data collection. FP: data analyses. VG: interpretation of results and draft manuscript preparation. All authors reviewed the results and approved the final version of the manuscript.

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Conflict of Interest: The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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