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Exploring safety-related behaviours of e-cyclists on urban streets; an observational study

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Abstract

E-bikes provide a potential for improving sustainable urban mobility. However, there are concerns of e-cycling related injury. In this study, observational surveys of e-bikes were conducted in Israeli cities to explore their presence and safety-related behaviours, at typical urban settings. The results showed that e-bike presence in urban traffic was similar to that of regular bicycles. Mean speeds of e-cyclists were higher than those of regular cyclists, by 5 km/h, on average, but were lower on sidewalks. E-bikes moved slower than vehicles on roadways but were faster than pedestrians on sidewalks. At intersections, 20% of e-cyclists crossed on red. In general, the study showed a mixed use of urban facilities by e-bikes, with heterogeneous traffic both on vehicle and pedestrian settings and multiple risk factors. For a safer integration of e-bikes in Israeli cities, a wider application of cycling infrastructure, with separation from sidewalks and roadways, is needed.

Keywords: E-bikes; observation; behaviours; speeds; urban streets.

1. Introduction

Cycling for transport is being advocated to address important societal challenges such as traffic congestion, global warming, air pollution and chronic diseases associated with obesity and an inactive lifestyle (OECD/ITF, 2013). Internationally, transport policy makers and urban planners are interested in encouraging cycling. However, the expansion of cycling for transport is deterred due to the physical efforts required for riding, dependency on road terrain and other obstacles. Electric power-assisted bicycles (e-bicycles or e-bikes) reduce the physical efforts required for riding and thus may level out common barriers to cycling (Fishman and Cherry, 2016).

Over the last decade, there has been a sharp increase in the use of e-bikes, throughout the world. In Europe, the annual e-bike sales tripled between 2010 and 2016 (Jahre et al., 2019), with a remarkable increase of e-bike sales observed in Germany, the Netherlands, Austria, Switzerland, Italy and France (Fishman and Cherry, 2016). The sale's share of

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e-bikes, related to all bicycles sold, ranged from 1%-3% in Great Britain and France to 22%-23% in the Netherlands and Belgium (Van Cauwenberg et al., 2018).

In Israel, a country with a population of over 9 million and low bicycle use in general (the bicycle share in the modal split in Israel is about 1% at the national level), the amount of e-bikes in use has grown recently. The Israeli Tax department reported that e-bikes presented 16% of total bicycle imports into the country. As estimated, by the end of 2017, between 227 to 246 thousands of e-bikes were in use (Shachak, 2018).

Studies from European countries, USA and Australia showed that the frequency and distances of trips performed by e-bikes increased compared to trips on ordinary bicycles and that e-bicycles can replace private car travels for daily purposes (Johnson and Rose, 2015; Jones et al., 2016; MacArthur et al, 2018; Jahre et al., 2019). E-bicycles are particularly helpful for people who are unable to ride regular bicycles due to physical limitations or ageing (Johnson and Rose, 2015; MacArthur et al, 2018; Van Cauwenberg et al., 2018). Owing to the use of electrical power, e-bikes are environment-friendly. For these reasons, e-cycling has a great potential for improving the sustainability of urban transport. However, along with mobility benefits, there is a growing concern of e-cyclists' injuries, resulting from the increasing exposure, higher speeds and, perhaps, riskier behaviours of e-riders.

For example, in China, a higher risk for e-bike riders to be killed or suffer severe injuries in a road crash was reported compared to ordinary bicycle riders (Hu et al., 2014). In the Netherlands, Schepers et al. (2014) showed that the risk for e-cyclists to be injured in a road crash is higher compared to regular cyclists, yet, the difference in injury severity was not ascertained. A more recent study, which controlled for the health status of e-bike users, found that e-riders were not more likely to be involved in a crash or to sustain severe injuries compared to conventional cyclists (Schepers et al., 2020). In Israel, based on police reports (Shachak, 2018) and hospital records (Siman-Tov et al., 2017), a substantial increase was reported in the number of people who were killed or injured in crashes involving e-cyclists, in 2013-2018, that was apparently associated with the increased use of e-bikes.

Behaviour studies conducted in the USA and Europe showed that e-cyclists usually ride faster than ordinary cyclists, though the speed differences are not large; for example, the mean speeds of standard e-bikes, known as *pedelec* in Europe, were found to be higher by 2-4 km/h (Langford et al., 2015; Dozza et al., 2016; Schleinitz et al., 2017; Twisk et al., 2021). Some findings indicated a higher involvement of e-riders in conflicts with other road users, mainly at intersections and near crosswalks (Dozza et al, 2016; Petzoldt et al, 2017). At the same time, safety-related behaviours of e-cyclists in European and US studies, such as helmet use, compliance with traffic signs or red lights, or manner of riding on bicycle-shared paths, were identical or even more safety-aware than those of conventional cyclists (Langford et al., 2015; Scaramuzza et al. 2015; Schleinitz et al., 2019). In contrast, studies from China reported high rates of traffic violations and dangerous behaviours among e-bike riders, such as passing through red lights or riding at unnecessarily high speeds, compared to regular bicycles (Du et al., 2013; Yang et al., 2018). Evidently, the findings on riskier behaviours of e-bike users compared to regular cyclists are not uniform across countries, and are related to the local context.

Furthermore, the state of urban infrastructure plays an essential role. In Israel, similar to Europe, an e-bicycle should satisfy the conditions defined by EN15194, with limited engine power, speed up to 25 km/h and obligatory pedalling. E-bikes meeting these requirements do not need licensing and can use bicycle lanes, like a regular bicycle. They can ride on bicycle facilities and on roadways, but are not allowed on sidewalks and pedestrian crosswalks. However, when cycling infrastructure is absent, e-bicycles should travel in mixed vehicle traffic, whereas some riders may prefer pedestrian facilities. From a safety viewpoint, both alternatives are flawed as they increase the risk of injury for various road users. In addition, design guidelines for planning urban streets, like those published in Israel (Ministry of Transport, 2009), do not explicitly consider the e-bike presence in urban traffic.

Recognizing the importance of observational studies for better understanding of road user behaviours and for safer integration of e-cycling in urban areas, in this study, observational surveys of e-cyclists were undertaken in Israeli cities. The study focused on adult e-cyclists, as in most previous research. To note, teen e-cyclists' behaviours were explored in another Israeli study (Gitelman et al., 2018).

The study intended to characterize safety-related behaviours of e-riders at typical urban settings, aiming to enrich the knowledge on e-cycling behaviours in urban areas. Among safety-related behaviours examined in the study were: riding speeds, place of riding (in the road layout), helmet wearing, interactions with other road users, compliance with traffic lights. The selection of behaviours was in line with previous observational studies (Langford et al., 2015; Dozza et al., 2016; Schleinitz et al., 2019) and also intended to reflect the compliance with traffic rules, in the local context.

2. Methodology

Three complementary observational surveys were performed in the study: traffic counting, a speed survey and video-recordings. The different surveys intended to measure both the general presence and detailed behaviours of e-riders in urban traffic and, thereby, to provide a comprehensive picture of the phenomenon. Traffic counting was conducted in September-November 2016, other observations - in November 2016-March 2017.

The traffic counting took place at 50 urban intersections, in nine cities, aiming to estimate the extent of e-bicycle presence in urban traffic as related to vehicle, pedestrian and regular cyclists' volumes. The survey sites were signalized intersections and roundabouts, situated in the vicinity of city centers and/or on main traffic routes. The count data were processed to produce hourly figures and then regression models were fitted to quantify the relationships between the presence of various road users. More details on this survey are given in Gitelman et al. (2020).

The *speed survey* was conducted for electric and ordinary bicycles, on the same streets. For that purpose, six street sections were selected in two cities in the central region of the country (Tel-Aviv and Ram Gan), near the intersections where the traffic counting took place. The survey sites represented typical streets for both cities, with mixed traffic of various road users, and different types of road layouts and land uses, i.e. single- and dual-carriageway collector or arterial streets, with or without a commerce/bike path.

Speeds were measured using a speed gun, in the middle of street sections, and under conditions of undisturbed cycling. The survey took place on working days, between the hours of 8-17. Beside speed measurement, rider's characteristics were recorded on an observation form, such as gender, age group (19-34, 35-64, 65+), place of riding (roadway, sidewalk or bike path), and helmet wearing. The age groups were estimated visually, by a trained observer. At each site, data were collected for 30-50 e-bikes and 10-30 regular bicycles, with more measurements taken on busier streets. It can be noted that a speed gun is a common tool for speed surveys in urban areas (Hakkert and Gitelman, 2007). As the speed gun values are sensitive to the angle of measurement, the measurement should be as close as possible to zero angle relative to the moving object. To reflect the estimation uncertainty, both means and standard deviations of speeds were estimated in the study, for both bicycle types.

Data analyses included, first, estimating summary speed indicators and rider's characteristics, with a *t-test* applied to examine differences in speeds between the two groups of cyclists. Second, multivariate models were fitted to identify factors that affect riding speeds and other behaviours, e.g. helmet wearing and place of riding. For predicting riding speed a stepwise linear regression was applied (Cohen et al., 2013), while for other behaviours binary logistic regression models were adjusted.

Furthermore, to explore e-cyclist behaviours in urban traffic, field observations were conducted using *video-recordings*. For that purpose, the observers were deployed at the pre-defined sites, near intersections. They were instructed to activate a camera when an e-cyclist appears, while the film should record how the e-cyclist approaches the intersection, crosses it and moves away from the intersection (if visibility allowed that). In addition, the video should cover the street scene and other road users near the e-rider, while the films should mostly include the cases when the e-bike was interacting with other road users, and was not alone. The observations took place on working days, between the hours of 9-16, i.e. in daylight hours, with vehicular and pedestrian activities on the streets.

The video-recordings were taken in the city of Tel-Aviv, near intersections with busy traffic of various road users. A total of ten sites were selected for the survey representing three types of areas: (a) signalized intersections on divided main streets, with a built median (4 sites); (b) intersections on undivided collector streets (3 sites); (c) intersections on streets with boulevards - wide medians enabling walking and cycling (3 sites). Figure 1 presents examples of sites where the study observations took place.

Figure 1: Examples of typical urban intersections included in the study: (a) on a divided street; (b) on an undivided street; (c) on street with a boulevard.

The film contents were coded to reflect the road and traffic conditions during the e-bike travels and their interactions with other road users. The coded data were analysed to characterize behaviour patterns of e-cyclists in various infrastructure settings, and to identify common interactions and conflicts. Statistical tests were performed to examine the impacts of infrastructure characteristics on e-cyclist behaviours. For uni-variable examinations, a *Pearson Chi-square* test was used, for multi-variable examinations of selected behaviours, binary logistic regression models were fitted (Fleiss et al., 2004).

A conflict was defined as an abrupt change in the speed and/or the direction of travel, by the rider or other road user in order to avoid a collision, in line with previous research (Ewing and Dumbaugh, 2009; Van der Horst et al., 2014; Gitelman et al., 2017). A further analysis of conflicts was applied using a method based on the Dutch traffic conflict technique (van der Horst and Kraay, 1986; Van der Horst et al., 2014).

3. Results

3.1 E-bike presence in urban traffic, based on traffic counting

The traffic counts showed that e-bike presence at urban intersections was similar to that of regular bicycles. For example, related to pedestrian traffic on sidewalks, the presence of both bicycle types was: 2% at roundabouts, 6%-8% at signalized intersections on urban arterials, 4% at signalized intersections on collector streets. On the roadways, related to motor vehicle traffic, the presence of e-bikes was 0.7%-1.3%, of regular bicycles - 0.5%-0.6% (see more data in Gitelman et al., 2020).

The regression models fitted to the data were as follows:

$$ebikes = \exp[-0.76 + 0.32 * \log(veh) + 0.17 * \log(ped) + 0.28 * \log(bikes)]$$
$$ebikes\_r = \exp[-0.72 + 0.43 * \log(ped) + 0.28 * \log(bikes)]$$
$$ebikes\_s = \exp[-4.16 + 0.81 * \log(veh) + 0.23 * \log(bikes)]$$

where: *ebikes, ebikes_r, ebikes_s* – predicted hourly numbers of total e-bikes in traffic, e-bikes on the roadway and e-bikes on sidewalks, respectively; *veh, ped, bikes* – hourly numbers of vehicles, pedestrians and regular bicycles passing the intersection; *log* – natural logarithm. (All the models were significant with $p<0.001$ and adjusted R^2 of 0.32-0.41; see more details in Gitelman et al., 2020).

Using the models, Figure 2 provides graphical examples of relations between the hourly vehicle traffic, regular bicycle numbers and the number of e-bikes expected at an urban intersection. For instance, at a site with hourly traffic of 2000 vehicles, 300 pedestrians and 20 cyclists, about 30 e-bikes are expected, of which 15 will use the sidewalks.

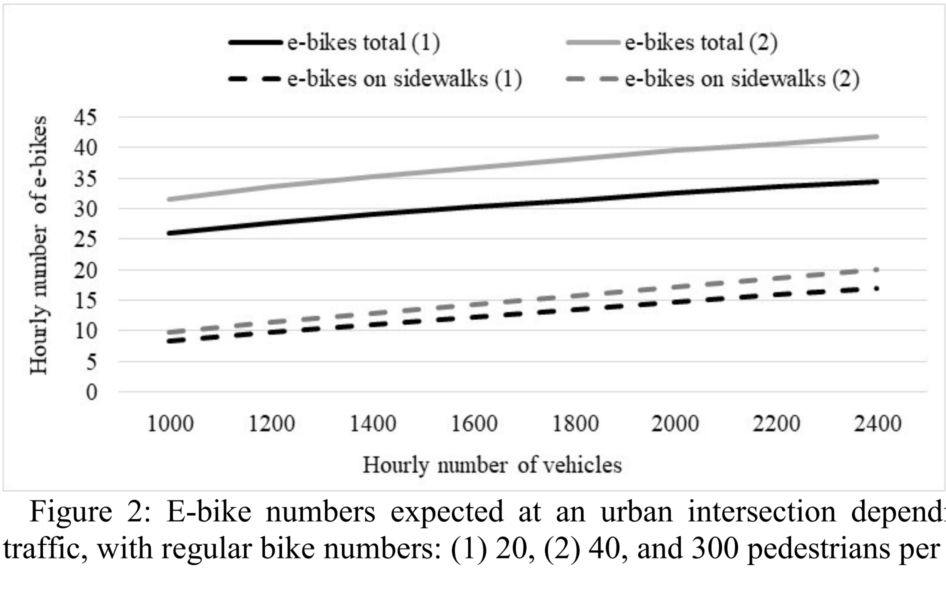

Figure 2: E-bike numbers expected at an urban intersection depending on vehicle traffic, with regular bike numbers: (1) 20, (2) 40, and 300 pedestrians per hour.

The models showed that e-bike numbers were in a direct relation with motor vehicle, pedestrian and regular bicycle volumes at the intersections, indicating that they are used for the same destinations in the city. The models supported the finding on a similar presence of both bicycle types in urban traffic that was originally seen in the data. In addition, the number of e-bikes on the roadway increases with the increase in the number of pedestrians, while the number of e-bikes on sidewalks increases with the increase in vehicle traffic. It can be also noted that under higher traffic volumes more e-bikes use sidewalks, in spite of the law's prohibition, apparently reflecting their choice of safer travel conditions.

3.2 Speeds and other behaviours of e-cyclists compared to regular cyclists, based on the speed survey

In the speed survey, data on 349 riders were collected, of whom 229 were e-cyclists. Table 1 presents summary metrics of riding speeds and cyclist characteristics, for both bicycle type; Figure 3 shows the mean speeds, with standard deviations. At all sites, the speeds of e-bikes were higher than of regular bicycles, with a difference of 4-7 km/h in the mean speeds (p<0.05). The mean speeds of e-bikes were of 19-20 km/h at most sites and about 14 km/h at two sites, without clear association with road layout or the presence of commerce. The influence of bicycle paths was fuzzy in the raw data, while speeds at sites with the bike paths (sites *c, d* in Table 1) were not consistently higher or lower than on streets with a similar layout but without a bike path (sites *b, e*). Interestingly, the trends in riding speeds, across various sites, were similar for both bicycle types, indicating a similar impact of infrastructure settings on speeds of both transport means.

Table 1: Riding speeds and cyclist characteristics, for both bicycle types, in the speed survey.

Street type[#]	Bicycle type	N	Mean speed (sd), km/h	Males, %	Aged 19-34, %	Aged 35-64, %	Helmet wearing, %	Riding on roadway, %	Riding on a bike path, %
a	e-bike	31	13.5* (6.8)	84%	94%	6%	10%	77%	--
	regular	10	9.6 (4.5)	80%	90%	10%	10%	80%	
b	e-bike	49	19.2** (7.4)	82%	82%	18%	12%	82%	--
	regular	31	14.9 (5.4)	77%	68%	32%	10%	84%	
c	e-bike	37	19.3*** (5.5)	68%	97%	3%	3%	30%	38%
	regular	31	12.0 (4.4)	65%	77%	23%	6%	3%	55%
d	e-bike	52	20.1*** (4.6)	87%	85%	13%	2%	25%	58%
	regular	28	14.6 (4.5)	29%	75%	21%	11%	11%	61%
e	e-bike	30	14.0** (3.8)	73%	77%	17%	7%	53%	--
	regular	10	10.5 (2.6)	60%	70%	10%	30%	50%	
f	e-bike	30	19.0*** (5.5)	73%	77%	23%	17%	57%	--
	regular	10	12.3 (3.8)	40%	60%	40%	30%	0%	

[#]***a, f*** - single-carriageway collector streets; ***b*** - a dual-carriageway arterial with commerce, no bike path; ***c*** – a dual-carriageway collector street with commerce and a bike path; ***d*** – a dual-carriageway arterial, no commerce, with a bike path; ***e*** – a dual-carriageway collector street, no commerce, no bike path.
Significant difference between bicycle types, with *p<0.05, **p<0.01, ***p<0.001.

Most of the riders on both bicycle types (79% on e-bikes and 58% on regular bikes, in total) were males. At all types of sites, the majority of riders, on both bicycle types, were young adults aged 19-34 (85% and 73%, respectively), whilst cyclists aged 65+ were rare

(1% and 3%, in total). Most riders on both bicycle types did not wear helmets: 92% and 87%, in total. It should be noted that helmet wearing is not obligatory for adult cyclists, in urban areas in Israel.

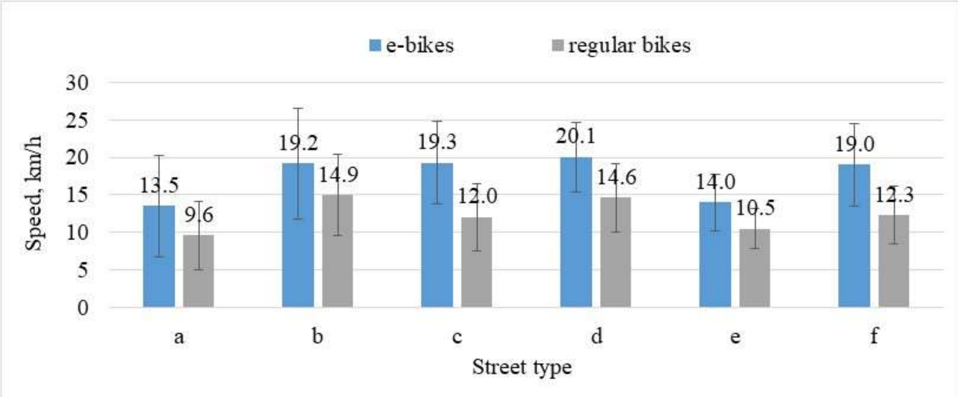

Figure 3: Mean speeds of both bicycle types, with standard deviations. (See street types in Table 1).

The distribution of riding places indicated (see Table 1) that, at sites without bike paths, most riders on both bicycle types (69% of e-cyclists and 64% of regular cyclists, in total) were on the roadway, and the remainder – on the sidewalks. As expected, the presence of bicycle paths reduced the share of riders on the roadway but did not lead to an exclusive use of the bike paths by cyclists (see sites *c, d* in Table 1). At these sites, 40%-60% of the cyclists used the dedicated paths, while 20%-40% still rode on the sidewalks.

An explanatory model fitted to riding speeds (Table 2-a) showed that speed was affected by three characteristics ($p<0.001$): type of site, type of bicycle and place of riding, whereas the effects of riders' gender and age group were insignificant. According to the model, the riding speed increases on busier roads – arterials and dual-carriageway collector streets compared to single-carriageway streets. After controlling for other characteristics, the e-bike speed was higher than that of a regular bicycle, by 4.7 km/h, on average. Furthermore, the speed on sidewalks was lower compared to that on the roadways, by 4.1 km/h, indicating the rider's awareness of the place of riding.

In the model fitted for predicting the use of helmet (Table 2-b) two variables were significant: type of site and type of bicycle. It showed that the probability of helmet use was twice as high for riders of regular bikes related to e-cyclists and that the incidence of wearing was lower at sites with bike paths. The latter may reflect a higher perceived safety of dedicated bicycle paths, by both groups of cyclists.

In the explanatory model which examined the place or riding - sidewalk vs. the roadway, on streets without designated bicycle paths (Table 2-c), the impact of bicycle type was insignificant, while the choice was influenced by rider's characteristics and the type of site. The model indicated that the probability of riding on the sidewalk was higher for females compared to males, and for older riders (aged 35+) compared to the younger age group, in both bicycle types. However, this probability was lower on a dual-carriageway road with commerce, apparently, due to disturbances to cycling on the sidewalk. A complementary model which examined the preference of riding on a bike path vs. other places, on streets with arranged bike paths (Table 2-d), showed that such preference was twice as high on a street without commerce vs. a street with commerce, reflecting, again, a possible disturbance to cycling on streets with commerce. In addition, the model indicated a higher use of bike paths by ordinary bicycles compared to e-bikes but a lower use by riders aged 35+ vs. younger age. The latter findings are somewhat surprising and need further research as they may be related to habits of traditional cyclists vs. new e-cyclists.

Table 2: Explanatory models fitted using the speed survey data.

(a) Model for predicting riding speeds

Coefficients	Estimate	Std. Error	t-value
(Intercept)	17.68	0.67	26.38***
Street type *b* vs. *a,f*	2.41	0.86	2.79**
Street type *c* vs. *a,f*	3.80	0.93	4.10***
Street type *d* vs. *a,f*	5.44	0.89	6.10***
Street type *e* vs. *a,f*	-1.41	1.03	-1.37
Riding on sidewalk/ bike path vs. roadway	-4.09	0.68	-6.01***
Regular bicycle vs. e-bike	-4.70	0.61	-7.65***

(b) Model for predicting helmet wearing

Coefficients	Estimate	Std. Error	z-value	Odds ratio
(Intercept)	-2.11	0.5	-4.24	--
Street type *b* vs. *a,f*	-0.41	0.49	-0.83	0.66
Street type *c* vs. *a,f*	-1.42	0.69	-2.07*	0.24
Street type *d* vs. *a,f*	-1.22	0.62	-1.98*	0.29
Street type *e* vs. *a,f*	-0.18	0.59	-0.31	0.82
Regular bicycle vs. e-bike	0.67	0.4	1.69&	1.95
Male vs. female rider	0.04	0.43	0.09	1.05
Aged 35+ vs. younger age	0.42	0.44	0.96	1.51

(c) Model for predicting the place or riding - sidewalks vs. roadway, on streets without bike paths

Coefficients	Estimate	Std. Error	z-value	Odds ratio
(Intercept)	-0.17	0.38	-0.44	--
Street type *b* vs. *a,f*	-1.24	0.40	-3.14**	0.29
Street type *e* vs. *a,f*	0.25	0.41	0.61	1.29
Regular bicycle vs. e-bike	0.29	0.36	0.81	1.34
Male vs. female rider	-0.71	0.37	-1.91&	0.49
Aged 35+ vs. younger age	0.98	0.39	2.48*	2.65

(d) Model for predicting the place or riding – bike paths vs. others, on streets with bike paths

Coefficients	Estimate	Std. Error	z-value	Odds ratio
(Intercept)	-0.46	0.43	-1.07	--
Street type *d* vs. *c*	0.76	0.35	2.14*	2.13
Regular bicycle vs. e-bike	0.71	0.39	1.79&	2.02
Male vs. female rider	0.15	0.39	0.38	1.16
Aged 35+ vs. younger age	-1.22	0.51	-2.41*	0.29

Notes to Table 2: Model statistics: (a) Adjusted R^2=29.4%; F-statistic: p<0.001. (b) Null deviance: 212.92 on 343 degrees of freedom (df); Residual deviance: 201.51 on 336 df; AIC: 217.51. (c) Null deviance: 246.15 on 195 df; Residual deviance: 219.94 on 190 df; AIC: 231.94. (d) Null deviance: 203.23 on 146 df; Residual deviance: 192.51 on 142 df; AIC: 202.51. See *street types* below Table 1. Significant impacts with $^{\&}$p<0.1, *p<0.05, **p<0.01, ***p<0.001.

3.3 E-cyclist behaviours, based on video-recordings

Following the quality checks, 337 video-films with e-cyclist behaviours were coded and analysed in the study. Most of the e-riders observed (86%) were young adults aged 19-34, 13% were aged 35–64, and 1% were aged 65+. Most e-bike users (78%) were male; 99% rode without a helmet. As evident, e-riders' characteristics were similar across various study surveys, see Sec.3.2 above and Gitelman et al. (2020). The distribution of the films by street type was fairly uniform: 37% were recorded on divided main streets, 29% on undivided streets, and 34% on streets with boulevards. Statistical tests did not show significant differences between the street types in terms of the e-riders' gender, age group or helmet use.

Using the videos, samples of e-riders' behaviours were obtained for various *situations* which reflect the steps of their movement near the intersection, such as: *sit.1* – travelling on a street section before the intersection (N=275); *sit.2* – passing the intersection by using crosswalks (N=212); *sit.3* – passing the intersection on the roadway, together with vehicles (N=92); *sit.4* – travelling on a street section after the intersection (N=319). The findings indicated that:

- When travelling on a street section before the intersection (*sit. 1*), in total, 30% of e-cyclists chose to ride on a sidewalk, 35% were on a bike path and 35% on the roadway. However, using these data, a significant difference ($p<0.05$) was found between the sites with designated bike paths vs. others, where in the first case, 75% of e-cyclists rode on the bike path, 10% on the sidewalk and 15% on the roadway, while in the second case, 46% rode on the sidewalk and 54% on the roadway.
- In *sit. 1*, among e-riders travelling on the roadway (N=96), the majority were in the right-hand lane (as prescribed by the law), yet in 23% of cases they used other lanes or even travelled against the traffic direction. Most e-riders (65%) were observed in heavy vehicle traffic, and in 47% of cases the riders moved slower than the vehicle traffic. On the main streets, the share of cases with heavy vehicle traffic was higher (over 80%) and, respectively, the share of cases in which the e-cyclist was slower than vehicles, was greater than on other street types ($p<0.001$). In addition, certain shares of the riders changed their position on the roadway (13%) or moved onto the sidewalk (18%), which might disturb other road users. In 4% of cases, a conflict was observed between an e-cyclist and another road user.
- In *sit. 1*, when e-cyclists rode on the sidewalk or a bike path, frequently little or no pedestrian or bicycle traffic was present on the street. However, when a pedestrian was observed (in 36% of the cases), the e-riders always moved faster than pedestrians. In some cases (2%-5%), the e-cyclist changed the place on the sidewalk or went down to the roadway. In 5% of cases, a conflict with a pedestrian was observed.
- When travelling on a street section after the intersection (*sit. 4*), the behaviours of e-cyclists were generally similar to those observed in *sit. 1*. While traveling on the roadway (N=119), the share of e-riders who were slower than the vehicle traffic was about 40%, and this share was higher on the main streets; 15% of the riders changed their position on the roadway, hence, increasing the disturbance to vehicle traffic; in 4% of cases, a conflict was observed. When travelling on the sidewalk and a pedestrian was present (in 46% of the cases), the e-riders were usually faster than pedestrians; in 6% of cases, a conflict with a pedestrian was observed.
- Among the riders passing the intersection on crosswalks (*sit. 2*), about a third crossed two or more crosswalks at the same site. In most cases (55%) it was a signalized crosswalk for pedestrians, in 35% - a signalized crossing for pedestrians and cyclists.

In 18% of cases, the e-cyclist crossed on red. In addition, a third of the riders moved faster than crossing pedestrians and 17% started on crosswalks but continued the ride on the roadway. Regression models fitted to these data showed that the probability of crossing on red or went down to the roadway, during the crossing, was higher on less busy streets (undivided streets and those with boulevards) as opposed to the main streets. In the areas of crosswalks, e-bike conflicts with a pedestrian or a vehicle were observed, in 3% and 1% of cases, respectively.

- When e-cyclists crossed an intersection on the roadway (*sit. 3*), in 23% of cases they passed on red. Moreover, in 12% of cases, the riders moved against the direction of traffic and in another 12% of cases, they went onto the sidewalk while crossing. In 4% of cases, a conflict with another road user was observed.

Figure 4 provides a summary of the main behaviours of e-riders while travelling on a street section before and after the intersection, and when passing through the intersection. In general, the observations showed a variety of e-cyclist behaviours in the urban settings, with a heterogeneous use of both vehicle and pedestrian facilities. Many indications were received that e-bikes present a disturbance for vehicle and pedestrian traffic, may be unpredictable for other road users and exhibit risky behaviours.

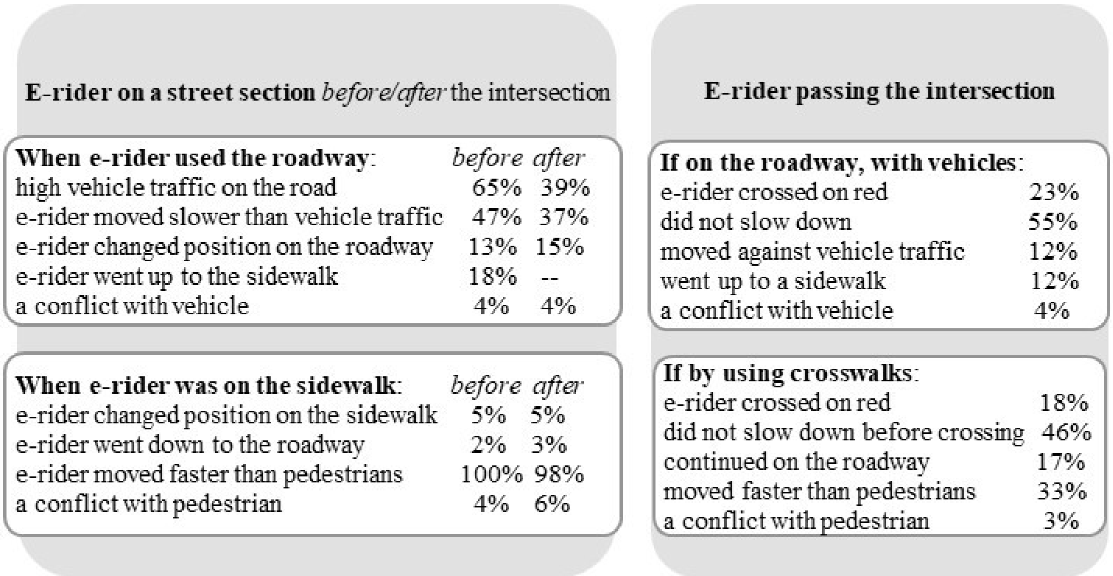

Figure 4: Main behaviours of e-riders on street sections and intersections.

Furthermore, to characterize e-riders' interactions with other road users, we applied a conflict analysis based on the Dutch traffic conflict technique (van der Horst and Kraay, 1986) and its adaptations by more recent studies (e.g. van der Horst et al., 2014; Gitelman et al., 2017). In this method, the extent of consequences if a collision had occurred depends on a combined consideration of speeds of the parties involved in the conflict and the time left before reaching the same place by both parties if the evasive manoeuvers were not applied; the time gap is known in the literature as Time-to-Collision or Post-Encroachment Time. To classify the interactions in the current study three levels of conflicts were defined, as follows: (1) a slight conflict, when the interaction had a time gap of more than 2 seconds and speeds of both parties were low, below 15 km/h; (2) a medium conflict, when the interaction had a time gap of 2 seconds and one of the parties moved at speed of 15 km/h or more; (3) a serious conflict, when the interaction occurred with a time gap of less than 2 seconds. The speeds were estimated related to the distances between the fixed objects, e.g. sidewalk curbs. The time values were estimated using the films' runs and stops.

Table 3 presents the results of the conflict analysis, which included 46 cases. No serious conflicts were observed in the study films, most conflicts were slight, four (8.7%) were classified as medium. The majority of e-bike conflicts (57%) involved a pedestrian, other conflicts were with another e-bike or a regular bike (34%) and in 9% of the cases a vehicle or motorcycle was involved.

Table 3: Analysis of conflicts observed between e-riders and other road users, near intersections.

Steps of e-bike movement near intersection	Conflict party	Conflict severity			Average of		
		slight	medium	total	e-bike speed (km/h)	other party's speed (km/h)	time gap (sec)
(a) *Sit.1* – e-rider on a street section before the intersection							
on divided main streets	pedestrian	1	0	1	3.0	2.0	2.0
	e-bike	1	0	1	7.0	5.0	3.0
on undivided streets	pedestrian	5	0	5	9.2	3.4	2.2
	e-bike	2	0	2	13.0	14.5	2.5
	regular bicycle	2	0	2	8.0	4.5	2.0
on streets with boulevards	pedestrian	2	0	2	6.5	3.0	2.5
(b) *Sit.2* – e-rider passing the intersection on crosswalks							
on divided main streets	pedestrian	6	0	6	7.2	2.0	2.2
	motorcycle	0	1	1	4.0	15.0	2.0
	regular bicycle	1	0	1	5.0	10.0	2.0
on undivided streets	pedestrian	4	0	4	9.8	4.0	2.8
	e-bike	2	0	2	8.0	5.0	2.5
on streets with boulevards	pedestrian	1	0	1	8.0	3.0	3.0
	e-bike	1	0	1	5.0	10.0	3.0
	regular bicycle	1	0	1	5.0	10.0	4.0
(c) *Sit. 3* – e-rider passing the intersection on the roadway							
on undivided streets	vehicle	1	0	1	12.0	0.0	2.0
	e-bike	1	0	1	14.0	14.0	3.0
	regular bicycle	1	0	1	8.0	7.0	2.0
on streets with boulevards	regular bicycle	1	0	1	5.0	10.0	3.0
(d) *Sit.4* – e-rider on a street section after the intersection							
on divided main streets	pedestrian	1	0	1	5.0	3.0	2.0
	vehicle	1	0	1	15.0	20.0	3.0
on undivided streets	pedestrian	3	1*	4	11.3	3.3	2.5
	vehicle	0	1	1	15.0	20.0	2.0
	e-bike	0	1	1	12.0	15.0	2.0
	regular bicycle	2	0	2	14.0	10.0	3.0
on streets with boulevards	pedestrian	2	0	2	6.5	4.0	3.0
Sit.1, total		13	0	13	28%		
Sit.2, total		16	1	17	37%		
Sit.3, total		4	0	4	9%		
Sit.4, total		9	3	12	26%		
All		42	4	46	100%		

* In this event, e-bike speed was 15 km/h and time gap - 2 sec.

More conflicts occurred when an e-bike crossed at a crosswalk (37%) or travelled on a road section before or after the intersection (28% and 26%, respectively). An additional observation was that many conflicts (57%) occurred on undivided streets and a quarter – on the main divided streets while on streets with wide boulevards such events were rare. Therefore, the conflict analysis supported previous study findings indicating that a heterogeneous use of urban infrastructure leads to multiple conflicts between various road users and that e-cycling on pedestrian facilities creates dangerous situations for pedestrians. In addition, it should be mentioned that all medium conflicts were observed on the roadway, thus, reflecting that riding in mixed vehicle traffic is associated with a higher risk for e-riders.

4. Discussion and Conclusions

Over the last decade, e-cycling is rising in Israel, in line with trends reported in other countries (Van Cauwenberg et al., 2018; Jahre et al., 2019). The study findings indicated that e-bike volumes in Israeli cities are tangible and that e-bikes are used to reach the same travel destinations in the city as other transport modes. The higher vehicle and/or pedestrian traffic at a site, the more e-cyclists are expected. Therefore, when planning urban streets, e-cycling should be accounted for.

According to various field observations in this study, the majority of adult e-bike riders in Israel are young men aged 19-34, similar to findings reported in Europe and the USA (Scaramuzza et al., 2015; MacArthur et al., 2018). Most e-cyclists were observed without helmets, while helmet wearing is not obligatory by the Israeli law. However, as consistently emphasized in the research literature (OECD/ITF, 2013; Siman-Tov et al., 2017), non-wearing a helmet is a risk factor for the riders. When crossing an intersection, about 20% of e-riders in Israel crossed on red; a rate similar to that reported in Europe (Schleinitz et al., 2019) but lower than the rate found in China (Du et al., 2013; Yang et al., 2018). Thus, the study supported the role of local context in e-cyclist behaviours.

As expected, the riding speeds of e-bikes were higher than those of regular bikes. However, the estimated gaps in the mean speeds of two bicycle types were not large, of 4-7 km/h in the detailed data and of about 5 km/h, on average, in the final model, having controlled for other factors. The speed gaps found in this study were slightly higher compared to previous research (Langford et al, 2015; Petzoldt et al, 2017; Schleinitz et al., 2017), which may be related to differences in the way of measurement. At the same time, the mean speeds of e-cyclists measured in this study, of 19-20 km/h or less, were similar to the values reported in studies in Europe (Petzoldt et al., 2017; Twisk et al., 2021). In general, the mean speeds of e-bikes at all study sites satisfied the law's restriction (of 25 km/h), however, some riders moved at higher speeds, thus violating the law.

The study indicated that the place of riding affects e-bike speed, while riding speeds were higher on the roadway compared to the sidewalk; a similar finding was reported in Germany, by Schleinitz et al. (2017).

In general, e-bike behaviours in Israel have much in common with those observed in Europe and the USA. However, due to the scarcity of cycling infrastructure in Israeli cities, a mixed use of urban facilities by e-bikes was observed in this study, with heterogeneous traffic both on vehicle and pedestrian settings and multiple risk factors. When e-cyclists used the roadway, they frequently were in heavy vehicle traffic, and moved slower than vehicles, especially on busy streets, thus disturbing the traffic and increasing the risk of injury. In spite of the law's prohibition, many of the e-riders travelled on sidewalks and crossed at pedestrian crosswalks. When riding on a sidewalk or crosswalk, most e-riders, in this study, were faster than pedestrians and in 5%–6% of cases, conflicts were observed. Moreover, some e-riders sought to change their position in the road layout, while riding. Clearly, a mixed use of urban settings increases the risk of e-bike conflicts with other road users and deprive their incorporation into urban space. A previous local study of teen e-cyclists' behaviours found (Gitelman et al., 2018) that the extent of risky behaviours among young e-cyclists was even higher, which was apparently associated with lacking cycling infrastructure and insufficient knowledge of traffic rules by young e-riders.

The national strategy for sustainable development in Israel set a target to increase bicycle use in the urban modal split. In the coming years, an extension of bicycle facilities is planned in many Israeli cities. Both the national strategy and the design guidelines do not focus separately on the use of e-bikes. However, it can be expected that a wider application of cycling infrastructure will promote a safer integration of e-bikes in Israeli cities, as well. In addition, previous research reported consistently that establishing cycling infrastructure, with a separation from vehicle traffic, is a prerequisite for promoting e-cycling in the cities (Johnson and Rose, 2015; Jones et al., 2016; MacArthur et al., 2018).

Therefore, to promote a safer integration of e-bikes in Israeli cities, the main focus should be on a wider application of cycling infrastructure. Better separation of bicycle paths from sidewalks and roadways, both on street sections and at junctions, will reduce the conflicts and risk factors in interaction between various road users and provide less interrupted traffic conditions. Regarding the existing streets, among the infrastructure solutions for safer e-bike integration can be considered: adding bicycle paths at the expense of reducing the area dedicated to motor traffic, e.g. roadway narrowing, reducing the number of vehicle lanes, and a wide implementation of traffic calming measures. In addition, enforcement and publicity efforts can be useful to improve the traffic rules' compliance by e-riders, for example, regarding the proper use of urban infrastructure and the compliance with red lights at intersections.

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