Journal of Transport & Health 15 (2019) 100657

Contents lists available at ScienceDirect

Journal of Transport & Health

journal homepage: www.elsevier.com/locate/jth

Do advanced stop lines for motorcycles improve road safety?

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ARTICLE INFO

Keywords:
ASL
Road safety
Motorcycle
Before-after study
Motorized mobility

ABSTRACT

Background: In Barcelona, Advanced Stop Lines (ASL) for motorcycles, were implemented since 2009. This paper aims to assess the effectiveness of ASL for motorcycles in preventing road traffic collisions.

Methods: A quasi-experimental design of an evaluation study of an intervention with comparison group was performed. 35 ASL were implemented in 2009 (phase I) and 16 in 2010 (phase II). The study areas were: ASL area and 30 m preceding (34 m); Crosswalk and intersection (CROSS). For each ASL, a nearby comparison zone was chosen. Data on crashes were provided by police and included geocodes. Outcome variables were the number of injury collisions, people injured, collisions involving motorcycles, and of motorcycle drivers involved. Relative risks (RR) and their 95% confidence intervals, in the post-intervention period with respect to the pre-intervention, were estimated using Poisson-lognormal regression models, with a random area factor. The models were adjusted for traffic volume and street characteristics.

Results: In Phase I, the annual mean of people injured were 50 pre- and 63 post-intervention in the ASL-34m area, and 234 and 197 in the ASL-CROSS area. After adjustment, in the ASL-34m, significant increases were found in the risk of collision (RR = 1.34 [1.12–1.61]), being injured (RR = 1.26 [1.01–1.58]), motorcycle involvement (RR = 1.44 [1.17–1.78]), and being a motorcycle driver involved (RR = 1.39 [1.10–1.75]). In the comparison zones (34 m), only the risk of being injured increased (RR = 1.42 [1.09–1.85]). In the ASL-CROSS area, there were no significant changes in risk, but in the comparison zones (CROSS) decreases were found in the risk of being injured (RR = 0.86 [0.75–0.98]) and of being a motorcycle driver involved (RR = 0.85 [0.74–0.98]). In phase II, there were no significant changes in risks.

Conclusion: ASL are not effective in improving road safety. In some circumstances, they increase the risk of traffic injury.

1. Introduction

Intersections are areas with a high risk of traffic collisions, especially in urban areas where the road system is characterized by multiple junctions. In Barcelona, approximately half of all collisions involving victims occur at street crossing. On working days in Barcelona, more than 400,000 journeys are done in two-wheeled motor vehicles, representing almost 30% of all journeys in private motor vehicles (more than 1.5 million journeys) (Autoritat del Transport Metropolità (ATM) and Ajuntament de Barcelona, 2016). According to the city's 2016 vehicle census, of 946,914 registered vehicles, 23.6% (223,671) were motorcycles and 6.0% (57,037)

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https://doi.org/10.1016/j.jth.2019.100657
Received 27 May 2019; Received in revised form 8 September 2019; Accepted 18 September 2019
Available online 04 October 2019
2214-1405/

were mopeds, representing 280,708 registered two-wheeled motor vehicles (Ajuntament de Barcelona, 2016). In 2016, of the 9,345 collisions occurring in the city with at least one person injured, a two-wheeled motor vehicle was involved in 6,198, representing 66,3% of collisions. Among all people injured (12,116), 6,845 (56.5%) were a motorcyclist or a moped user. Among all two-wheeled motor riders involved in collisions (7,990), 84.3% were slightly injured, 1.3% severely injured, and 0.1% died. (Santamariña-Rubio, 2017).

In Barcelona between 2003 and 2009 the number of motorcycles increased by 38% mainly due to a national law passed in 2004 allowing car drivers in possession of a driver's license for at least 3 years to drive a light motorcycle (engine capacity 51–125 cc) without an additional license or test. In 2003 there were 148 two-wheeled motor vehicles per 1000 habitants and in 2009 it was 177. This was correlated with an increase in the number of injury collisions with motorcycles (Perez et al., 2009). It was a common practice for two-wheeled motor vehicles to reach the pole-position invading pedestrian zones.

Within this context advanced stop line (ASL) for two-wheeled motor vehicles were implemented in Barcelona to improve vehicles mobility in the city, and to avoid them to invading pedestrian crossings. Thirty five crosswalks were adapted in 2009 to include ASL and 16 more were adapted in 2010. A major concern about this measure was an increase in collisions where two-wheeled motor vehicles hit pedestrians in the same crossing or in the right turn. In 2008, 60.6% of all collisions involving two-wheeled motor vehicles occurred in a street crossing. Of the total number of collisions at junctions (n = 5,137), 71.4% had a two-wheel motor vehicle involved, a significantly higher proportion than outside junctions (63.1%). A motorcyclist or moped rider was injured in 68.3% of collisions at junctions and 60% outside. The most frequent type of collisions at junctions were frontside (41.1%), side (24.4%), motorcycles or moped fall (12.1%) and rear-end (11.3%) while out of junctions were respectively 12.3%, 25.1%, 27.7% and 17.6%. Pedestrians were hit 6.5% in the crosswalk and 7,3% outside. The most frequent cause of collisions at junctions when two-wheeled motor vehicles were involved were to disobey the traffic light (17,1%) and undue turn (14.9%).

ASL for two-wheeled motor vehicles was an innovation, with no previous experiences except in the setting of bicycle mobility. Several studies have evaluated cycling, risk situations, and opinions of infrastructure and safety in advanced stop lines for bicycles (Hunter, 2000; Newman, 2002; Wall et al., 2003; Allen et al., 2005; Atkins Services, 2005; Rodgers, 2005; Dill et al., 2012; DiGioia et al., 2017). None of the published studies have been able to draw definitive conclusions on road safety due to a lack of statistical power. Comparison between advanced stop lines for bicycles and for two-wheeled motor vehicles, is difficult because of differences in mobility and because, unlike bicycles, motorcycles and mopeds do not have dedicated access lanes.

To our knowledge, only two published studies have assessed the use of ASL by motorcycles. A study conducted in the United Kingdom evaluated the suitability of allowing motorcycles to use advanced stop lines for bicycles (Ball et al., 2011). That track-trial, conducted at the test track of the Transport Research Laboratory, aimed to identify the effects on safety, cyclist and motorcyclist behavior, and their opinions. The trial was conducted in a closed circuit, over 4 days, with 30 participants per day, with simulation of real-world junction configurations. The authors concluded that the combination of cyclists and motorcyclists produced no major difficulties and that both types of drivers participating in the trial were in favor of allowing the use of ASL for cyclists by motorcyclists. In Indonesia, a red motorcycle box was added to an intersection to reduce incidents with motorcycles and other vehicles and improve traffic flow (Mulyadi, 2013). Assessment one year later showed that average daily traffic (ADT) increased by 13% and traffic conflict involving motorcycles decreased by 39%.

1.1. Study objective

The aim of this study was to assess the effectiveness on street injury traffic collisions of the advanced stop lines for motorcycles and mopeds (ASL) implemented in 2009 and 2010 in Barcelona.

2. Material and methods

2.1. Study population

The study population consisted of people travelling through Barcelona between 2002 and 2014.

2.2. Study design

We performed an evaluation study of an intervention (ASL) with a quasi-experimental design and a comparison group.

The ASL is a 4-m grid painted before the crosswalk with vertical signaling. Thirty-five ASL were implemented in 2009 (Phase I) and 16 in 2010 (Phase II) distributed mainly in the city center (Fig. 1). The intervention zone is divided in two areas: a) ASL area and a preceding 30-m area (ASL-34m); b) crosswalk and intersection (ASL-CROSS) (Fig. 1). For each ASL, a nearby comparison zone was chosen, also with two areas (34 m and CROSS). Selection of comparison zones was based on criteria of proximity, in the same street if there were no ASL, or in nearby streets with similar characteristics.

The study periods were as follows: 2002–2009 pre-intervention and 2010–2014 post-intervention for phase I; 2002–2010 pre-intervention and 2011–2014 post-intervention for phase II.

2.3. Information sources

The following information sources were used:

- Barcelona Local Police Register of Road Traffic Accidents and Victims, which provides information on traffic collisions in Barcelona city from 2002 to 2014.
- The Barcelona City Council, Area of Prevention, Mobility and Safety, which provides information on the location of points for measuring traffic congestion in the city and estimates the annual average daily traffic (ADT) for all street sections in the city. This allowed to have ADT for all the interventions and comparison areas from 2002 to 2014.
- The INCA Inventory. Geographic Information System for Signaling Street Furniture and Traffic Signals, which provides information on street characteristics.
- Municipal Institute of Informatics, which provides georeferencing of the polygons corresponding to the study areas (ASL-34m, ASL-CROSS, and similar for the comparison zones).

Data on crashes included geocodes and allowed identification of those occurring in the intervention and comparison zones.

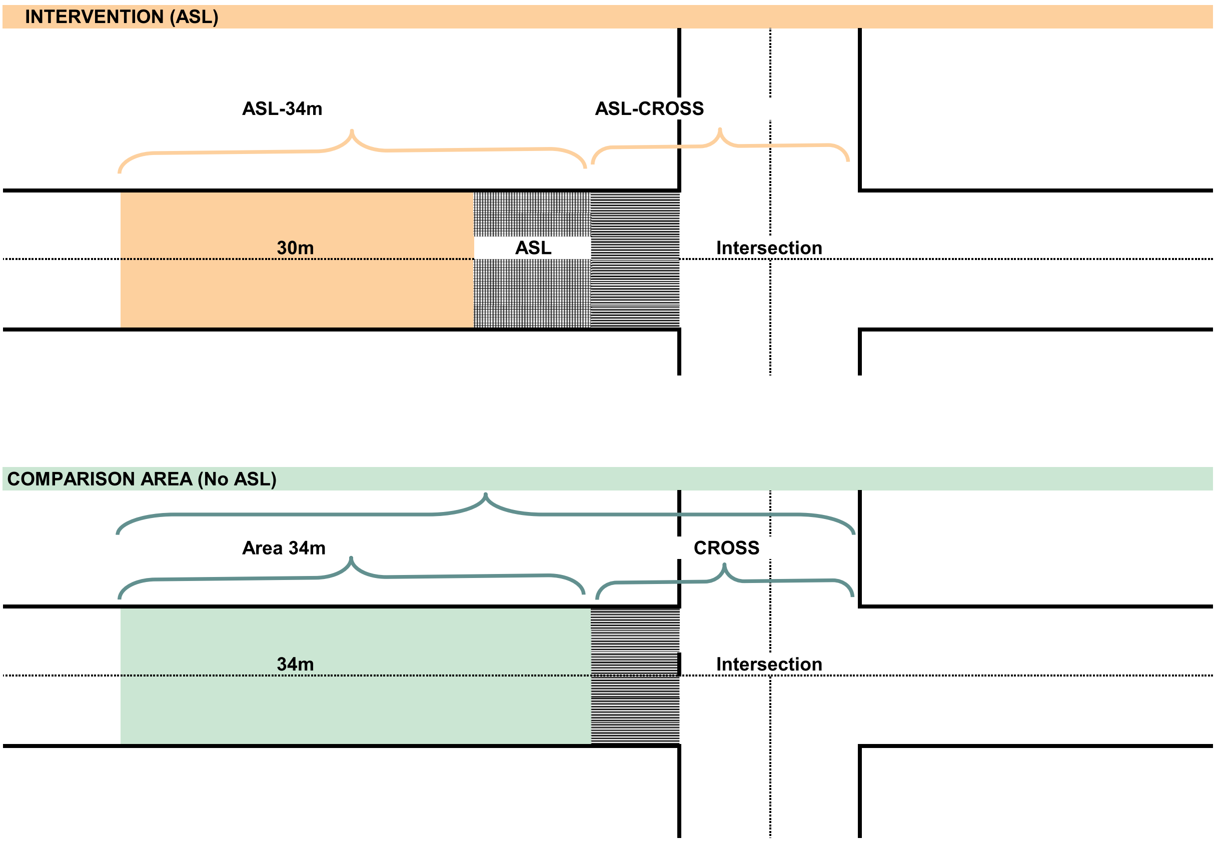

Fig. 1. Design of the study areas in the Advanced Stop Lines for Motorcycles (ASL) area and in the comparison area.

2.4. Variables

Outcome variables consisted of the total number of injury collisions, people injured, collisions involving motorcycle or moped drivers, and of motorcycles or moped drivers involved in a injury collision.

Explanatory variables were as follows:

- Year (from 2002 to 2014).
- Period: Pre-intervention and post-intervention.
- Type of areas: ASL, Comparison.
- Street characteristics:
  - o Average daily traffic (ADT), which is a measure of the traffic volume of motor vehicles expressed in thousands. It is an annual measure per section of street derived from direct measures and modelling.
  - o Carriageway width
  - o Number of traffic lanes
  - o Number of service streets with street furniture, parking spaces, etc.
  - o Number of bus lanes

- Collision characteristics:
  - o Type of collision: run over, head-on, side-impact, front-side impact, rear-end, crash against a static element, overturning (4 wheels), falls (2 wheels) and falls inside a vehicle. All these variables were dichotomous (yes, no).
  - o Motorcycle or moped involvement (yes, no).
  - o Pedestrian involvement (yes, no).
  - o Bicycle involvement (yes, no).
  - o Collision producing a serious or fatal injury (yes, no).

Phase I and II have different characteristics. Phase I areas include streets with different number of lanes, width, and/or bus lane or parking lane (Table 1). Mean Average Daily Traffic (ADT) before the intervention was 38 for ASL areas and 32.5 for comparison areas. No significant changes were observed in the post-intervention period. Phase II ASL areas, on the other hand, correspond to a single street, wider, with more lanes and greater traffic intensity than phase I and than its own comparison group. ADT before the intervention was 71.2 for ASL areas and 28.0 for comparison areas. In the post-intervention period ADT a statistically significant increase was observed for ASL areas (74.6) but not significant for the comparison group (30.2). The traffic intensity of the comparison group in Phase II is much lower than the intervention group. It was very difficult to find a street with similar characteristics as a comparison group.

2.5. Statistical analysis

A descriptive analysis of the number of collisions, injured people, collisions with motorcycle or moped drivers involved, motorcycle or moped drivers involved and the annual ADT, in each of the two study areas (34 m and CROSS) for both the intervention and comparison groups, was performed using the annual mean and its 95% confidence interval, in each period (pre- and post-intervention). A descriptive analysis of the characteristics of the collisions according to the type of collision, the involvement of cyclists or motorcyclists and the severity of the collisions, was also performed in each of the two study areas for both the intervention and comparison groups and in each period, using proportions. Changes in the annual means and in the proportions were compared between periods (pre- and post-intervention) and between intervention and comparison zones based on the Student t-test and Chi-Square test, respectively.

To assess the effectiveness of the intervention (ASL), each of the four outcome variables were modeled, through a Poisson-lognormal regression model, stratified by study areas (ASL-34m and ASL-CROSS). This model was based on a Poisson regression model (suitable for modeling non-negative integer values, especially when their occurrence is low, as in the case of traffic collisions) but it allows over-dispersion (the variance observed exceeds the mean since the occurrence of traffic collisions is not an independent phenomenon or constant over time) and a correlation structure (Elston et al., 2001; Aitchison and Ho, 1989).

$$\mu_{ij} = \exp(x_i \beta_j + b_{ij}) \ on \ y_{ij} | b_i, \beta_j \sim \text{Poisson}(\mu_{ij}), \quad b_i | \Sigma \sim Normal_j(0, \Sigma)$$

$$on \begin{cases} \text{i}=1,\ldots,\text{n} \ ; \text{j}= 1,\ldots,\text{p} \\ \text{y}_\text{i}, \ \text{number of traffic collisions} \sim \text{Poisson}(\mu) \\ \text{x}_\text{j}, \text{explanatory variables} \\ \beta_\text{j}, \text{regression coefficients} \\ \beta_0, \ \log(\text{probability of a collision in a unit size interval}), \ \text{when all the covariables are zero} \\ \varepsilon_\text{i}, \text{error term} \\ \Sigma\text{: covariance matrix} \\ \text{Var}(\text{y}_{\text{ij}}) > \text{E}(\text{y}_{\text{ij}}), \ \text{allowing over-dispersion} \end{cases}$$

The explanatory variables included in the model were type of area, period, ADT, the variables related to street characteristics and a variable gathering the linear trend. The interaction between period and type of area was also introduced into the model, allowing assessment of whether the effect of the intervention (number of collisions, people injured, collisions involving motorcycle, and motorcycle drivers involved, in the pre-intervention vs post-intervention periods) differed in the intervention and comparison zone. The model also included area as a random factor, since for each area, both ASL and comparison zones, repeated measures were available from 2002 to 2014. The models were adjusted for traffic volume and street characteristics.

The impact of implementing ASL area was determined based on the interpretation of the model coefficient referring to the parameter period, when the type of reference area was the ASL area and when the type of reference area was the comparison zone. A significant result for the interaction "period*Type of area" indicate that the change in the number of collisions in the post-intervention period versus the pre-intervention period in the intervention zones (ASL) was due to their implementation, since the change was not also produced in the comparison zones. A significant reduction in the number of collisions in the intervention zones indicates that the ASL intervention was effective.

The coefficients were interpreted in terms of relative risk (RR), which is the exponential of the coefficients of the model parameters, and their 95% confidence intervals were calculated. Based on the RRs, the percentage of change in the number of traffic collisions in the post-intervention period versus the pre-intervention period to quantify the impact of the implementation of the ASL (% of change = (-(1-RR)) were calculated.

Table 1
Structural characteristics of Advanced Stop Line (ASL) for two-Wheeled Motor and Average Daily Traffic Intensity (ADT), average number of vehicles in circulation on a working day, expressed in thousands.

Advanced Stop Line (ASL) for two-Wheeled Motor Phase I												
ASL	Intervention (ASL)						Comparison Group					
	Service Lanes	Circulation Lanes	Bus lanes	Street Width	ADT Pre	ADT Post	Service Lanes	Circulation Lanes	Bus lanes	Street Width	ADT	ADT Post
1	0	4	1	14.9	39.4	34.7	0	4	1	14.8	47.3	42.2
2	0	4	1	15.4	60.9	57.2	0	4	1	15.4	61.9	57.0
3	0	4	0	10.0	22.5	16.3	2	2	0	10.5	22.5	16.6
4	0	4	1	15.6	62.2	55.1	0	4	1	15.7	58.7	53.3
5	2	2	0	14.0	7.8	5.0	2	2	0	9.9	7.8	5.8
7	2	2	0	10.0	8.9	10.5	2	2	0	10.0	8.9	6.9
8	2	2	0	10.2	9.0	8.9	2	2	0	10.2	13.0	9.5
9	2	2	0	9.9	8.1	8.6	2	2	0	10.0	8.9	7.3
10	1	2	0	10.1	19.0	17.3	1	2	0	10.1	19.0	18.9
11	1	2	0	10.1	15.3	16.5	1	2	0	9.9	15.7	15.0
12	1	2	0	10.1	19.8	18.8	1	2	0	10.0	15.7	14.2
13	2	2	0	10.0	14.7	12.9	2	2	0	10.0	14.7	11.1
14	1	2	0	10.0	11.3	9.1	2	2	0	9.6	2.3	3.8
15	2	2	0	10.0	13.0	6.8	1	2	1	10.0	9.3	5.9
16	1	3	0	10.1	29.1	20.6	2	2	0	10.2	18.4	13.0
17	1	2	0	10.1	17.5	20.9	2	2	0	10.1	13.1	13.1
18	0	5	0	15.3	61.0	54.4	0	4	1	15.7	60.0	56.2
19	0	4	1	15.7	59.5	55.0	0	4	1	15.9	59.6	55.8
20	0	4	0	10.1	28.3	38.9	0	4	0	10.4	76.3	71.0
21	1	5	0	18.4	77.4	80.3	0	3	1	10.1	20.0	26.0
22	1	6	0	18.4	90.0	87.5	0	3	1	10.0	23.3	25.7
23	1	6	0	18.3	87.0	82.4	0	3	1	10.0	23.3	26.7
24	0	4	1	15.5	64.5	60.2	0	4	1	15.5	63.7	59.7
25	0	4	1	15.7	65.6	58.7	0	4	1	15.3	66.3	63.3
26	0	4	1	15.7	67.0	63.1	0	4	1	15.3	66.3	59.7
27	0	4	1	15.5	68.5	59.7	0	4	1	15.6	62.6	52.7
28	0	4	1	15.6	62.3	52.5	0	4	1	15.7	62.2	53.2
29	0	4	1	14.1	48.2	36.6	0	4	1	14.0	42.9	35.4
30	0	5	0	14.1	43.4	40.8	0	4	1	14.0	43.4	37.2
31	0	4	2	17.8	22.3	20.3	0	3	3	17.6	25.2	19.6
32	0	4	0	11.6	26.6	28.7	1	2	1	8.8	9.3	10.1
33	0	3	3	17.7	19.5	13.4	0	3	3	17.8	19.5	16.3
34	0	3	1	9.9	25.7	34.0	0	3	1	10.0	23.6	23.8
35	0	3	1	10.5	29.2	25.9	0	3	1	10.0	29.2	29.0
36	2	4	1	17.7	24.0	22.5	2	4	1	17.6	24.0	22.5
Mean	0.7	3.5	0.5	13.4	38.0	35.3	0.7	3.0	0.7	12.4	32.5	29.6
Median	0.0	4.0	0.0	14.1	28.3	28.7	0.0	3.0	1.0	10.2	23.3	23.8
Advanced Stop Line (ASL) for two-Wheeled Motor Phase II												
37	1	6	0	18.0	61.2	68.1	0	3	1	10.0	22.5	25.3
38	1	6	0	18.0	61.2	68.9	0	3	1	10.0	22.5	24.3
39	1	6	0	18.0	67.3	70.9	1	2	0	10.0	14.3	13.5
40	1	6	0	18.0	67.9	71.8	0	3	1	10.0	29.5	31.0
41	1	6	0	18.0	79.4	80.2	0	3	1	10.0	27.3	25.9
42	1	6	0	18.0	81.3	77.0	0	3	1	10.0	23.9	22.4
43	1	6	0	18.0	82.3	84.1	0	3	1	10.0	29.7	32.0
44	1	5	0	18.0	80.0	83.1	0	3	1	10.0	29.4	31.1
45	1	5	0	18.0	80.8	83.8	0	3	1	10.0	27.8	31.3
46	1	5	0	18.0	80.8	83.0	1	2	0	10.0	14.8	15.0
47	1	5	0	17.0	80.8	83.0	1	2	0	10.0	14.8	15.0
48	1	5	0	18.0	80.8	83.0	0	2	1	10.0	27.8	31.3
49	1	6	0	18.0	77.4	78.9	0	3	1	10.0	20.0	29.0
50	0	7	0	18.0	61.2	68.1	0	4	1	10.0	58.1	58.2
51	0	7	0	18.0	61.2	68.1	0	4	1	13.0	58.1	61.3
52	0	4	0	10.0	35.1	41.0	0	4	0	10.0	28.3	37.18
Mean	0.8	5.7	0.0	17.4	71.2	74.6	0.2	2.9	0.8	10.2	28.0	30.2
Median	1.0	6.0	0.0	18.0	78.4	78.0	0.0	3.0	1.0	10.0	27.6	30.0

ADT: Average Daily Traffic Intensity, average number of vehicles in circulation on a working day, expressed in thousands.

3. Results

In Phase I, in the ASL-34m area, the annual mean number of collisions, people injured, collisions involving a motorcycle and motorcycle drivers involved significantly increased in the post-intervention period versus the pre-intervention period in ASL area but not in comparison area (Table 2). After adjustment for mobility and street characteristics, significant increases were found in the risk of a collision (RR = 1.34 [1.12–1.61]), being injured (RR = 1.26 [1.01–1.58]), motorcycle involvement (RR = 1.44 [1.17–1.78]), and being a motorcycle driver involved (RR = 1.39 [1.10–1.75]) in the ASL-34m area, in the post- versus the pre-intervention period. The highest percentages of increase were observed in the two variables relating to two-wheeled vehicles, with a 38.9% increase in the annual mean number of two-wheeled motor vehicles drivers involved and a 44.1% increase in the annual mean number of collisions with involvement of two-wheeled motor vehicles drivers. In the comparison area (34m), after adjustment for mobility and street characteristics, only the risk of injury increased (RR = 1.42 [1.09–1.85]), with no other significant changes (Table 3).

In ASL-CROSS area, annual means did not change in the intervention zones but significantly decreased in the comparison area (Table 2). After adjustment for traffic flow and street characteristics, there were no significant changes in risk in the ASL-CROSS area, but the risk of injury (RR = 0.86 [0.75–0.98]) and of a motorcycle driver being involved (RR = 0.85 [0.74–0.98]) significantly decreased in comparison (CROSS) area (Table 3).

Table 2

Annual mean and 95% confidence interval of the number of collisions, injured people, collisions with motorcycle or moped drivers involved and motorcycle or moped drivers involved, in each study area (34 m and CROSS) and periods (pre- and post-intervention), for both the intervention and comparison zones.

	Intervention (ASL)					**Comparison areas**				
	Pre-intervention period		Post-intervention period			Pre-intervention period		Post-intervention period		
	Annual Mean	95%IC	Annual Mean	95%IC	p	Annual Mean	95%IC	Annual Mean	95%IC	p
PHASE I										
34m										
Collisions	38.6	33.5–43.8	49.8	44.6–55.0	0.002	21.5	17.6–25.4	25.2	14.8–35.6	0.324
Injured people	49.8	41.6–57.9	63.4	56.5–70.3	0.008	26.8	21.5–32.0	36.4	17.0–55.8	0.140
Collisions with motorcycle or moped involved	26.0	21.3–30.7	36.0	31.5–40.5	0.002	14.9	10.6–19.2	16.8	10.3–23.3	0.530
Motorcycle or moped drivers involved	28.8	23.0–34.5	39.4	35.4–43.4	0.004	17.3	12.9–21.6	20.6	11.6–29.6	0.354
CROSS										
Collisions	174.6	147.8–201.5	155.8	138.9–172.7	0.246	125.4	117.7–133.1	108.4	90.5–126.3	0.012
Injured people	233.9	196.2–271.6	196.8	172.5–221.1	0.114	172.4	160.6–184.2	142.4	114.0–170.8	0.007
Collisions with motorcycle or moped involved	134.1	111.2–157.1	125.0	106.4–143.6	0.514	87.0	81.7–92.3	73.2	53.1–93.3	0.025
Motorcycle or moped drivers involved	148.3	123.6–172.9	142.4	119.0–165.8	0.702	98.4	92.8–104.0	80.8	58.1–103.5	0.014
PHASE II										
34m										
Collisions	22.8	19.3–26.3	24.8	12.6–36.9	0.566	7.8	5.3–10.2	7.0	3.6–10.4	0.669
Injured people	30.2	25.6–34.9	35.0	20.6–49.4	0.281	9.8	6.5–13.1	9.8	7.4–12.1	0.990
Collisions with motorcycle or moped involved	16.1	12.5–19.7	18.8	8.8–28.8	0.415	5.4	3.0–7.9	5.3	2.9–7.6	0.912
Motorcycle or moped drivers involved	17.3	13.5–21.2	22.8	13.7–31.8	0.112	6.3	3.0–9.7	5.3	2.9–7.6	0.644
CROSS										
Collisions	71.2	64.6–77.9	65.5	48.6–82.4	0.324	49.1	42.4–55.8	54.5	27.4–81.6	0.455
Injured people	90.1	82.2–98.0	87.5	64.8–110.2	0.712	63.3	53.0–73.7	69.8	30.0–109.5	0.552
Collisions with motorcycle or moped involved	58.8	54.1–63.5	53.8	36.8–70.7	0.295	38.9	32.6–45.2	44.0	24.4–63.6	0.391
Motorcycle or moped drivers involved	68.7	62.4–74.9	63.0	46.0–80.0	0.311	43.3	36.1–50.5	50.3	28.4–72.1	0.307

p: Significance of the T-test that compares the changes in the post-intervention period versus the pre-intervention period in the intervention (ASL) and comparison zones.

Table 3
Adjusted relative risks (RR) and their 95% confidence intervals to assess the change in the number of collisions, injured people, collisions motorcycle or moped involved and motorcycle or moped drivers involved, in the post-intervention period with respect to the pre-intervention, both in the intervention and comparison zones.

	ASL areas				Comparison areas				
	RR[a]	95%IC[a]	p(pre-post)[a]	%change[b]	RR[a]	95%IC[a]	p(pre-post)[a]	%change[b]	p(ASL-comparison)[c]
PHASE I									
34M zone									
Collisions	**1.34**	**1.12–1.61**	**0.002**	**34.3**	1.24	0.97–1.58	0.081	24.0	0.607
Injured people	**1.26**	**1.01–1.58**	**0.042**	**26.2**	**1.42**	**1.09–1.85**	**0.009**	**41.8**	0.515
Collisions with motorcycle or moped involved	**1.44**	**1.17–1.78**	**0.001**	**44.1**	1.19	0.89–1.59	0.235	19.1	0.294
Motorcycle or moped drivers involved	**1.39**	**1.10–1.75**	**0.005**	**38.9**	1.26	0.95–1.67	0.115	25.8	0.599
CROSS zone									
Collisions	0.94	0.85–1.04	0.238	−5.9	0.90	0.80–1.01	0.078	−10.0	0.570
Injured people	0.90	0.80–1.01	0.067	−10.4	**0.86**	**0.75–0.98**	**0.019**	**−14.3**	0.574
Collisions with motorcycle or moped involved	0.99	0.88–1.10	0.814	−1.3	0.88	0.77–1.01	0.069	−11.8	0.202
Motorcycle or moped drivers involved	1.04	0.92–1.17	0.531	3.8	**0.85**	**0.74–0.98**	**0.027**	**−14.7**	**0.034**
PHASE II									
34M zone									
Collisions	1.02	0.79–1.31	0.887	1.82	0.85	0.55–1.33	0.480	−14.7	0.490
Injured people	1.12	0.82–1.53	0.493	11.64	0.95	0.60–1.49	0.813	−5.4	0.556
Collisions with motorcycle or moped involved	1.10	0.82–1.48	0.508	10.42	0.93	0.55–1.56	0.774	−7.3	0.561
Motorcycle or moped drivers involved	1.24	0.90–1.71	0.187	24.11	0.81	0.48–1.39	0.449	−18.7	0.181
CROSS zone									
Collisions	0.85	0.73–1.01	0.057	−14.64	1.05	0.88–1.25	0.585	5.0	0.078
Injured people	0.89	0.74–1.07	0.199	−11.41	1.04	0.86–1.25	0.693	3.9	0.222
Collisions with motorcycle or moped involved	0.85	0.72–1.01	0.069	−14.85	1.07	0.88–1.29	0.493	6.9	0.073
Motorcycle or moped drivers involved	0.87	0.72–1.05	0.159	−12.80	1.11	0.91–1.36	0.309	11.0	0.077

[a] Relative Risks, 95% Confidence Intervals and significance from the period parameter of the adjusted models.
[b] %change = (-(1-RR)), show the percentage of change in the number of traffic collisions in the post-intervention period versus the pre-intervention period to quantify the impact of the implementation of the ASL.
[c] The significance of the interaction between period and type of area parameter from the adjusted models, to see if the changes in the number of collisions has been significantly different in the ASL areas than in the comparison areas and therefore it can be assumed that the changes are due to the intervention.

In phase II, no significant changes were observed in either 34 m or CROSS, in the ASL area or in the comparison area (Table 2). After adjustment for mobility and street characteristics, no changes in risks were observed (Table 3).

In phase I, the characteristics of the collisions changed between the pre- and post- intervention periods (Table 4). The proportion of collisions with pedestrians, front-side impact collisions and those with motorcyclist involvement were significantly reduced, however rear-end collisions increased significantly, in the ASL-34m area, but no changes was observed in the comparison area. Front-side impact collisions decreased significantly in the CROSS area, while side-impact and rear-end collisions and falls (two-wheeled vehicles) increased significantly, in both the intervention and comparison zones. The proportion of collisions with pedestrians decreased significantly in CROSS comparison area. In phase II, similar changes to those in phase I were observed but only in the CROSS area (Table 4).

Table 4
Description of Average Daily Traffic and the characteristics of the collisions according to the type of collision, the involvement of cyclists or motorcyclists and the severity of the collisions, in each area (34 m and CROSS) and periods (pre- and post-intervention), for both the intervention and comparison zones.

	ASL areas					**Comparison areas**						
	Pre period		Post period			Pre period		Post period			Pre period	Post period
	N	%	N	%	p (pre-post)	N	%	N	%	p (pre-post)	p (ASL-comparison)	p (ASL-comparison)
PHASE I												
Motorized mobility												
Average Daily Traffic (Thousand) (Mean)	38.0		35.3		0.250	32.5		29.6		0.170	0.340	0.321
34m												
Collision type												
Head-on	2	0.7	1	0.4	0.693	0	-	1	0.8	0.423	0.540	0.999
Frontolateral	18	5.8	4	1.6	0.014	6	3.5	2	1.6	0.474	0.285	0.999
Side	63	20.4	49	19.7	0.835	41	23.8	29	41.4	0.891	0.419	0.501
Rear end	144	46.6	150	60.2	0.002	82	47.7	58	46.0	0.815	0.849	0.011
Múltiple rear end	20	6.5	20	8.0	0.512	16	9.3	15	11.9	0.565	0.280	0.260
Against fixed object	1	0.3	1	0.4	0.878	2	1.2	0	-	0.510	0.292	0.999
Motorcycles or moped fall	28	9.1	18	7.2	0.536	15	8.7	11	8.7	0.998	0.999	0.683
Falling inside a vehicle	11	3.6	10	4.0	0.825	9	5.2	6	4.8	0.854	0.475	0.789
Collision with involvement of												
Pedestrians	20	6.5	4	1.6	0.005	7	4.1	3	2.4	0.527	0.309	0.692
Motorcyclists	208	67.3	180	72.3	0.229	119	63.2	84	66.7	0.706	0.685	0.282
Cyclists	8	2.6	1	0.4	0.047	2	1.2	3	2.4	0.653	0.506	0.112
Severity												
Collisions with seriously injured or dead	6	1.9	8	3.2	0.418	3	1.7	2	1.6	0.917	0.999	0.506
CROSS												
Collision type												
Head-on	14	1.0	4	0.5	0.324	5	0.5	4	0.7	0.728	0.243	0.723
Frontolateral	578	41.4	203	26.1	< 0,001	452	45.1	189	34.9	< 0,001	0.072	0.001
Side	334	23.9	271	34.8	< 0,002	174	17.4	161	29.7	< 0,002	< 0,001	0.056
Rear end	144	10.3	100	12.8	0.077	103	10.3	55	10.2	0.940	0.999	0.140
Múltiple rear end	14	1.0	8	1.0	0.956	8	0.8	7	1.3	0.416	0.669	0.793
Against fixed object	25	1.8	16	2.1	0.743	23	2.3	12	2.2	0.921	0.460	0.848
Motorcycles or moped fall	100	7.2	91	11.7	< 0,001	53	5.3	49	9.0	0.005	0.075	0.146
Falling inside a vehicle	12	0.9	11	1.4	0.274	26	2.6	15	2.8	0.869	0.001	0.106
Collision with involvement of												
Pedestrians	188	13.5	99	12.7	0.644	177	17.7	72	13.3	0.029	0.006	0.803
Motorcyclists	1073	76.8	625	80.2	0.066	696	69.4	366	67.5	0.455	< 0,001	< 0,001
Cyclists	62	4.4	58	7.5	0.004	35	3.5	49	9.0	< 0,001	0.293	0.307
Severity												
Collisions with seriously injured or dead	52	3.7	26	3.3	0.719	44	4.4	20	3.7	0.593	0.460	0.762
PHASE II												
Motorized mobility												
Average Daily Traffic (Thousand) (Mean)	71.2		74.6		0.019	28.0		30.2		0.135	< 0,001	< 0,001
34m												
Collision type												
Head-on	0	-	1	1.0	0.326	2	2.9	0	-	0.999	0.064	0.999
Frontolateral	8	3.9	3	3.0	0.999	9	12.9	0	-	0.056	0.017	0.999
Side	39	19.0	24	24.2	0.295	16	22.9	6	21.4	0.999	0.492	0.999
Rear end	127	62.0	55	55.6	0.319	25	35.7	17	60.7	0.041	< 0,001	0.671
Múltiple rear end	15	7.3	8	8.1	0.820	4	5.7	0	–	0.576	0.789	0.198
Against fixed object	3	1.5	3	3.0	0.395	0	-	1	3.6	0.286	0.573	0.999
Motorcycles or moped fall	13	6.3	8	8.1	0.631	9	12.9	3	10.7	0.999	0.122	0.706
Falling inside a vehicle	21	0.5	0	-	0.999	5	7.1	2	7.1	0.999	0.005	0.047

(*continued on next page*)

Table 4 (*continued*)

Collision with involvement of												
Pedestrians	6	2.9	2	2.0	0.999	4	5.7	1	3.6	0.999	0.282	0.530
Motorcyclists	145	70.7	75	75.8	0.412	49	70.0	21	75.0	0.805	0.999	0.999
Cyclists	1	0.5	2	2.0	0.248	2	2.9	1	3.6	0.999	0.160	0.530
Severity												
Collisions with seriously injured or dead	2	1.0	1	1.0	0.999	2	2.9	0	-	0.999	0.269	0.999
CROSS												
Collision type												
Head-on	2	0.3	1	0.4	0.999	3	0.7	0	-	0.555	0.403	0.999
Frontolateral	215	33.5	46	17.6	< 0,001	197	44.6	46	21.1	< 0,001	< 0,001	0.352
Side	213	33.2	109	41.6	0.018	123	27.8	91	41.7	< 0,001	0.062	0.999
Rear end	100	15.6	56	21.4	0.042	39	8.8	28	12.8	0.131	0.001	0.016
Múltiple rear end	6	0.9	4	1.5	0.487	4	0.9	4	1.8	0.450	0.999	0.999
Against fixed object	7	1.1	6	2.3	0.216	9	2.0	6	2.8	0.584	0.212	0.777
Motorcycles or moped fall	38	5.9	20	7.6	0.370	32	7.2	32	14.7	0.003	0.451	0.018
Falling inside a vehicle	0	-	0	-	-	4	0.9	2	0.9	0.999	0.028	0.206
Collision with involvement of												
Pedestrians	65	10.2	31	11.8	0.476	41	9.3	22	10.1	0.779	0.678	0.562
Motorcyclists	529	82.5	215	82.1	0.848	350	79.2	176	80.7	0.681	0.179	0.725
Cyclists	18	2.8	8	3.1	0.828	11	2.5	14	6.4	0.017	0.849	0.084
Severity												
Collisions with seriously injured or dead	21	3.3	13	5.0	0.249	29	6.6	7	3.2	0.999	0.012	0.369

p (pre-post): Significance of the T-test and the Chi-square test that compares the changes in the post-intervention period versus the pre-intervention period in the intervention (ASL) and comparison zones.
p (ASL-comparison): Significance of the T-test and the Chi-square test that compares the changes in the the intervention zones (ASL) versus comparison zones, in the pre-intervention and post-intervention periods.

4. Discussion

4.1. Main findings

In phase I, in the 34 m area, there was a significant increase in the risk of collisions with victims, being injured, motorcycles involvement and being a motorcycle driver involved, in the post-intervention period versus the pre-intervention period, only in the intervention area (except for the risk of being injured which also increased in the comparison area). Moreover, in the CROSS area, the risk of being injured and of motorcycle involvement was significantly reduced in the comparison area but not in intervention area (ASL-CROSS). In phase II, there were no significant changes in overall risk. The increase in risk in ASL-34m could be explained by circulation of motorcycles between cars to reach ASL. The ASL-34m area becomes then conflict zones between motorcycles and cars and could explain the increase in rear end collisions in this area (ASL-34m) and not in the ASL-CROSS area.

This study reveals that, in some circumstances, implementing ASL can increase the risk of crashes. The ASL implemented in phase I were associated with an increase in risk, which was maintained after 4 years of follow-up, whereas, in phase II, there were no significant changes in the risk of crashes, while the traffic intensity increased. These differences can probably be explained by certain street characteristics and the number and width of lanes. Phase II ASL areas correspond to a single street with wider lanes and greater traffic intensity. It is a street of connectivity across the city. It is likely that wider lanes allow to pass more easily in between other vehicles to reach the ASL more easily with no risk of side or rear-end collision.

Although the impact on the population is small (with few collisions and most injuries being of slight severity), these results suggest the need to revise the design of ASL and their situation. It is also important to bear in mind that the results of this study cannot be extrapolated to other cities with a much lower two-wheeled motor vehicles density and different street characteristics.

In the comparison area, there was a significant decrease in risk, particularly in the number of injured persons and of motorcycle driver involvement, in the CROSS area but not in ASL area. Given the study design, this reduction could be due to the implementation of ASL, promoting higher use of streets with these grids. This could have caused changes in mobility characteristics in other areas of the city. Some changes have been observed in the characteristics of collisions in the comparison zones that have not been observed in those of intervention.

At the same time, it is important to highlight the fact that this measure reduces significantly the proportion of front-side collisions and run over pedestrians. This was one of the concerns when implementing a measure of this type, which facilitates the exit of two-wheeled motor vehicles at the traffic light. On the other hand, the proportion of side collisions and falls in the CROSS increases in both phases I and II and in the comparison areas. Therefore it does not seem likely to be a consequence of the implementation of the ASL but it probably reflects the increase in the number of users of two-wheeled motor riders throughout the city.

4.2. Limitations and strengths

An increased risk of injury was also observed in the comparison 34 m area in phase I. A possible explanation could be rerouting of two-wheeled motor vehicles toward street with ASL. This study coincided with the financial crisis, which led to a decrease in traffic volume. Other unidentified factors could also have had an effect, such as periods of roadworks restricting traffic flow. It is important to bear in mind that the available measure of ADT is an annual average obtained from direct measures and estimates from modelling. It is not very sensitive to changes and, moreover, gathers overall traffic flow rather than specific mobility of two-wheeled motor vehicles.

The number of cases overall is small and there was a high proportion of areas without collisions. Consequently, we have not been able to assess pedestrians and crossroads separately or collisions involving motorcycles or mopeds and accidents separately. Nevertheless, the methodology used allowed robust and unbiased estimates to be obtained, as well as sufficient statistical power to allow conclusions to be drawn on the effectiveness of implementing ASL.

The comparison areas were not strictly comparable to ASL areas. They were not always situated in the same street, leading to differences in their characteristics. Overall, comparison area had lower ADT and fewer collisions, as well as other differences that were not controlled for in the final models such as changes due to street works, structural changes during the study period or patterns of mobility. This was more notable in phase II. However, having a comparison area, even being imperfect, increased the strength of the assessment. Despite differences between ASL and comparison area, adjustment variables were introduced into the final models to compensate for them.

The lack of ADT specifically for two-wheeled motor vehicles did not allow adjustment for differences between areas and possible changes in the traffic flow of these vehicles, which were the focus of the intervention. However, the availability of measurements of ADT, despite their limitations, did allow adjustment for the change in mobility that a measure such as ASL can produce in intervention intersections and consequently at other intersections.

4.3. Conclusion

This study reveals that the implementation of ASL at certain intersections in the city was not effective in reducing traffic collisions at these sites. The results also show that the implementation of ASL significantly increased the risk of traffic collisions in the area preceding the ASL in some streets, although not in the area after the ASL (ASL-CROSS).

4.4. Recommendations

There is a need for in situ study of the ASL with the highest and as well as those of lack of risk. Given that the highest risk of collision was observed in the space leading up to the ASL for certain characteristics such those of phase I, a pilot study could be performed of a lane providing direct access to ASL. Evaluation should be performed before implementing any new ASL to allow for accurate post-implementation comparisons. Information should also be gathered on two-wheeled motor vehicles ADT before ASL implementation.

Funding

This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

Declaration of competing interest

None.

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