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Analysis of the Factors Influencing Speed Cushion Effectiveness in the Urban Context: A Case Study Experiment in the City of Bari, Italy

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Abstract: The installation of Traffic-Calming Devices (TCDs) is an extremely valuable countermeasure to prevent vulnerable road users from fatalities in urban contexts. Among all the TCDs, Berlin Speed Cushions (BSCs) seem to be one of the most promising because they reduce speeds but do not affect emergency vehicles. However, previous research on BSCs is limited and lacks some important aspects, such as the analysis of speeds at different distances from the cushion or the investigation of the influence of other context variables. In this study, BSCs of different lengths (2.20 m, 2.70 m, and 3.20 m) were deployed in the City of Bari on three roads belonging to the same area. To overcome the limitations of previous research, speeds were recorded using a laser-speed gun before and after the implementation of BSCs, in different conditions, in order to take into account the effect of the following factors: the time of day, day of the week, and average hourly traffic. An ANOVA analysis was performed, with speed as the dependent variable and the above-reported factors and the test road site (proxy variable for the cushion length) as factors, independently repeated for six distance ranges with respect to the cushion. The results reveal that speed evidently decreases immediately before (down to about 13 km/h) and after the cushion (down to about 12 km/h), time of the day is an important factor (speed decrease is much more evident during the morning than the evening), and the length of the cushion has some influence on speed decrease (the speed decrease is lower for the longest cushion).

Keywords: Berlin speed cushions; traffic-calming device; vulnerable road user; urban context; speed reduction; real-world tests

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1. Introduction

The use of Traffic-Calming Devices (TCDs) is supposed to target and overcome several issues arising in urban areas related to pollution [1,2] and safety [3,4]. Concerning the latter, in urban areas, it is crucial not only to safeguard drivers but also Vulnerable Road Users (VRUs), who seem to be more exposed to fatalities than other road users [5–8]. One of the main causes of VRU fatalities and injuries is the high speed of vehicles traveling on roads [9–11], even in urban environments [12–15]. The installation of TCDs has been widely found to be beneficial in speed reduction [16–21]. They also contribute to another main scope of modern cities: their livability for all citizens and not only for vehicle drivers [22,23]. In this paper, the positive effects on speed reduction of one typology of TCDs, the Berlin Speed Cushion (henceforth referred to as BSC), was studied. The main reason for choosing the BSC, among all the other devices, is related to its cost-effectiveness, easy installation, and materials, as will be dealt with in more depth in the next section. Another advantage of the speed cushion is linked to the possibility that emergency vehicles can pass over them without any disturbance [24] and to stormwater management. Since the speed cushions are devices not covering the entire road platform, stormwater can easily flow away without modifying the existing water collection systems. Moreover, in Italy, their use is still not regulated by national standards. For this reason, this experimental study was approved and authorized by the Ministry of Infrastructure and Transport (M.I.T), which set the height and the width of the devices to be installed in the investigated area in the city of Bari (Italy).

Hence, the main contribution of this study is to investigate the effects of BSCs on vehicle speeds with the aim of providing grounds for practical implications which may be useful for updating standards and guidelines (the Italian regulations currently do not explicitly allow speed cushions). In fact, the main objectives of this study are:

(1) Highlighting the effects of BSC on driving speeds, considering different ranges of distance from the speed cushions;
(2) Studying the influence of other context variables (period of day, day of the week, hourly average traffic volume, and the cushion length) on the effectiveness of BSCs for different ranges of distance from the speed cushion, given the lack of specific previous research on this topic;
(3) Assessing whether the cushion length influences the difference in speed once the other factors have been accounted for.

The remainder of this paper is organized as follows. The next section reports the literature review of studies analyzing the effect of traffic-calming devices, particularly focused on speed cushions. After, the methodology used for this study is presented. Section 4 then shows and discusses results with reference to the relevant literature studies. Finally, some conclusions are drawn, and the limitations and further recommendations are highlighted.

2. Literature Review

TCDs (such as speed humps, speed tables, speed bumps, speed cushions, chicanes, lane narrowing, and so forth) are crucial in urban and peri-urban environments to reduce fatalities, inducing speed reduction. For instance, decreasing speed from 50 km/h to 30 km/h leads to huge benefits to urban safety [25]. The results showed that a vehicle traveling at 50 km/h, which impacts a vulnerable user, causes a mortality rate between 55% and 90%. However, traveling at 30 km/h, but maintaining all the other boundary conditions unchanged, has been shown to lead to a mortality rate of less than or equal to 10%. Moreover, this speed change does not significantly affect travel times on urban roads: the difference has been estimated as equal to around 10% [1].

Analyzing in depth the effects of speed reduction on injuries, a difference of 1 mph could reduce the frequency of injury accidents by 5% [26]. However, this reduction could not be achieved solely by vertical signals and speed limits because their effects could not exceed a 1 mph speed reduction. Combining the speed limits with some TCDs (road humps, speed cushions, and raised intersections); for instance, in 20 mph zones, the average speed drastically decreased (9 mph), as did the frequency of fatal (−70%) and injury crashes (−61%). This comparison was made based on 5 years of observing crashes before the countermeasures and 1 year of observing crashes after the countermeasure. The traffic-calmed roads showed traffic volume reduced by up to 27% (average by 15%). Another study [21] went into detail about the correlation between TCDs and traffic volumes. One speed cushion in an urban environment in Poland was tested using aerial video recording. The performance of roads was simulated in the presence and absence of the TCD by means of two traffic simulators (microscopic and macroscopic). Similar results to the previous study were found for traffic volumes, highlighting a volume decrease of up to 33% in traffic-calmed roads. In addition, relying on microsimulations, the correlation between TCDs and road capacity was calculated using the time delay as a metric [27]. Sixteen speed tables and five speed humps were tested in Spain. It was found that the TCDs reduce the road capacity, regardless of the type of TCD. The slope of the TCD can have significant effects on road capacity: slopes greater than 5% reduce road capacity by 50% if spaced at 25 m intervals.

The effects of geometry of these devices and their spacing also have effects on the comfort and satisfaction perceived by the users. Sdoukopoulos [28] investigated the user acceptance of TCDs in Greece with a before–after approach. Surveys highlighted a great rate of appreciation of the TCDs by citizens in the tested area. Kveladze [29] made a first attempt at linking the spacing between two consecutive speed bumps and driver behaviors, finding that rule-based behavior is positively affected by reduced spacing. The effects of the spacing were then measured quantitively on the speed by recording data using a laser speed gun [30]. The data recorded was used to find the traveling speed related to 2 consecutive speed humps: 20 m of TCD spacing enables drivers to speed up to 30 km/h maximum. Perez-Acebo et al., 2020 [20] investigated the effects of consecutive vertical TCDs. This layout prevents users from ignoring the presence of TCDs. The experiments were run in Spain and Poland with different spacing and different TCDs (raised crosswalks, raised intersections, speed humps, and speed cushions). The operative speed and the average speed were recorded for the investigated roads using a speed gun in the middle point between two TCDs, during the day and not in adverse weather conditions. It was found that the operative speed was always lower than 50 km/h for 200 m of spacing. For 75 m of spacing, the operative speed was always lower than 40 km/h. An ANOVA analysis, commonly used in this field [31,32], was run to correlate the speed, spacing, and type of TCD.

The geometry of TCDs can have a significant effect on speed reductions as well as the correct spacing. Webster and Layfield [33] investigated 2 sinusoidal speed humps, finding that speed drastically decreases (maximum average speeds 30 mph), not affecting the perceived comfort, thanks to the hump layout (S or H shaped). The main characteristics affecting the comfort and the speeds are the slope, the height of the speed hump [34], and the traveling speed imposed on the selected road. In fact, varying the traveling speed on roads, the speed bump was found to be more effective than a speed dip for speed ranges between 15 km/h and 45 km/h [35]. However, it is possible that such devices can also negatively affect not only vehicles but also other types of users, such as cyclists and pedestrians [36,37]. Even if placing TCDs in proximity to the entrance to urban areas has considerable effects on pedestrian and cyclist safety since drivers perceive a great difference in the road environment and tend to slow down, combining more TCD typologies together enhances the benefits [37].

The influence of TCD geometry was also investigated in the light of finding the best shape to ensure comfort and safety. It was found that a perfect speed bump should be 30 cm wide and 16.8 cm tall [38], and a quadratic relationship between width and speed reduction was noted. As for speed tables, it was found that 6.5 m and 8.5 m speed tables provided very different results. The influence of geometry was significant according to the speed table length: increasing the length by 1 m increases the operative speed by 3 km/h [39]. The speed table length can be fundamental to forcing user speed below the speed limit. From this study, as well as others [40–43], the need to define a standard framework for the geometry of TCDs for future installations is evident. This framework should guide practitioners and engineers in correctly designing TCDs according to the selected environment. A total of 51 sinusoidal speed humps were analyzed in [42] by recording 1 h of vehicle flow with a speed camera. The operative speed of vehicles was used as a metric to understand the influence of geometry on speed. It was found, according to [39], that increasing the length increased the speed and that increasing the height decreased the speed, as previously highlighted by [20,38].

The same need for homogenous international standards in TCD (raised pedestrian crossings) design was also stated in [43], which highlighted the better comfort of a trapezoidal shape than other vertical shapes. Despite these considerations, another study [40] found that the speed hump profile did not affect the vehicle dynamics and that the comfort experienced by drivers is still present if the vertical acceleration stays below 0.6 g. Moreover, smoothing the slope of humps reduced the dynamic effects of the hump on the vehicle and driver by 20%. The maximum suggested height for this TCD was 8 cm, and short humps should be compensated by a notable width.

Considering the geometric characteristics of the device and its effects, it is possible to understand the reason for choosing one TCD rather than another. This choice can be made by considering, primarily, environmental and safety aspects. All TCDs are supposed to greatly reduce the severity and frequency of crashes [4,31,44–48]. It was found that speed humps reduced collisions by 37.5% [4]. In urban and peri-urban areas, the frequency and severity of crashes are generally reduced [46], even if few studies have been carried out on this topic. The speed profiles obtained from naturalistic data were used to correlate TCDs (16 speed humps, 5 speed tables, and 1 roundabout) and safety.

In another study, the effects of speed cameras and speed humps were investigated [44], in one hundred and fifty 30 mph areas, in Great Britain. It was found that speed humps reduced crashes by 44% (twice the reduction obtained by cameras) and prevent fatalities, as also stated by a case study in Lithuania with speed bumps, humps, and raised crosswalks [47]. The best results in terms of crash reduction among speed tables, chicanes, and speed humps were researched through ANOVA analysis [32]. Chicanes were the best in terms of crash frequency reduction, while speed tables were the best for environmental benefits. The same comparative approach between TCDs was pursued in another study [48]. Speed tables, chicanes, and lane narrowing were compared in Catania. Changing the context, the results were different from [31]. Speed tables were found to be the most effective for crash reductions (40%) and for pedestrian safety, too (−50% crashes involving pedestrians).

However, among all the TCDs, speed bumps were found to be not that safe or comfortable for vehicles, especially for emergency ones, which can be badly affected by the bumping effects [49]. In this optic, other devices were strongly recommended, especially after testing 23 sites. Speed cushions (often named "Berlin Speed Cushions"-BSCs) overcame the problem of safety, comfort, and emergency vehicle travel, even if in Italy, where the tests were run, they are still not legal according to the current design standards and regulations. The M.I.T. must provide authorization for research purposes to run the tests. All the Italian experiments on speed cushions must be authorized, and their aim is to show the benefits of such devices to make them legal in the future [50]. According to [45], speed cushions are largely more effective than speed humps for several reasons: they are cost-effective [45,51], decrease speeds down to 10 km/h, and increase road safety (40% of prevented crashes).

After the comparison of several TCDs, the benefits of speed cushions were also assessed [24], highlighting how they force drivers to slow down and drive correctly over them. According to this research, speed cushions are easy to perceive by drivers who feel safe and comfortable passing over them. The same outcomes were achieved by [52], who found the operative speed with speed cushions always fell in the 27–35 km/h range. This result could be a milestone for the introduction of speed cushions in 30 km/h zones. The applicability and benefit of safety and speed of speed cushions in urban areas have been tested and assessed since the early 1990s by the Department for Transport in the United Kingdom [53]. Table 1 reports a summary of results obtained from previous experimental studies on BSCs.

Table 1. Studies on speed cushions—synoptic table.

Investigated Variables		Perez-Acebo et al., 2020 [20]	Paszkowski et al., 2021 [21]	Johnson and Nedzesky, 2004 [24]	Webster and Layfield, 2003 [26]	Minnema, 2006 [41]	Mountain et al., 2005 [44]	Berthod and Leclerc, 2013 [45]	Berloco et al., 2022 [50]	Layfield and Parry, 1998 [52]
Speed	**Average**			−60%	−14.6 km/h	−10.8 km/h			−20 km/h	
	Operative	<40 km/h (for 75 m spacing; <50 km/h (for 200 m spacing)		<20.6 km/h		−14.1 km/h			−22 km/h	
Crashes	**All**				−46%				−65%	
	Severe				−60%					
Geometry	**Shape**			Rectangular or square				Rectangular or square		
	Length			3 m		2 m			3 m	
	Height			7.5–9.0 cm	7.5–8.0 cm	7.5–10.0 cm			7.5 cm	
	Width			2.1 m	1.6–1.9 m	1.9 m	1.8 m		1.6–2.0 m	
Traffic volume			up to −33%		−15%	−33%				−24%
Material				Asphalt		Asphalt, Rubber		Asphalt	Rubber	
Spacing		75–200 m		85.5–190.2 m (Speed increases with greater spacing)	50–125 m	50–150 m		80–150 m		
Driving behavior				Driving centrally or toward the left of the lane					54% of vehicles pass it centrally, the others laterally	55% of cars and 90% of buses drive centrally

Case Study

In this light, the choice of Berlin speed cushions (BSCs) for the experiment proposed in this research is justified, together with the results from the surveys conducted using low-cost equipment [54]. The experiments were authorized by the M.I.T., which assessed the width and height of the cushion to implement in the city of Bari but did not provide indications about the length. For this reason, three different cushion lengths were tested to understand the influence of length on speeds, similar to previous research [39,42]. The dimensions used for the three speed cushions were in line with the current international guidelines from the Delaware Department of Transport, CERTU, and the Department for Transport (UK), as already highlighted in [50].

The tests on the speed cushions followed a methodology already used in other studies. A before–after analysis was run (as in [3,28]), recording speeds using a laser speed gun [28,30,55], as will be explained in detail in the next section. A preliminary speed data analysis was conducted by the authors of [50], revealing speed-decreasing tendencies in the proximity of the implemented BSCs. However, in that preliminary study, no additional context variables were considered while analyzing the effect of BSCs on vehicle speeds in comparing the before and the after periods. In this study, starting from the same dataset, other context variables, namely road site (a proxy variable for the cushion length, which varies across the test sites), week period, day period, and traffic volume ranges, were included in the speed data analysis to better understand the overall effects of BSCs in the considered context (see also [46,56]), by using an ANOVA approach (as in [20,31]). The influence of BSCs on the rearrangements of traffic routes and on encouraging people to shift towards other and more sustainable means of transport than cars has not been investigated in this paper. This effect can be more reliably investigated several years after device implementation since users may become familiar with the TCD, thus reducing its effect [57].

Moreover, in the optics of more livable cities [23], the speed cushion can provide a significant contribution, pushing citizens towards walkable cities with fewer pedestrian collisions. This outcome could be extremely beneficial, also considering the area of the city where the cushions were installed. The area is in the city center of Bari (Italy) along local roads, characterized by a single-lane, one-way flow. In future developments of this study, it should be possible to correlate traffic violations and crashes with the land use of the investigated area [58].

3. Materials and Methods

The methodology used in this study is divided into two parts: the experimental test procedure is explained in the first, and the statistical methods used to analyze data are presented in the second.

3.1. Experimental Setup

The analysis of the speed before and after the implementation of the speed cushions was possible thanks to three testbeds located in the city center of Bari, Italy, on three different streets parallel to each other, see Figure 1.

The chosen sites have some major characteristics in common. They fall into Zone 30, which becomes Zone 10 only at the intersection with a pedestrian area (Via Sparano). Moreover, lateral parking spaces are absent since there is lane narrowing at the intersection. These characteristics were crucial to achieving authorization from the M.I.T. to allow the safe installation of the devices.

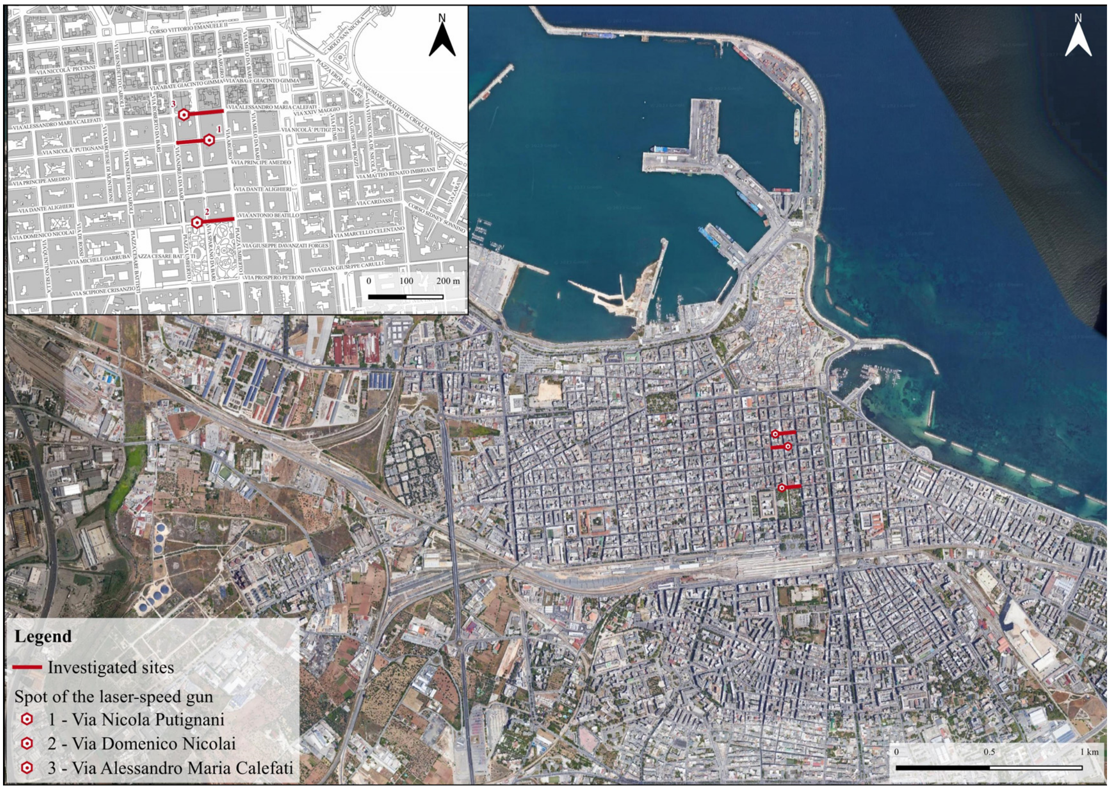


Figure 1. Experimental set-up in the city of Bari, Italy. In red are the investigated sites, and pink dots indicate the location of the laser-speed gun.

Among all the possible materials used for speed cushions, the installed ones are made of vulcanized rubber, a material which enables modularity and compactness. The used BSC has a standard length of 3.20 m. However, thanks to the modularity of the speed device, it was possible to remove sections 0.50 m long from the central part of the cushion. Hence, the length of the cushion was not fixed. It was varied, as shown in Table 2 and Figure 2, by removing 1 or 2 modules from the cushion (down to a total length of 2.20 m and 2.70 m, respectively). This choice was useful in investigating the relationship between device length and driver behavior. Moreover, according to Swiss and French Regulations and M.I.T. suggestions, the width of all the devices was equal to 1.70 m.

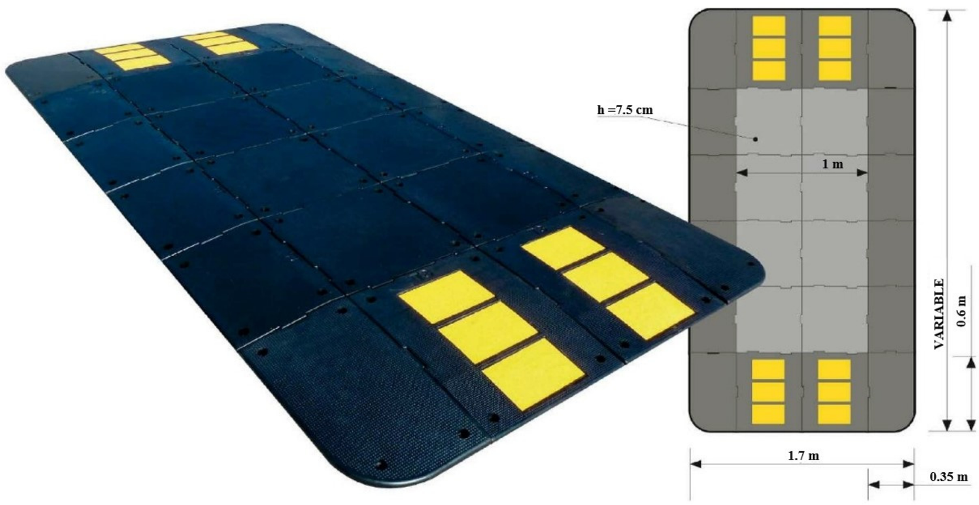


Figure 2. Speed cushions used for the experiment.

Table 2. Speed cushion dimensions according to the installation site.

Site ID	Site Name	Length (m)	Width (m)
1	Via Putignani	2.20	1.70
2	Via Nicolai	2.70	1.70
3	Via Calefati	3.20	1.70

The speed cushions were installed close to the start of the pedestrian areas to make the speed reduction effective for pedestrian safety. The center of the speed cushion was set, for all 3 devices, 8 m from the start of the pedestrian area. This distance was also compatible with the different device lengths used. The furthest edge of the cushion was approximately 10 m from the pedestrian zone at the 3 sites. The device was placed in the middle of the lane, which was 3.75 m wide in all 3 streets.

It was possible to record speed data after the implementation of the speed cushion in the same location since the overall road design was unchanged with respect to the "before" condition. The speed was recorded using a Laser-Speed Gun device (LaserTech TruSpeed®, Centennial, CO, USA) placed on a tripod and manipulated by an operator. The location of the speed gun was defined after three on-site inspections propaedeutic to test the device and to let vehicle users be comfortable and get used to the presence of the operator with the device. The operator with the speed gun was hidden by the presence of parking lots, greenery, and pedestrian area. In this way, the user behaviors while approaching the speed cushion could be recorded independently of the presence of the operator. The operator was visible only from the middle of the pedestrian area, so after drivers had passed the cushion, hence the effect of the speed cushion had already occurred.

The characteristics of the speed gun were useful to set the optimal position of the operator. The maximum range of detection of the tele-laser is 650 m, and the minimum detected distance is 15 m. The accuracy of the measurement is approximately 0.2 m for distance and 2 km/h for speed. Moreover, the tripod can be located at the side of the lane, parallel to the traffic flow. Considering these details, the instrument with the tripod was placed approximately 30 m from the center of the speed cushion (Figure 3).

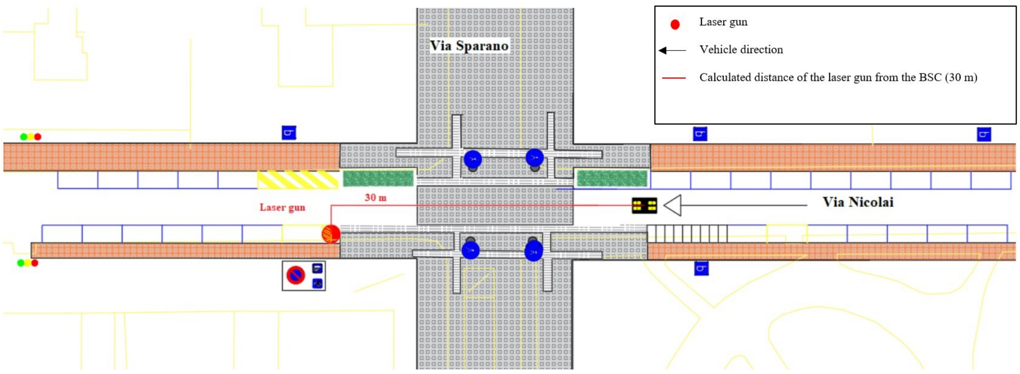


Figure 3. Experimental set-up in the city of Bari, Italy, highlighting the distance between the laser-speed gun and the center of the speed cushion (30 m) for the case of Via Nicolai.

The position allowed speeds to be recorded up to 110 m by the operator and to collect speed data of all the approaching vehicles. The measurements were made using the tele-laser continuous recording function to monitor driver behavior, pointing it at each vehicle 3 times with a time span of 3 s between each recording: when the vehicle approached the cushion, passed onto it, and then left it. When the time span between 2 recordings was greater than 7 s, the recordings were attributed to 2 different vehicles.

To observe possible speed reduction effects, the recording should optimally capture free-flow speeds without start–stop phenomena. Since the selected road segments intersect with a pedestrian area, the traffic flow regime strongly depends on the pedestrian flow too. The time spots for the data collection were thus selected so that few pedestrians and few vehicles were present. In-field observations were conducted to define those optimal pedestrian and vehicular traffic conditions. The pedestrian flow crossing the 3 site roads was considered significant but not disturbing for the regular vehicular flow when it was lower than 350 pedestrians/h. At the same time, the traveling vehicles should have been more than 100 vehicle/h to reach a significant sample of undisturbed traffic flow. The average daily traffic measured for the 3 sites during the preliminary surveys was between 52 vehicle/h and 203 vehicle/h, highlighting a great variability depending on the day of the week. Despite this variability, the three sites showed comparable traffic flows during the same investigated time intervals. Thus, the time spots were chosen, also according to the COVID-19 pandemic rules, to meet the mentioned prerequisites, and they were as follows:

- From 7 a.m. to 8 a.m.;
- From 2 p.m. to 3 p.m.;
- From 9 p.m. to 10 p.m.

These time spots were used for the two different periods of the measurements: before the installation of the cushions (to investigate the "before user behavior") and after the installation. Measurements after the installation were recorded at least one month after the installation itself to let users get used to the novelty and to record an actual "after user behavior". In fact, according to [59], a minimum of four repetitions should be needed to get test drivers used to a given condition. Hence, a one-month period can be sufficient to get drivers familiar with the area and accustomed to the speed cushions. In both phases, the same position of the instrument was used, and the same number of campaigns were carried out for a total of 18 days of measurements. The first campaign (before period) was run between September and October 2020. The second campaign (after period) was run between February and March 2021. All the weekends included in the 18-day period were used in the analysis. The recorded data, discretized according to the distance and the time of detection, exploiting a recursive algorithm (in Visual Basic Advanced language), were then plotted versus distance diagrams (from the furthest detection point to the closest one).

3.2. Statistical Methods

Data collected through the above-described experimental setup were analyzed by means of statistical techniques. In particular, the ANalysis Of VAriance (ANOVA) method was used to inquire into variations in average speed after the introduction of Berlin speed cushions (as in previous studies related to TCDs [20,31,32]), controlling for other variables. Six different analyses were conducted: one for each distance range from the observation point, assuming that the driving behavior can be differently influenced by the presence of the Berlin speed cushions as a function of the distance from it.

The 6 distance ranges from the fixed observation point are defined as follows: (1) 18.8 m–28.1 m; (2) 28.2 m–39.1 m; (3) 39.2 m–54.2 m; (4) 54.3 m–69.1 m; (5) 69.2 m–84.9 m; and (6) 85.0 m–108.9 m. Distance ranges were determined, independently of the cushion length, by discretizing the number of observations according to a trade-off between groups of recordings with similar amounts of data and distance ranges, which should be of adequate lengths to be interpreted (that is, not too short or long). However, the first distance range coincides with the space immediately after the speed cushion (i.e., the distance between the observer placed after the pedestrian area and the speed cushion, see Figure 3). The second distance range is the space immediately before the speed cushion (including the cushion itself because the cushion axis is 30 m from the observer, see Figure 3).

The number of total speed observations used as the dataset for the analysis was 43,324 (19,758 in the before period and 23,566 in the after period), divided as follows: 17% for distance range 1, 28% for distance range 2, 30% for distance range 3, 17% for distance range 4, 6% for distance range 5, and the remaining 2% for distance range 6. The limited amount of data in the fifth and sixth ranges are clearly explained by the measuring capacity of the laser-speed gun. It was decided to remove distance range 6 from the further analyses, given that there were only 168 valid observations in the after period.

An ANOVA test was conducted for each distance range. Before running the tests, data samples disaggregated by different factor levels, which are independent samples according to the study design, were checked for normality and homoscedasticity of variances. In the model structure, the measured speed is the dependent variable, and other five factors are the independent variables. These factors are:

- The observation period, i.e., before or after the implementation of the speed cushion (factor label: "BoA"). This factor is henceforth briefly referred to as "BoA" (factor label);
- The road site in which cushions were implemented: Via Calefati, Via Nicolai, and Via Putignani. Since, as indicated in the methods, these roads are similar in their geometric and functional characteristics, this variable should be interpreted as a proxy for the cushion length which is different for each site (2.20 m at the Via Putignani site, 2.70 m at the Via Nicolai site, and 3.20 m at the Via Calefati site). This factor is henceforth briefly referred to as "ID_site";
- The week period is classified into three groups: working day, Saturday, or holiday (factor label: "WP");
- The day period is classified into three groups: morning (6 a.m.–9 a.m.), afternoon (1 p.m.–3 p.m.), and evening (7 p.m.–10 p.m.) (factor label: "DP");
- The hourly average traffic volume is classified into three groups: low, medium, and high traffic volumes. The 3 traffic groups were defined based on the measured traffic volume distribution, that is, by dividing the traffic volume distribution into 3 percentile classes (low-volumes: from the 0th to the 33rd percentile, medium-volumes: from the 33rd percentile to the 67th percentile, high-volumes: from the 67th percentile to the 100th percentile). The 2 threshold percentiles are 85 vehicles per hour (33rd percentile) and 110 vehicles per hour (67th percentile). The factor label is "HAT".

Given the aims of this study, interested in the effects of the main factors and their interactions, and that observations were severely unbalanced across the different groups for some considered factors, a type III ANOVA was chosen (see, e.g., [60]), among different possible options [61]. The ANOVA model is specified as follows, where each variable is labeled as previously defined, and the $\beta_{i,j}$ are the estimated coefficients, where I varies according to the number of considered factors, and j varies according to the number of levels for each factor, coded through effects coding (see, e.g., [62–64]), thus excluding the reference level:

$$\begin{aligned} \text{Average speed} = {} & \beta_0 + \beta_1 BoA + \sum_j \beta_{2,j} ID_{site,j} + \sum_j \beta_{3,j} WP_j + \sum_j \beta_{4,j} DP_j \\ & + \sum_j \beta_{5,j} HAT_j + \sum_j \beta_{6,j} (BoA * ID_{site})_j \\ & + \sum_j \beta_{7,j} (BoA * WP)_j + \sum_j \beta_{8,j} (BoA * DP)_j \\ & + \sum_j \beta_{9,j} (BoA * HAT)_j \end{aligned} \quad (1)$$

The above-defined model structure was independently applied to each of the six distance ranges. Factors were included as independent variables to define their general effect on the average speed, independently of the observation period (i.e., before/after) and combined into interaction terms to define the influence of each factor considering the before/after period.

The influence of each term on the average speed was considered statistically significant at the 5% significance level. Post hoc tests were conducted for individual factors, which showed statistically significant effects, in the case of non-binary variables (i.e., ID_site, WP, DP, HAT). In detail, Bonferroni-corrected pairwise *t*-tests were used to compare average speeds. As they are based on model results, the interactions considered for each distance range were graphically represented through interaction plots (before/after condition on the x-axis and the other considered factor on the y-axis). This is useful to provide an interpretation of the interaction between each factor and the observation period.

4. Results

4.1. General Effects of BSCs on Driving Speeds

According to the first objective of this study, the results concerning the general effects of BSCs on driving speeds are reported in the next table (Table 3), disaggregated by the considered distance ranges and the three test road sites (provided with BSCs of different lengths).

Table 3. Results in terms of average speed values (km/h) disaggregated by road test site and distance range from the BSC (standard deviations in parenthesis calculated on the available number of observations for the selected combination of factors as well as mean values).

Road Test Sites	Condition	Distance Ranges from the Observation Point (m)				
		18.8–28.1 (Range 1)	**28.2–39.1 (Range 2)**	**39.2–54.2 (Range 3)**	**54.3–69.1 (Range 4)**	**69.2–84.9 (Range 5)**
Via Putignani (cushion length = 2.20 m)	**Before**	19.6 (6.2)	20.5 (5.8)	21.7 (5.6)	22.1 (5.5)	21.1 (5.3)
	After	12.4 (5.4)	13.5 (5.6)	21.0 (5.4)	22.3 (5.5)	20.1 (5.6)
	D%	−36.7	−34.1	−3.2	+0.9	−4.7
Via Nicolai (cushion length = 2.70 m)	**Before**	19.2 (6.2)	20.0 (5.9)	21.4 (5.6)	22.3 (5.6)	20.4 (5.9)
	After	12.8 (5.1)	14.2 (5.7)	21.1 (5.5)	23.3 (5.6)	23.1 (6.0)
	D%	−33.3	−29.0	−1.4	+4.5	+13.2
Via Calefati (cushion length = 3.20 m)	**Before**	17.3 (5.6)	18.3 (5.4)	21.2 (6.0)	22.4 (6.4)	22.3 (6.3)
	After	12.5 (5.5)	13.0 (5.4)	20.4 (6.0)	23.9 (6.8)	23.7 (7.0)
	D%	−27.7	−29.0	−3.8	+6.7	+6.3

The simple before–after calculated percentage speed difference for each distance range reveals that there is an evident decreasing speed tendency in the first two distance ranges, variable with the test road site. For the first two distance ranges (that is, immediately after the speed cushion), the maximum speed decrease was recorded where the shortest cushion is implemented (Via Putignani), while the opposite is noted for the longest cushion (Via Calefati). Speed differences in the other distance ranges are less evident or practically absent, as expected. In some instances, speeds seem to slightly increase at a considerable distance from the cushion (i.e., 4th and 5th distance ranges, that is, at least 24 m before the cushion axis).

These descriptive statistics are in accordance with the preliminary study made by the authors [50], where different speed profiles were plotted against distance, and a simple relationship between speed difference and the cushion length was sought. However, it is evident that several other factors which may be influential on these speed differences are neglected here. They are examined in the next sub-section.

4.2. Influence of Other Factors on Speed Differences

The results from the application of the ANOVA tests used to investigate the influence of the other factors, according to the second objective of this study, are summarized in Table 4, where all the results obtained for the different distance ranges are plotted.

Moreover, based on both the estimated model and the results obtained from the post hoc tests, average speed contrasts between the different levels of the factors are calculated. They are reported in the next table (Table 5). Interaction plots are then reported in Figure 4 for those interactions revealed as statistically significant based on the ANOVA tests (see previous table).

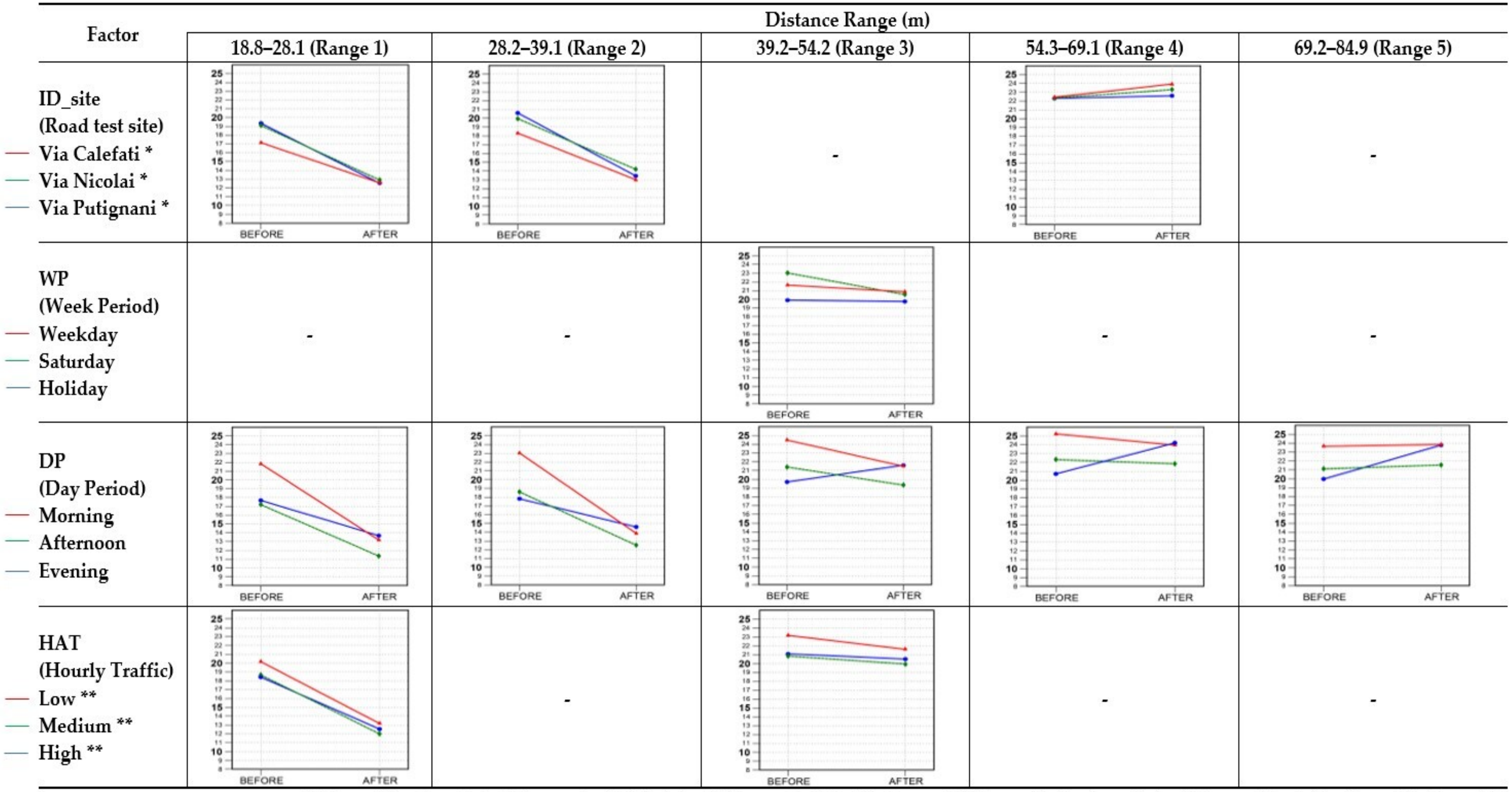
Table 4. Summary of results obtained from the ANOVA tests for the 6 distance ranges (sum of squares, F-statistic, and *p*-value reported in each cell; in case of $p < 0.05$, cell contents are in bold type).

Factor	df	Distance Range (m)				
		18.8–28.1 (Range 1)	**28.2–39.1 (Range 2)**	**39.2–54.2 (Range 3)**	**54.3–69.1 (Range 4)**	**69.2–84.9 (Range 5)**
(*Inter.*)	1	**404,745, 14,097.8 <0.001**	**787,832, 27,050.2 <0.001**	**1,617,257, 54,328.7 <0.001**	**963,975, 29,704.4 <0.001**	**241,439, 6859.9 <0.001**
BoA	1	**17,060, 594.2 <0.001**	**29,538, 1014.2 <0.001**	**1639, 55.1 <0.001**	1, 0.0 0.853	17, 0.5 0.482
IDsite	2	**1024, 17.8 <0.001**	**2839, 48.7 <0.001**	**1866, 31.3 <0.001**	**2353, 36.2 <0.001**	**2345, 33.3 <0.001**
WP	2	**942, 16.4 <0.001**	**1517, 26.0 <0.001**	**1721, 28.9 <0.001**	**382, 5.9 0.003**	22, 0.3 0.733
DP	2	**8111, 141.2 <0.001**	**11,485, 197.2 <0.001**	**12,197, 204.9 <0.001**	**6756, 104.1 <0.001**	**1939, 27.6 <0.001**
HAT	2	**492, 8.6 <0.001**	**860, 14.8 <0.001**	**1890, 31.7 <0.001**	**1309, 20.2 <0.001**	**230, 3.3 0.038**
BoA * IDsite	2	**882, 15.4 <0.001**	**369, 6.3 0.002**	116, 1.9 0.143	**211, 3.2 0.039**	122, 1.7 0.178
BoA * WP	2	46, 0.8 0.452	12, 0.2 0.808	**342, 5.7 0.003**	65, 1.0 0.367	36, 0.5 0.598
BoA * DP	2	**4516, 78.6 <0.001**	**11,815, 202.8 <0.001**	**9415, 158.1 <0.001**	**5928, 91.3 <0.001**	**1232, 17.5 <0.001**
BoA * HAT	2	**289, 5.0 0.007**	78, 1.3 0.260	**612, 10.3 <0.001**	149, 2.3 0.101	29, 0.4 0.660

* Legend: BoA: test period (Before, After), ID_site: road test site (Calefati, Nicolai, Putignani), WP = week period (Weekday, Saturday, Holiday), DP = day period (Morning, Afternoon, Evening), HAT = hourly average traffic (Low, Medium, High).

Table 5. Summary of contrasts (in km/h) between the different levels of the factors (ID_site: road test site, WP = week period, DP = day period, HAT = hourly average traffic) after post hoc tests (only statistically significant contrasts are shown).

Factors	Compared Levels (*Reference Level on the Left*)		Distance Range (m)				
			18.8–28.1 (Range 1)	**28.2–39.1 (Range 2)**	**39.2–54.2 (Range 3)**	**54.3–69.1 (Range 4)**	**69.2–84.9 (Range 5)**
BoA	**Before**	**After**	−3.11	−3.14	−0.67	-	-
ID site	**Putignani**	**Calefati**	−0.51	−0.73	−0.44	+0.51	+1.31
	Putignani	**Nicolai**	-	+0.68	-	+0.48	-
	Calefati	**Nicolai**	+1.12	+1.40	+1.04	−0.03	−0.69
WP	**Holiday**	**Weekday**	+0.78	+0.71	+0.62	+0.45	-
	Holiday	**Saturday**	-	−0.01	+0.04	−0.19	-
	Weekday	**Saturday**	−1.06	−0.72	-	−0.64	-
DP	**Evening**	**Morning**	+1.55	+1.56	+1.53	+1.50	+1.50
	Evening	**Afternoon**	−1.35	−1.00	-	-	-
	Morning	**Afternoon**	−2.90	−2.56	−2.27	−2.28	−2.37
HAT	**High**	**Low**	+0.52	+0.55	+0.69	+0.71	+0.57
	High	**Medium**	−0.10	−0.25	−0.14	-	−0.30
	Low	**Medium**	−0.62	−0.80	−0.83	−1.17	−0.87



* The cushion length is 3.20 m at the Calefati site, 2.70 m at the Nicolai site, and 2.20 m at the Putignani site. ** Low: <85 vehicles/hour, Medium: 85–110 vehicles/hour, and High: >110 vehicles/hour.

Figure 4. Significant interactions between the test condition (before/after) and the other factors considered in this study (in all diagrams, average speeds are on the y-axis while the test condition is on the x-axis: the before condition on the left and the after condition on the right).

As emerges from the results of both the exploratory analysis and statistical tests, the average speeds generally decrease after the implementation of BSCs. In particular, this decrease in speeds is significant in the first 3 distance ranges (up to 54 m from the observer, that is, up to 24 m from the BSC axis). Moreover, considering the other factors, some consistent tendencies arise. Average speeds are higher during morning hours than during the other day periods for all distance ranges. Average speeds are higher in low traffic conditions than in all other conditions and during weekdays than during other days (except in the fifth distance range). Different speed tendencies can be noted for the test sites instead.

Considering interactions between test conditions (before/after) and the other factors, different results can be highlighted. For distances close to the cushion (ranges 1 and 2), the Via Calefati site (in which the longest speed cushion, 3.20 m long, was installed) shows the least evident speed-decreasing tendency. This, however, seems to depend on the different average speeds in the before condition (slightly lower than the other two sites), while the average speeds converge to similar values in the after condition (about 13 km/h for range 1 and about 14 km/h for range 2). There are no particular interactions between the test condition (before/after) and the factors week period and hourly average traffic (except in some limited cases). It is possible that the week period is not influential since, once controlled for the other factors, including traffic and hour of the day, differences between weekdays and other days do not influence speeds. At the same time, the traffic volume range is scarcely influential, even if in low traffic conditions, a steeper decrease can be noted in the after versus before period. This was clearly expected since, in low traffic conditions, speed cushions may be more effective than in congested traffic, where speeds are more influenced by the presence of other vehicles. The interaction between the test condition (before/after) and the day period is significant for all distance ranges. In particular, speed change tendencies during the evening period are different and, in some cases, in contrast, with speed changes during the morning and afternoon periods. In distance ranges from the third to the fifth, speeds decrease (or they are practically stable) during the morning and afternoon periods in the transition from the before to the after condition, while they consistently increase in the evening period. Hence, while the final outcome in terms of speed reduction is satisfactory and similar in all-day periods at distances close to the cushion (first and second distance range), a higher variability emerges at greater distances, particularly for the evening period. In fact, during evenings, the scarce pedestrian traffic may increase the variability of driving behavior, which may depend to a larger extent on their own risk propension. On the other hand, a smaller number of vehicles circulate during the evening period than in the other day periods. The combination of these two factors is responsible for the higher variability in the obtained results, which in this case has led to a contrasting tendency for the evening period in the before-after comparison.

4.3. Assessment of the Influence of the Cushion Length

According to the third objective of this study, the influence of the cushion length is here explicitly assessed based on the results obtained. As already stated, the road test site is used as a proxy variable for the cushion length, given the experimental design. Starting from the interaction plots reported in Figure 4, the interactions between the test road site and the before/after condition are only significant for the first, second, and fourth distance ranges. However, speed differences in the case of the fourth distance range are practically negligible with respect to the first two ranges. For this reason, the first two ranges are studied in detail here. Based on the ANOVA models for these two distance ranges, it is possible to estimate the speed differences reported in Tables 6 and 7.

Table 6. Distance Range 1: estimated speed difference (km/h, %) and estimated speed in the after condition (km/h) for each combination of the factors included in the ANOVA model (WP = week period, DP = day period, and HAT = hourly average traffic). For each combination of factors, the cushion length corresponding to the highest and lowest speed reduction is reported.

WP	DP	HAT	Via Calefati (L = 3.20 m)			Via Nicolai (L = 2.70 m)			Via Putignani (L = 2.20 m)			Length: Highest Reduction	Length: Lowest Reduction
			V after	DV	DV (%)	V after	DV	DV (%)	V after	DV	DV (%)		
Weekday	Morning	Low	13.691	−7.594	−35.678	13.873	−9.484	−40.605	13.260	−9.286	−41.187	2.200	3.200
		Med.	12.931	−7.866	−37.823	13.113	−9.756	−42.660	12.500	−9.558	−43.331	2.200	3.200
		High	13.236	−6.632	−33.380	13.418	−8.522	−38.842	12.805	−8.324	−39.396	2.200	3.200
	Afternoon	Low	12.116	−4.942	−28.972	12.298	−6.832	−35.714	11.685	−6.634	−36.214	2.200	3.200
		Med.	11.356	−5.214	−31.467	11.538	−7.104	−38.107	10.925	−6.906	−38.730	2.200	3.200
		High	11.661	−3.980	−25.446	11.843	−5.870	−33.140	11.230	−5.672	−33.558	2.200	3.200
	Evening	Low	14.135	−3.196	−18.441	14.317	−5.086	−26.212	13.704	−4.888	−26.291	2.200	3.200
		Med.	13.375	−3.468	−20.590	13.557	−5.358	−28.327	12.944	−5.160	−28.502	2.200	3.200
		High	13.680	−2.234	−14.038	13.862	−4.124	−22.929	13.249	−3.926	−22.859	2.700	3.200
Saturday	Morning	Low	12.858	−7.132	−35.678	13.040	−9.022	−40.894	12.427	−8.824	−41.523	2.200	3.200
		Med.	12.098	−7.404	−37.965	12.280	−9.294	−43.080	11.667	−9.096	−43.809	2.200	3.200
		High	12.403	−6.170	−33.220	12.585	−8.060	−39.041	11.972	−7.862	−39.639	2.200	3.200
	Afternoon	Low	11.283	−4.480	−28.421	11.465	−6.370	−35.716	10.852	−6.172	−36.255	2.200	3.200
		Med.	10.523	−4.752	−31.110	10.705	−6.642	−38.289	10.092	−6.444	−38.970	2.200	3.200
		High	10.828	−3.518	−24.523	11.010	−5.408	−32.939	10.397	−5.210	−33.382	2.200	3.200
	Evening	Low	13.302	−2.734	−17.049	13.484	−4.624	−25.536	12.871	−4.426	−25.588	2.200	3.200
		Med.	12.542	−3.006	−19.334	12.724	−4.896	−27.787	12.111	−4.698	−27.949	2.200	3.200
		High	12.847	−1.772	−12.121	13.029	−3.662	−21.940	12.416	−3.464	−21.814	2.700	3.200
Sunday	Morning	Low	12.172	−8.098	−39.951	12.354	−9.988	−44.705	11.741	−9.790	−45.469	2.200	3.200
		Med.	11.412	−8.370	−42.311	11.594	−10.260	−46.948	10.981	−10.062	−47.816	2.200	3.200
		High	11.717	−7.136	−37.851	11.899	−9.026	−43.135	11.286	−8.828	−43.890	2.200	3.200
	Afternoon	Low	10.597	−5.446	−33.946	10.779	−7.336	−40.497	10.166	−7.138	−41.251	2.200	3.200
		Med.	9.837	−5.718	−36.760	10.019	−7.608	−43.161	9.406	−7.410	−44.065	2.200	3.200
		High	10.142	−4.484	−30.658	10.324	−6.374	−38.172	9.711	−6.176	−38.875	2.200	3.200
	Evening	Low	12.616	−3.700	−22.677	12.798	−5.590	−30.400	12.185	−5.392	−30.676	2.200	3.200
		Med.	11.856	−3.972	−25.095	12.038	−5.862	−32.749	11.425	−5.664	−33.144	2.200	3.200
		High	12.161	−2.738	−18.377	12.343	−4.628	−27.270	11.730	−4.430	−27.413	2.200	3.200
	Average		12.125	−5.028	−28.625	12.307	−6.918	−35.511	11.694	−6.720	−35.985	-	-

Table 7. Distance Range 2: estimated speed difference (km/h, %) and estimated speed in the after condition (km/h) for each combination of the factors included in the ANOVA model (WP = week period, DP = day period, and HAT = hourly average traffic). For each combination of factors, the cushion length corresponding to the highest and lowest speed reduction is reported.

WP	DP	HAT	Via Calefati (L = 3.20 m)			Via Nicolai (L = 2.70 m)			Via Putignani (L = 2.20 m)			Length: Highest Reduction	Length: Lowest Reduction
			V after	DV	DV (%)	V after	DV	DV (%)	V after	DV	DV (%)		
Weekday	Morning	Low	13.934	−8.748	−38.568	14.948	−9.526	−38.923	14.228	−9.716	−40.578	2.2	3.2
		Med.	13.287	−8.456	−38.891	14.301	−9.234	−39.235	13.581	−9.424	−40.965	2.2	3.2
		High	13.390	−8.152	−37.842	14.404	−8.930	−38.270	13.684	−9.120	−39.993	2.2	3.2
	Afternoon	Low	12.794	−5.908	−31.590	13.808	−6.686	−32.624	13.088	−6.876	−34.442	2.2	3.2
		Med.	12.147	−5.616	−31.616	13.161	−6.394	−32.698	12.441	−6.584	−34.607	2.2	3.2
		High	12.250	−5.312	−30.247	13.264	−6.090	−31.466	12.544	−6.280	−33.362	2.2	3.2
	Evening	Low	14.555	−3.266	−18.327	15.569	−4.044	−20.619	14.849	−4.234	−22.187	2.2	3.2
		Med.	13.908	−2.974	−17.616	14.922	−3.752	−20.092	14.202	−3.942	−21.726	2.2	3.2
		High	14.011	−2.670	−16.006	15.025	−3.448	−18.665	14.305	−3.638	−20.275	2.2	3.2

Table 7. *Cont.*

WP	DP	HAT	Via Calefati (L = 3.20 m)			Via Nicolai (L = 2.70 m)			Via Putignani (L = 2.20 m)			Length: Highest Reduction	Length: Lowest Reduction
			V after	DV	DV (%)	V after	DV	DV (%)	V after	DV	DV (%)		
Saturday	Morning	Low	13.108	−8.976	−40.645	14.122	−9.754	−40.853	13.402	−9.944	−42.594	2.2	3.2
		Med.	12.461	−8.684	−41.069	13.475	−9.462	−41.252	12.755	−9.652	−43.076	2.2	3.2
		High	12.564	−8.380	−40.011	13.578	−9.158	−40.280	12.858	−9.348	−42.097	2.2	3.2
	Afternoon	Low	11.968	−6.136	−33.893	12.982	−6.914	−34.751	12.262	−7.104	−36.683	2.2	3.2
		Med.	11.321	−5.844	−34.046	12.335	−6.622	−34.932	11.615	−6.812	−36.967	2.2	3.2
		High	11.424	−5.540	−32.657	12.438	−6.318	−33.685	11.718	−6.508	−35.707	2.2	3.2
	Evening	Low	13.729	−3.494	−20.287	14.743	−4.272	−22.466	14.023	−4.462	−24.138	2.2	3.2
		Med.	13.082	−3.202	−19.663	14.096	−3.980	−22.018	13.376	−4.170	−23.766	2.2	3.2
		High	13.185	−2.898	−18.019	14.199	−3.676	−20.565	13.479	−3.866	−22.289	2.2	3.2
Sunday	Morning	Low	12.609	−8.586	−40.510	13.623	−9.364	−40.736	12.903	−9.554	−42.544	2.2	3.2
		Med.	11.962	−8.294	−40.946	12.976	−9.072	−41.147	12.256	−9.262	−43.043	2.2	3.2
		High	12.065	−7.990	−39.840	13.079	−8.768	−40.134	12.359	−8.958	−42.023	2.2	3.2
	Afternoon	Low	11.469	−5.746	−33.378	12.483	−6.524	−34.324	11.763	−6.714	−36.337	2.2	3.2
		Med.	10.822	−5.454	−33.509	11.836	−6.232	−34.492	11.116	−6.422	−36.618	2.2	3.2
		High	10.925	−5.150	−32.037	11.939	−5.928	−33.178	11.219	−6.118	−35.289	2.2	3.2
	Evening	Low	13.230	−3.104	−19.003	14.244	−3.882	−21.417	13.524	−4.072	−23.142	2.2	3.2
		Med.	12.583	−2.812	−18.266	13.597	−3.590	−20.888	12.877	−3.780	−22.693	2.2	3.2
		High	12.686	−2.508	−16.507	13.700	−3.286	−19.345	12.980	−3.476	−21.123	2.2	3.2
	Average		12.647	−5.700	−30.185	13.661	−6.478	−31.447	12.941	−6.668	−33.269	-	-

The above-reported tables show that the minimum estimated speed difference is always related to the longest speed cushion (Via Calefati, L = 3.20 m). The maximum estimated speed difference is almost always related to the shortest speed cushion (Via Putignani, L = 2.20 m), except for 2 specific conditions, in which it is related to the medium cushion (Via Nicolai, L = 2.70 m): weekday and Saturday evenings with high traffic. Hence, on average, it is possible to argue that the longer the cushion is in the considered range (2.20 m–3.20 m), the less the percentage speed reduction is in all conditions. However, while it is not possible to provide a reliable indication of the functional form of the relationship between the speed difference and the cushion length, some interesting remarks can be made.

For distance range 1 (after the cushion), the longest cushion is related to the lowest percentage speed reduction. However, while the shortest cushion is related on average to the greatest percentage speed reduction, percentage speed reductions are almost equal between the shortest and the average cushion. Hence, the relationship between the percentage speed difference and cushion length does not seem linear. On the other hand, for distance range 2 (before and on the cushion), there is a more evident gradation of percentage speed differences with the cushion length, even if, on average, the percentage speed differences of the three cushions are more similar than in the case of distance range 1. However, it is also important to note that, regardless of the cushion length, the estimated average speed after the condition is similar for all the cushions, on average: about 13 km/h before the cushion and about 12 km/h after the cushion. Even if the combination of factors leading to the highest speed is considered (weekday–evening–low traffic), the estimated average speed is about 15 km/h before and 14 km/h after the cushion, which is a satisfactory result in the proximity of a pedestrian area.

5. Discussion

In this section, the obtained results are discussed in light of previous research on the topic and considering the objectives of this study.

This study first aimed to assess the effects of BSCs on driving speed in the urban environment. A speed-decreasing tendency was actually found in this study: estimated between 5 and 7 km/h, down to about 12–13 km/h depending on the study site and the point considered, that is, before or after the cushion (Tables 5 and 6). The average speed difference is coherent with the previous research about speed cushions: 10 km/h reduction in [45], operative speeds (which are significantly higher than average speeds) down to 27–35 km/h in [52]. As shown in the literature review section, very few studies have been dedicated to speed cushions, thus it is also possible to consider results related to other similar vertical TCDs, such as [26], in which speed humps, cushions, and raised intersections are studied. A reduction of 9 mph (about 14 km/h) was found in this study after the implementation of a 20 mph speed zone provided with TCDs.

The second objective of this study was to assess the influence of other context variables on the speed differences after the implementation of BSCs. This analysis was also disaggregated by distance ranges with respect to the BSC. This approach is a particular contribution of this article since previous research on BSCs was not detailed at this level. From this perspective, the major findings of this study are:

- Speeds are evidently affected by the BSC in the distance range immediately before and after the cushion. The effect starts to become insignificant at more than around 10 m from the cushion;
- The day period significantly influences the effect of BSC on speed: the speed-decreasing tendency is much more evident in the morning than in the evening (see Figure 4, the morning DV is double that of the evening period in the first two distance ranges);
- The cushion length has some influence on the speed decrease (the longer the cushion is, the lower the DV), even if speed differences between test road sites are not as evident as those related to different day periods;
- The influence of traffic is marginal, while the type of day (weekday, Saturday, or Sunday) is practically uninfluential.

These highlighted findings can be useful for highway practitioners/managers, especially when deciding where to place cushions, given the demonstrated distance range of effectiveness in reducing speeds before approaching a pedestrian area. The other important practical finding is that BSCs may be coupled with other signals (eventually provided with lights) to increase their effectiveness in the evening periods.

These findings are also coherent with visual inspections performed during the experiment showing that most vehicles drove over the cushion appropriately. However, during the time slot when there was no significant pedestrian traffic, and the vehicles were almost absent (at around 10 p.m.), drivers tended to speed up, not considering the device. As far as motorcycles and mopes are concerned (while very few cyclists were noticed), they were not affected by the presence of the cushion except when cars were in a queue before the device, and so they had to avoid stationary cars.

The third objective was particularly related to the influence of the cushion length, given that 3 different lengths were used at the 3 test road sites (2.20 m, 2.70 m, and 3.20 m). As previously explained, an inverse cushion length–DV relationship was argued, especially in the space before the cushion (distance range 2), even if the effect of length is weaker than the day period factor. The relationship between speed decrease and the BSC length is in contrast with previous research [53]. On the other hand, Layfield and Parry [52] developed a formulation that linked the cushion dimensions and the speed before the installation of a cushion to determine the speed after the installation. By applying this formula to the investigated case, reductions in the recorded and calculated average speeds could be achieved only for very short cushions (shorter than 1.20 m), and speeds might increase by increasing the cushion length after the cushion installation. Moreover, Refs. [24,45] highlighted that, among all TCDs like speed humps and cushions, the shortest ones are the most effective in terms of speed reduction (i.e., speed humps are more effective than long speed cushions). This could be explained by driver perception. In fact, when the cushion is longer, its impact on the vehicle could be perceived by the driver as less dangerous in terms of the grounding phenomenon or damage to the vehicle suspension than a shorter cushion. However, given the different results in previous research, this aspect should be further investigated.

6. Conclusions

This study focuses on the effects of Berlin speed cushion on driving speeds considering the influence of other context variables: a period of the day, day of the week, hourly average traffic volume, and the cushion length. Currently, speed cushions are not regulated by Italian standards, but given their importance for both speed and crash reductions, the Ministry of Transport allowed real-world tests of such devices to investigate their benefits. Under this light, the speed cushions were installed in three sites of the City of Bari, upon permission from the M.I.T., respecting all the necessary boundary conditions (the presence of 30 Zones, the absence of parking lots). The tests were run in two phases to make before–after assessments, recording the average traffic and the average speeds for each site. All the recorded data were analyzed using statistical analysis (ANOVA) and were aggregated by type of day (weekday/workday), site, time of the day (morning, evening, and night), and traffic volume ranges.

The speed reduction achieved by implementing the speed cushions was around 30%, on average, at distances immediately before and after the cushion. The effect starts to become insignificant at more than around 10 m from the cushion, and the speed-decreasing tendency is much more evident in the morning than in the evening period. Furthermore, the cushion length has some influence on the speed decrease (the longer the cushion is, the lower the DV). The first aim of this study is to support the legislative regulation of BSCs. In addition, it suggests placing them 5–10 m from pedestrian areas (or pedestrian crossings) and preferring a cushion length included between 2.20 m and 2.70 m rather than longer. To improve their effects during the hours of darkness, other measures may be coupled with BSCs, such as lighting, signs and markers.

7. Limitations and Recommendations

Despite this article presenting some crucial novelties in the context of Berlin speed cushions and their applicability and influencing variables in the urban environment by means of a statistical approach, some limitations could be overcome in further studies. One of those is represented by the investigation of crash patterns and driving violations before and after the implementation of speed cushions, as well as the possible increase in the livability of the interested pedestrian area through a scientific approach. Moreover, as suggested by [65], it should be possible to correlate crashes to the specific area of investigation since each urban area can show different relationships between explanatory variables and crash frequency [66].

These points will be investigated in further studies when more data is available for the tested roads and at least 3 years of crash data. When these data are available, a possible familiarity effect by regular users [59], which could negate the positive effects of BSCs on speed and safety, should also be investigated.

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