The implications of situation and route familiarity for driver-pedestrian interaction at uncontrolled mid-block crosswalks

# THE IMPLICATIONS OF SITUATION AND ROUTE FAMILIARITY FOR DRIVER-PEDESTRIAN INTERACTION AT UNCONTROLLED MID-BLOCK CROSSWALKS

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**Abstract**

Most routine daily trips take place along the same route, a fact that previous studies have not investigated together with the repeated situation of conflicting with other road users. Consequently, our study addresses driver behaviour by separating the driving experience into three categories: (i) drivers unfamiliar with the route, (ii) those route-familiar, and (iii) situation-familiar drivers. The specific case of driver-pedestrian interaction at uncontrolled mid-block crosswalks is investigated. A multi-level factorial experiment including (i) crosswalk design (linear sidewalk and curb extension), (ii) driver familiarity, and (iii) pedestrian time gap acceptance (4, 6, and 8 s) was conducted using a driving simulator. Fifty-two participants were divided into four groups and stratified by age, gender, and driving experience. The minimum instantaneous time to collision, post-encroachment time, maximum car deceleration, and maximum car speed were all used as surrogate safety measures (SSM).

Route-familiarity led to higher speed, while situation-familiarity positively affected driving behaviour making drivers more inclined to decrease their speed at circa 100 m before a crosswalk. The curb extension layout enhanced pedestrian safety and mitigated any adverse effects due to familiarity, with a particularly relevant impact on SSM at low accepted time gaps for pedestrians. Situation- and route-familiarity treatment protocols lead to different behaviours among drivers, indicating a clear need to account for these two familiarity levels in experiments on safety-related countermeasures.

**Keywords**: driving familiarity; surrogate safety measures; road safety countermeasure; unsignalized crosswalks; driving simulation.

## 1. INTRODUCTION

The term familiarity refers to the attitude that an individual adopts after repeated exposure to a relationship, a place, or a situation. This repeated exposure stimulates both learning and satiation leading to a behavioural adaptation (Zajonc, 1968; Montoya *et al.*, 2017). Since most drivers use the same route(s) every day, route familiarity has been assumed as a factor in many road safety studies (Harms *et al.*, 2021).

Route familiarity has been investigated using two main methods which are both consistent with the concept of repeated exposure (Intini *et al.*, 2019): (i) distance-, and (ii) frequency-based. In the first case, drivers are familiar with a route whenever their residence is in the same country or environment (Donaldson *et al.*, 2006). In the second, the driver becomes familiar with a route by driving several times on it (Yanko and Spalek, 2013; Colonna *et al.*, 2016). In these studies, familiarity is achieved when drivers get to know the environmental features of the road, *i.e.*, alignment, cross-section, road signs, and it also depends on driver interaction with other users along the same route.

Route familiarity may be a source of crash risk when drivers adopt negative behaviours such as reduced attention and inattention caused by an increased "mind-wandering" effect (Harms *et al.*, 2021; Martens and Fox, 2007). Burdett *et al.* (2017) investigated the effects of being "close to home" on driver behaviour, and discovered that drivers were more likely to crash along familiar roads due to loss of attention and alcohol abuse (drivers who have drunk alcohol are less likely to drive the further they are away from home, and thus in relatively unfamiliar surroundings). Furthermore, Wu and Xu (2018) pointed out that route-familiar drivers adopt higher speeds than unfamiliar drivers do.

These behaviours can have extremely harmful consequences for other road users moving within the same environment, like pedestrians who are more unsafe when interacting with drivers that are unaware of or fail to pay sufficient heed to their presence (Kadali and Vedagiri, 2016). The Italian ACI-ISTAT (2019) dataset revealed that pedestrians have the highest fatality rate among vulnerable road users (*i.e.*, VRUs), with 2.7 deaths in every 100 collisions. It should be borne in mind that any risk to pedestrians is determined by a combination of driver and pedestrian behaviours and infrastructure configuration (Sisiopiku *et al.*, 2003; Foster *et al.*, 2014). Furthermore, the behaviour of drivers approaching a crosswalk depends on the presence of pedestrians (Varhelyi, 1998; Yannis *et al.*, 2013) and/or regulations (*e.g.*, in Germany and Italy car drivers must yield to pedestrians, while in Austria drivers do not need to yield). The above scenarios can result in three possible behaviours: (i) the driver slows down to give priority to the pedestrian(s) (*i.e.*, the anticipatory avoidance response), (ii) the driver maintains the speed with no apparent intention of yielding (*i.e.*, the non-avoidance response) (Fuller, 1984), (iii) the driver fails to give right of way to the pedestrian with the result that either the pedestrian has to stop and/or take a step back or the driver performs an emergency braking manoeuvre to try to avoid a collision.

Drivers learn from repeated exposure to these conflict situations and adapt their behaviour accordingly (Elvik, 2015). It is worth noting that if repeated exposure to a conflict situation leads to a reduction in the level of uncertainty experienced (Montoya *et al.*, 2017) and the probability of an accident (Elvik, 2015), this new-found route familiarity causes drivers to shift their attention to the off-road areas in their immediate surroundings (Young *et al.*, 2018) and induces hazardous overconfidence and risk underestimation (Rosenbloom *et al.*, 2007). However, the degree to which route familiarity is influenced by repeated exposure to a specific conflict situation is not yet known.

As far as the different crosswalk layouts are concerned, many driver-pedestrian (DP) accidents occur at uncontrolled mid-block crosswalks rather than at signalised intersections (Diogenes and Lindau, 2010; Rothman *et al.*, 2012; Kumfer *et al.*, 2019). Empirical and experimental evidence indicates that a curb extension at these crosswalks provides superior protection since pedestrians are more visible to drivers and vice versa (Bella and Silvestri, 2016; Schneider *et al.*, 2018). As a result, an increment in the number of drivers yielding to pedestrians (Johnson, 2005), and a significant reduction in operational vehicle speeds (Replogle, 1992) were observed. DP conflicts are also influenced by the risk acceptance of pedestrians. Temporal gaps accepted by pedestrians before crossing (*i.e.*, the pedestrian time gap acceptance) were found to be in the 4.1 to 9.4 s range (Pawar and Patil, 2015; Brewer *et al.*, 2006). However, the safety implications of driver familiarity in DP interactions at uncontrolled crosswalks have yet to be considered.

Based on the literature review, the behavioural responses of route-familiar drivers repeatedly exposed to conflicts with other road users, indicated here as “situation familiarity”, and the more basic familiarity with the actual road, indicated here as “route familiarity”, still need to be assessed. Furthermore, we sought to establish whether a different pedestrian crossing design would influence the driving behaviour of (i) those who did not know the road, (ii) those who knew the road, and (iii) those who, in addition to knowing the road, adapted their behaviour following repeated conflict with pedestrians.

Therefore, in this driving simulation experiment we included (i) unfamiliar, (ii) route-familiar, (iii) and situation-familiar protocols. The experiment was carried out under the main hypothesis that situation-familiar and “pure” route-familiar drivers behave differently, so different patterns of yielding behaviour may be observed under different familiarity protocols. Surrogate safety measures (SSM) were used to evaluate the time crash proximity of DP interactions under different time gaps accepted by pedestrians.

## 2. METHODS

### 2.1 Participants

Fifty-two volunteers (age range 23-60, 16 females) took part in this study. They were stratified by age (*M* = 36, *SD* = 11), gender, and driving experience in terms of years (*M* = 18, *SD* = 10) and km/years (*M* = 12000, *SD* = 9575) into four groups. The participants were contacted by email and phone, and the study was conducted in conformity with the Italian anti-Covid19 rules and the Code of Ethics of the World Medical Association (World Medical Association, 2018). All participants signed an informed consent form before starting the experimental activity.

## 2.2 Driving simulator

The experiment was carried out using the fixed-base driving simulator (AV Simulation, France) of the Road Safety and Driving Simulation (RSDS) laboratory at the Politecnico di Torino (Italy). The simulator was equipped with a force-feedback steering wheel, six-speed manual gearbox, pedals, dashboard, and an adjustable seat with seatbelt. The road environment was displayed on three 32” full HD screens with 1920 x 1080-pixel resolution and a 130° horizontal field of view. Figure 1 shows an example from the participant’s point of view. The cockpit of a small family car was virtually reproduced to provide an authentic sense of vehicle lane occupancy. A surrounding sound system (*Dolby Surround 5.1*) reproduced car engine and environmental noises. SCANeR™Studio 1.9 (https://www.avsimulation.com/scanerstudio/) was used to model the road scenarios, run the simulations, and collect data. The data acquisition frequency was set to 100 Hz. This simulator achieved a relative behavioural validation for longitudinal (Bassani *et al.*, 2018), lateral (Catani and Bassani, 2019), and passing behaviour (Karimi *et al.*, 2020). A relative behavioural validation is a requisite for transferring simulation outcomes to reality (Törnros, 1998).

## 2.3 Road scenarios

A rectangular-shaped urban block of about 2 km in length was designed to include six mid-block pedestrian crosswalks. The uncontrolled mid-block crosswalks were located at a distance of at least 200 m from each other, a line of traffic was created in the opposite lane, and pedestrians were featured moving along sidewalks (Figure 1). The posted speed limit was set to 50 km/h, and there were no vehicles in the ego-vehicle lane. Parking areas, horizontal markings, and vertical signs (stop signs, posted speed limits, and crosswalk signals) reflected current Italian standards (MIT, 1992; MIT, 2001).

**Figure 1. Three screen view of the road scenario. The picture shows the case of the curb extension layout.**

## 2.4 Design of the experiment

A multi-level factorial experiment including (i) crosswalk layouts, (ii) driver familiarity with route and DP interaction (*i.e.,* situation), and (iii) pedestrian time gap acceptance values as experimental variables was conducted. Two uncontrolled mid-block pedestrian crossing configurations were investigated: (i) the linear sidewalk (baseline), and (ii) the curb extension. Experimental factors are discussed in detail in Section 2.5.

The two "familiarity" (route and situation) levels were assumed as between-subject factors, while the "unfamiliarity" condition was a within-subject factor in the two groups dealing with situation familiarity. Thus, this procedure resulted in a nested type of training being an integral part of the design of this experiment. We adopted this design so as to have the same number of observations for each familiarity condition (*i.e.*, unfamiliar, route-, situation-familiar). Pedestrian time gap acceptance (PTGA) was a within-subject factor, *i.e.*, all participants experienced a range of values in their assigned scenario. Finally, mid-block layout was a between-subject factor. Figure 2 depicts the experimental design and highlights the differences among the groups of participants.

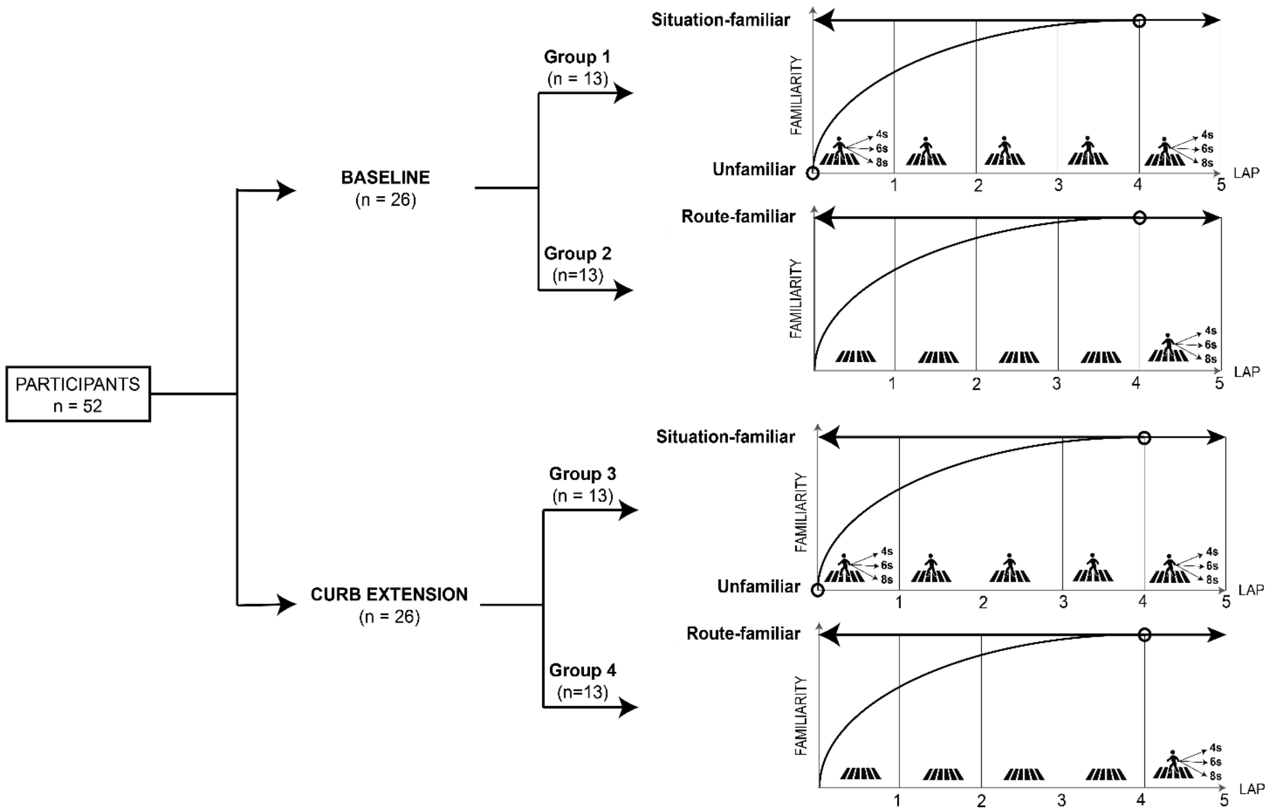



**Figure 2. Design of the experiment. The figure shows how the participants were divided into four groups. Experimental factors (mid-block layout, familiarity, PTGA) are represented. We depict the qualitative assumed learning curve for familiarity conditions.**

### 2.5 Experimental factors

#### 2.5.1 Driver familiarity

Unfamiliar, route-familiar, and situation-familiar were the three participant categories in the experiment (Figure 2). Route and situation familiarity were achieved as per the frequency-based training approach (Yanko and Spalek, 2013). Participants drove five times around the urban block to complete both familiarity protocols. The unfamiliar condition was investigated on the first lap, while the route and situation familiarity were investigated on the fifth lap. Route familiarity was achieved in about 9 min, while situation familiarity required about 12 min due to multiple DP interactions. In the route familiarity protocol, the only DP interaction occurred on the last (fifth) lap. Situation familiarity was accomplished by including three DP interactions on each of the six crosswalks encountered on every lap. On the second, third, and fourth laps, pedestrians crossed from left to right and vice versa, singly or in pairs, and at different, randomly-assigned speeds to avoid becoming overly familiar with any systematic scheme. On these laps, we did not collect any data.

### 2.5.2 Mid-block crosswalk layouts

We investigated linear sidewalk (baseline) and curb extension layouts (Figure 3). The first is the most common crosswalk configuration in Italy and, indeed, in many other countries; the second was introduced more recently to several urban roads. The geometry adopted for the curb-extension layout is trapezoidal in shape, which improves the reciprocal visibility for both the pedestrian and the driver. A 2 m wide sidewalk, 2.2 m of curb extension, and 12 m of crossing area were adopted in compliance with the *Automobile Club d'Italia* (2011) guidelines. Poles of 0.9 m in height were placed at the edge of the curb extended pedestrian area.

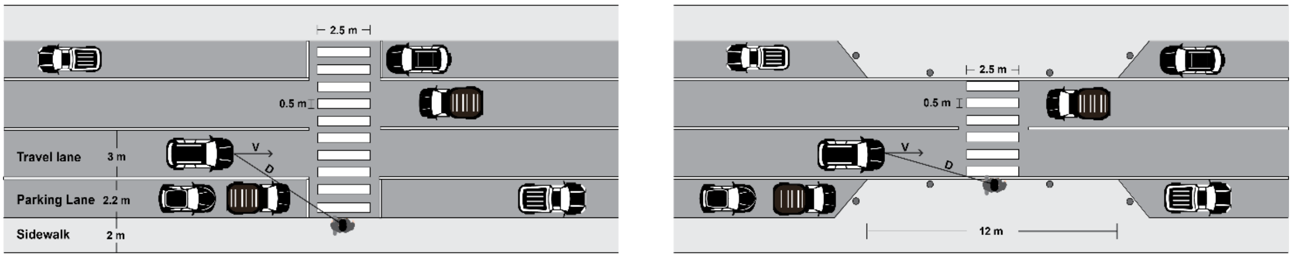



**Figure 3. Investigated uncontrolled mid-block crosswalk layouts: (a) linear curb (baseline), (b) curb extension. V is the actual vehicle speed, D is the distance between the pedestrian and vehicle bumper.**

### 2.5.3 Pedestrian time gap acceptance

The pedestrian crossing events were intended to analyse driver behaviour at times of potential conflict. The investigated DP interactions involved the pedestrian coming from the right side only, which is the more hazardous situation because of (i) the shorter arrival time to the potential conflict zone and (ii) the obstructed visibility due to the presence of parked cars before the crosswalk (Figure 1 and Figure 3). Pedestrian time gap acceptance (PTGA) values of 4, 6, and 8 s were adopted to investigate a wide spectrum of possible pedestrian behaviour impacting driver response (Pawar and Patil, 2015). Drivers experienced the three acceptance gaps on the first and last laps. To avoid any 'order' effect, each road scenario was provided with two different crossing event sequences (Bella and Silvestri, 2015; Wu *et al.*, 2018). Pedestrian speed was set at 1.1 m/s following the Manual on Uniform Traffic Control Devices (Federal Highway Administration, 2009). We calculated the PTGA by dividing the actual speed of the vehicle by the distance between the pedestrian and the vehicle bumper (PTGA = V/D) as specified in Figure 3. In the experiment, the pedestrian started to cross the road when the PTGA value reached the pre-determined value of 4, 6, or 8 s.

## 2.6 Procedure

Participants were instructed on the use of the driving simulator and their driving tasks, and they were requested to respect the rules of the road to the best of their ability throughout the duration (∼ 20 min) of the driving task.

First, the participants received a brief training (5 min) session with the driving simulator apparatus. The participant was invited to sit in the simulator, and the experimenter explained how to use it correctly (turning on the engine, using the pedals, the indicators, and the steering wheel). If needed, the experimenter intervened to assist the participant and provided any necessary further information. If participants did not experience any negative reactions (*e.g.*, simulation sickness), they were asked to start the testing phase in which they drove 5 laps on a randomly assigned scenario. Each scenario included six identical, uncontrolled mid-block pedestrian crossings so that each driver approached a total of 30 crosswalks during the test.

We did not interact directly with the drivers during the test. Directional signs (arrows) displayed on the three screens provided drivers with visual instructions while a message prompting them to park the car on the right was displayed at the end of the experiment. Finally, participants were asked to fill out a motion sickness questionnaire.

## 2.7 Data collection and dependent variables

We investigated DP conflicts by looking at both collision proximity and intensity of the evasive manoeuvre outcomes (Hayward, 1971; Saulino *et al.*, 2014; Tarko, 2020). Hence, (i) the minimum instantaneous time-to-collision (MTTC), (ii) the post-encroachment time (PET), (iii) the maximum deceleration rate (MaxD), and (iv) the maximum speed in the 100 m preceding the point of conflict (MaxS) were considered. Figure 4 provides examples of diagrams derived from the data extracted, which depict the behavioural driver response when approaching and moving away from the crosswalk.

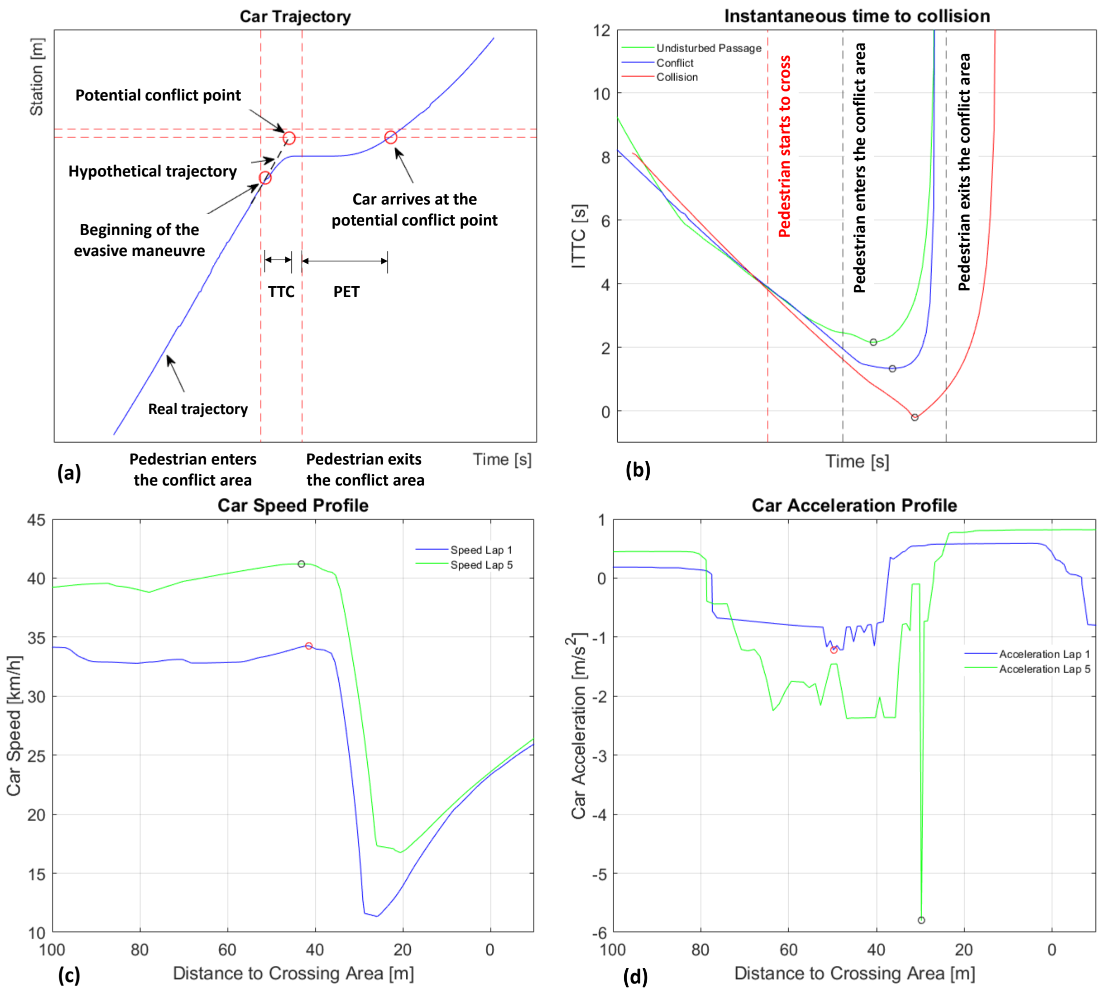


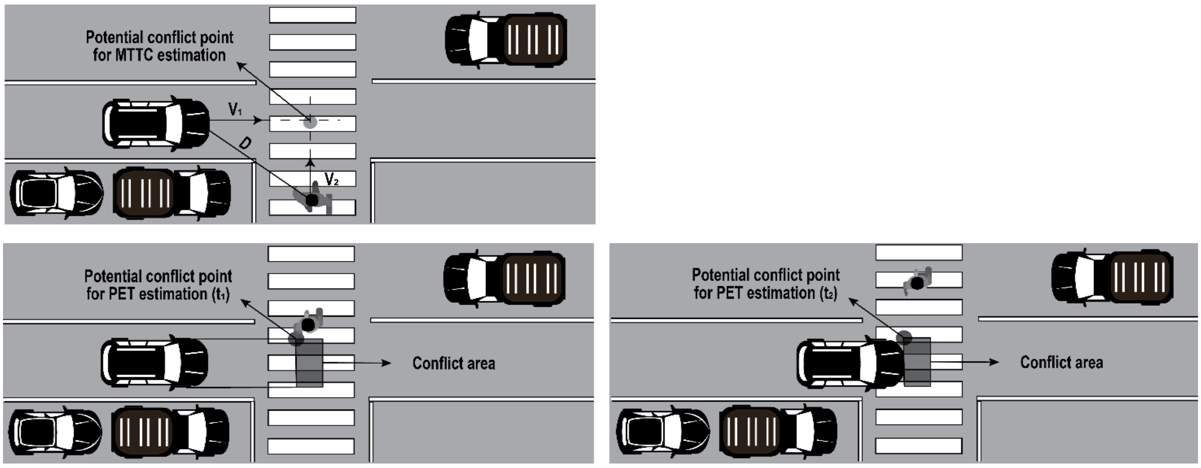

**Figure 4. (a) Example of spatial-temporal diagram with indication of TTC and PET. (b) Representation of three MTTC profiles corresponding to undisturbed passage, DP conflict and collision. (c) Examples of speed profiles to identify the MaxS in the 1st and 5th lap. (d) Examples of deceleration profiles to identify the MaxD in the 1st and 5th lap.**

### 2.7.1 Minimum instantaneous time to collision

Figure 4a shows the typical time-distance trajectory of a vehicle approaching a crosswalk (Saulino *et al.*, 2014). In this study, the instantaneous value of the time to collision (ITTC) was computed according to:

$$\textbf{ITTC (t) = D/}||\Delta \textbf{V}||$$

where D is the instantaneous distance between the potential collision elements (*i.e.*, the car bumper and the pedestrian), and $||\Delta V||$ is a module of the actual relative speed difference of the road users (Tarko, 2020) (see Figure 5a). Figure 4b shows the evolution of ITTC for undisturbed, conflict, and collision events; the graph evidences the minimum values (MTTC) for three different driver responses assuming the same pedestrian time gap acceptance of 4 s. The MTTC was originally proposed as an SSM for traffic events by Hayward (1971). A low MTTC value corresponds to a high probability of a collision between road users. Furthermore, the traffic events were classified according to the critical thresholds indicated in Pu *et al.* (2008): (i) undisturbed passage for MTTC ≥ 1.5 s, (ii) conflict for 1.5 > MTTC > 0 s, (iii) crash when MTTC = 0 s.




(a)

(b)

**Figure 5. Outline of the (a) ITTC and (b) PET computations ($t_1$=time at which the first user leaves the conflict point, $t_2$=time at which the second user arrives at the same point).**

### 2.7.2 Post-encroachment time

PET measures the crash nearness and is calculated post-event as follows:

$$\mathbf{PET = t_2 - t_1}$$

where $t_2$ is the arrival time of the second user at the conflict point, and $t_1$ the time at which the first road user left the conflict point (Figure 5b). It has already been considered in the literature for both vehicle-to-vehicle and DP interactions (Saulino *et al.*, 2014; Wang *et al.*, 2019). Three categories for PET were identified according to (Pu *et al.*, 2008): (i) undisturbed passage for PET ≥ 5 s, (ii) conflict for 5 > PET > 0 s, and (iii) crash when PET = 0 s.

### 2.7.3 Maximum Speed and Max Deceleration

MaxS and MaxD are normally used to evaluate conflict severity. The first is the maximum speed reached during the event (Figure 4c). The second is the maximum deceleration rate of the vehicle (Figure 4d) observed (Gettman *et al.*, 2008). Both were detected from the data for car speed/acceleration profiles in the 100 m leading up to the crosswalk.

### 2.8 Data analysis

Descriptive statistics, and the calibration of linear mixed-effects models (LMEM) were used for data analysis. Mixed models fit well within the framework of the experimental design (between- and within-subject factors). LMEM can predict the degree to which the experimental outputs depend on independent variables, *i.e.* factors, covariates, and clustered variables (West *et al.*, 2006).

Hence, LMEM also include random effects (RE) to account for heterogeneity (e.g., different driving styles of participants) in the dataset. When RE are considered, the effects identified in the model are true effects of the independent variables, so the coefficients of independent variables do not reflect unobserved differences between drivers. LMEM are an extension of the typical linear models (*e.g.*, linear regression or fixed-effects ANOVA) and were adopted here because of the multi-level design of this experiment. An LMEM for each of the four observed SSM variables was fitted and calibrated with the restricted-maximum likelihood (REML) approach. In the fitting process, the backward elimination technique was adopted. The initial model featured all the predictors, then step by step we removed those predictors that allowed the greatest reduction in the Bayesian Information Criterion (BIC), thus the number of independent factors and variables was reduced to obtain parsimonious models (Lindsey and Sheather, 2010). Jamovi (ver. 1.8.1.0) was used with the submodules GAMLj ver. 2.4.7 and Scatr ver. 1.2.0 (Jamovi Project, 2021). The general formulation for LMEM is:

$$\mathbf{y} = \mathbf{Xb} + \mathbf{Zu} + \mathbf{e}$$

where **y** is the observed SSM measure, **b** is the unknown fixed coefficients vector, **u** is the unknown and normally distributed with null mean random coefficients vector, **e** is the vector of normally distributed with zero mean residuals, and finally **X**, and **Z** are the independent factor vectors for fixed and random effects respectively. Familiarity, the presence of a mid-block crosswalk, PTGA, and driver gender were considered fixed factors. Driver age, driver experience in km/y and number of years with a driving licence were included as covariates, as these had been found to be significant in previous driving simulation investigations (Karimi *et al.*, 2021) as well as in previous investigations into DP interaction (Schneider *et al.*, 2018). The test driver ID was assumed as a RE (*i.e.*, a cluster variable in the models) to account for the subjective driving style of the participants involved (Portera and Bassani, 2021). A significance level (α) equal to .05 was assumed in the analyses. To assess the goodness of fit, both marginal and conditional $R^2$ factors were considered.

## 3. RESULTS

### 3.1 Descriptive statistics

Mean and standard deviation values for the four SSM are given in Table 1. MaxS values for route-familiar drivers and the baseline crosswalk layout were well above the posted speed limit (*i.e.*, 50 km/h). Lower MaxS values were found for the curb extension and route-familiar condition. Furthermore, the mean MaxS values for situation-familiar drivers exceeded the posted speed limit in the baseline configuration, while they were below it for the curb extension layout.

MTTC and PET values are lower for route-familiar drivers than other treatment protocols independently of the crosswalk layout and the PTGA. Considering a PTGA of 4 s and drivers in unfamiliar conditions, there is an even larger gap between the mean drivers' response observed in the two crosswalk layouts. The average MTTC values relating to situation-familiar drivers are all above the threshold identifying a safer conflict event (*i.e.*, larger than 1.5 s).

**Table 1. Mean (standard deviation) of the SSM observations**

| SSM | PTGA | Baseline | | | Curb Extension | | |
|---|---|---|---|---|---|---|---|
| | | Unfamiliar | Route | Situation | Unfamiliar | Route | Situation |
| MTTC [s] | 4 s | 1.23 (1.06) | 1.04 (1.08) | 2.08 (0.75) | 2.28 (0.80) | 1.77 (0.94) | 2.85 (0.92) |
| | 6 s | 3.61 (0.76) | 3.12 (0.87) | 3.48 (0.65) | 3.75 (0.69) | 3.37 (0.84) | 3.42 (0.82) |
| | 8 s | 4.16 (0.54) | 3.78 (0.63) | 4.37 (0.76) | 4.77 (1.11) | 4.31 (0.58) | 4.27 (0.74) |
| PET [s] | 4 s | 4.05 (2.58) | 2.66 (2.02) | 3.61 (1.75) | 4.82 (1.28) | 4.25 (2.12) | 3.62 (0.79) |
| | 6 s | 4.54 (0.70) | 4.26 (1.40) | 3.72 (0.58) | 4.38 (1.06) | 4.23 (0.90) | 3.74 (0.89) |
| | 8 s | 6.00 (1.39) | 4.7 (1.39) | 5.37 (1.19) | 5.26 (1.02) | 5.16 (1.22) | 5.18 (1.08) |
| MaxS [km/h] | 4 s | 50.40 (9.68) | 57.00 (9.88) | 52.10 (6.90) | 42.10 (9.76) | 53.50 (10.88) | 49.20 (6.58) |
| | 6 s | 50.10 (8.57) | 54.90 (12.23) | 51.20 (7.79) | 40.70 (7.55) | 48.10 (10.73) | 46.70 (6.78) |
| | 8 s | 51.50 (5.83) | 57.30 (11.97) | 54.10 (5.24) | 42.50 (8.50) | 49.80 (8.29) | 47.40 (7.09) |
| MaxD [m/s$^2$] | 4 s | -6.30 (0.34) | -6.31 (0.69) | -6.28 (0.45) | -5.64 (1.55) | -5.79 (1.41) | -5.85 (0.86) |
| | 6 s | -5.52 (1.07) | -5.92 (0.83) | -4.98 (1.28) | -4.53 (1.87) | -5.41 (1.32) | -4.37 (2.16) |
| | 8 s | -4.66 (1.56) | -3.48 (2.42) | -4.22 (1.56) | -3.35 (1.85) | -3.91 (1.91) | -3.26 (2.23) |

### 3.2 Behavioural models

The outcomes of the LMEM analysis are shown in Table 2. They indicate that the three experimental factors were all found to be significant (except for the crosswalk type on PET) and the familiarity condition on MaxD. Two covariates considered in the analysis (driver experience in km/years and the number of years with a driving licence), were not significant, while a third – test driver age – had a significant effect on the MTTC: the older the driver, the higher the MTTC.

**Table 2. LMEM results and summary (ICC = Interclass Correlation Coefficient, AIC = Akaike Information Criterion, BIC = Bayesian Information Criterion, KS = Kolmogorov-Smirnov)**

| | | Estimated model coefficients (p-value) | | | |
|---|---|---|---|---|---|
| **Variables** | **Effects** | **MTTC** | **PET** | **MaxS** | **MaxD** |
| **Fixed effects (main factors):** | | | | | |
| Intercept | | 3.203 (<.001) | 4.418 (<.001) | 49.92 (<.001) | -4.987 (<.001) |
| Crosswalk | (Curb – Baseline) | .425 (.007) | – | -6.53 (.009) | .558 (.046) |
| Familiarity | (Route – Unfamiliar) | -.381 (.022) | -.630 (.026) | 7.236 (.003) | – |
| | (Situation – Route) | – | -.636 (.001) | – | – |
| | (Situation – Unfamiliar) | – | – | 3.888 (<.001) | – |
| PTGA | (6 s – 4 s) | 1.585 (<.001) | .310 (.114) | -2.098 (.005) | .907 (<.001) |
| | (8 s – 4 s) | 2.406 (<.001) | 1.445 (<.001) | – | 2.214 (<.001) |
| Test driver age | | .017 (.016) | – | – | – |
| **Fixed effects (interactions):** | | | | | |
| Crosswalk*PTGA | (Curb – Baseline)*(6 s – 4 s) | -.074 (<.001) | -.850 (.030) | – | – |
| | (Curb – Baseline)*(8 s – 4 s) | -.505 (.022) | -.949 (.016) | – | – |
| Familiarity*PTGA | (Situation – Unfamiliar)*(6 s – 4 s) | -.931 (<.001) | – | – | – |
| | (Situation – Unfamiliar)*(8 s – 4 s) | -.850 (.002) | – | – | – |
| Crosswalk*Familiarity | (Curb – Baseline)*(Situation – Unfamiliar) | – | – | 4.263 (.004) | – |
| **Random effects components:** | | | | | |
| Test driver ID, p-value | | (<.001) | (<.001) | (<.001) | (<.001) |
| Test driver ID, SD | | .428 | .711 | 7.976 | .737 |
| Residual, SD | | .628 | 1.216 | 4.560 | 1.331 |
| ICC | | .282 | .255 | .754 | .233 |
| **Summary statistics:** | | | | | |
| AIC | | 553.4 | 814.9 | 1523.3 | 849.3 |
| BIC | | 636.0 | 858.6 | 1538.1 | 875.8 |
| Log-likelihood | | -277.1 | -402.0 | -741.8 | -421.5 |
| $R^2$ marginal | | .649 | .214 | .200 | .282 |
| $R^2$ conditional | | .748 | .414 | .803 | .450 |
| Observations, No. of drivers (Observation/drivers) | | 234, 52 (4.5) | | | |
| KS test on residual (p-value) | | .982 | .583 | .617 | .282 |

The REs associated with each participant were significant. Marginal and conditional $R^2$ values were noticeably different in the MaxS model thus highlighting the significant impact of individual behaviour on the speed levels adopted when approaching crosswalks. The intraclass correlation coefficient (ICC) was found to be always greater than 0.1, thereby lending support to the decision to use a multi-level model for the collected data (Barlow *et al.*, 2019). Finally, Kolmogorov-Smirnov tests ($\alpha = .05$) indicated that the residuals were normally distributed.

### 3.2.1 Effects of familiarity

The results with the LMEM show that familiarity significantly affected MTTC ($p = .011$), PET ($p = .003$), and MaxS ($p < .001$). When drivers are familiar with the route, they generate lower MTTC values than those who are unfamiliar ($Z = .381$, $p_{Holm} = .043$) and those who are familiar with the situation ($Z = .491$, $p_{Holm} = .010$). Moreover, the interaction between familiarity and PTGA was significant ($p_{Holm} = .002$) for MTTC. A Holm post-hoc test showed that the situation-familiar condition leads to significantly higher MTTC values than both the route-familiar ($Z = 1.037$, $p_{Holm} < .001$) and unfamiliar ($Z = .704$, $p_{Holm} = .003$) conditions for a PTGA value of 4 s. Furthermore, we found a higher PET value with the unfamiliar condition ($Z = .636$, $p_{Holm} = .004$) than with the situation familiar condition.

A Holm post-hoc test showed that MaxS was significantly higher in the route- ($Z = 7.240$, $p_{Holm} = .006$) and situation-familiar ($Z = 3.890$, $p_{Holm} <.001$) configurations than in the unfamiliar condition. Moreover, unfamiliarity led to lower MaxS values than familiarity conditions for all PTGA values. That is, repeated exposure to DP interactions and/or the same road environment resulted in higher maximum speeds. Figure 6 shows that the MaxS adopted in a situation-familiar condition is clearly lower than in a route-familiar one.

The interaction between the familiarity condition and mid-block layout was significant ($p = .017$). A post-hoc test showed a significantly higher MaxS in the situation-familiar than in the unfamiliar condition ($Z = 6.020$, $p_{Holm} <.001$) with the curb-extension layout. Finally, the MaxD model was not significantly affected by the familiarity factor.

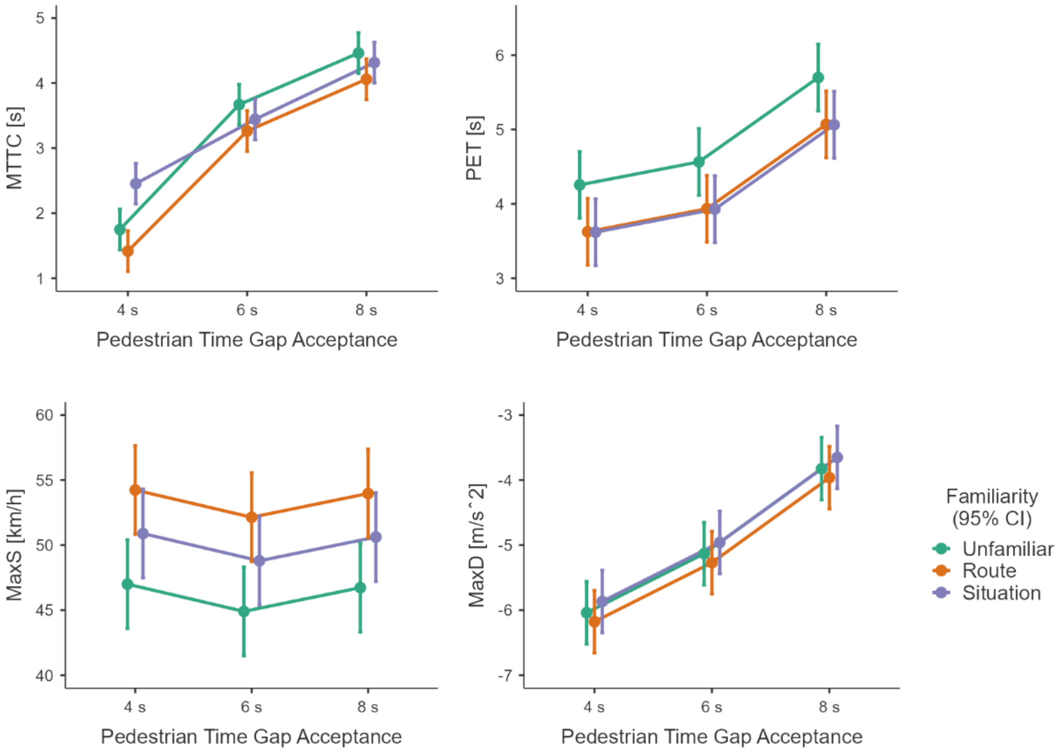



**Figure 6. Plots of the estimated marginal means for the four observed SSM as a function of the type of familiarity for the three pedestrian time gap acceptance values (bars indicate the 95% confidence level).**

### 3.2.2 Effects of the mid-block layouts

The results with the LMEM indicate that mid-block crosswalk layouts have a significant effect on MTTC ($p$ = .007), MaxS ($p$ = .009), and MaxD ($p$ = .046). The MTTC model revealed a significant interaction between the mid-block layout and PTGA value ($p$ = .003). A Holm post-hoc comparison revealed that when the PTGA is 4 s, MTTC ($Z$ = .841, $p_{Holm}$ < .001) increases with the curb extensions. However, no significant differences were found in MTTC and PET models for higher PTGA values. Generally speaking, the presence of a curb extension leads to higher MTTC and PET outcomes (*i.e.*, safer DP interactions) with respect to the baseline condition – especially when the PTGA is 4 s. That is, the baseline layout resulted in a higher probability of collision. In the MaxS model, the interaction between the mid-block layout and familiarity condition was significant ($p$ = .017). Moreover, the difference between the two layouts is even more apparent with the MaxS and MaxD models (Figure 7), with the curb extension resulting in lower speeds and deceleration rates than with the baseline layout across a full range of PTGA values. As a result, a curb extension is expected to have a lower degree of crash severity than a baseline crosswalk.

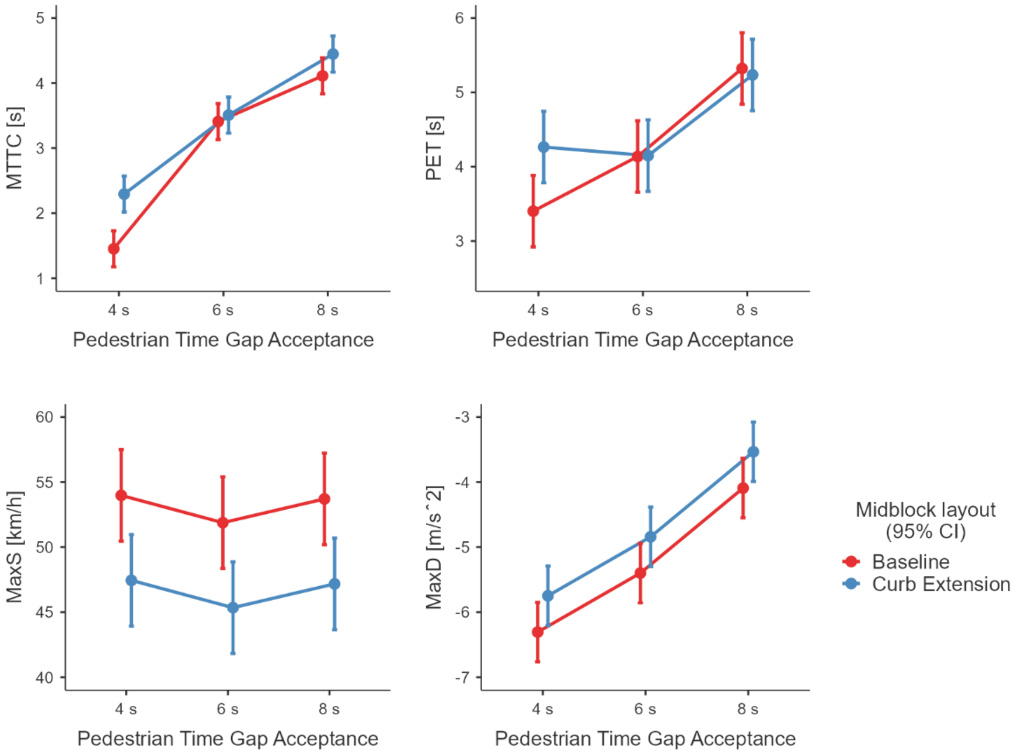



**Figure 7. Plots of the estimated marginal means for the four observed SSM as a function of the crosswalk layout for the three pedestrian time gap acceptance values (bars indicate the 95% confidence level).**

### 3.2.3 Effect of PTGA

The results for LMEM show that the PTGA variable has a significant effect on all the observed variables [MTTC ($p$ <.001), PET ($p$ < .001), MaxS ($p$ < .009), MaxD ($p$ < .001)]. A Holm post-hoc test shows that, whenever the PTGA value increases from 4 to 6 s ($Z$ = 1.585, $p_{Holm}$ <.001), from 6 to 8 s ($Z$ = .820, $p_{Holm}$ <.001), and from 4 to 8 s ($Z$ = 2.406, $p_{Holm}$ <.001), the MTTC values increase significantly. Moreover, interactions with mid-block layout ($p$ = .003) and familiarity ($p$ = .002) factors were significant. The same tests carried out on PET observations indicated significantly higher values only when the PTGA value increased from 4 to 8 s ($Z$ = 1.445, $p_{Holm}$ <.001), and from 6 s to 8 s ($Z$ = 1.135, $p_{Holm}$ <.001). Interaction with the mid-block layout was significant ($p$ = .030). Thus, the results for both models show that an increase in the PTGA value leads to a lower probability of a collision occurring.

The increase in the PTGA from 4 to 6 s led to a lower MaxS ($Z$ = 2.098, $p_{Holm}$ = .014), while the increase from 6 to 8 s produced a higher MaxS ($Z$ = 1.826, $p_{Holm}$ <.027) in the 100 m before the conflict point. However, the PTGA increment from 4 to 8 s did not produce any significant changes in the MaxS outcomes. No significant interactions with the other two factors (mid-block layout and familiarity) were found. The results with the MaxD model show that drivers adopt a lower maximum deceleration when the PTGA value increases from 4 s to 6 s ($Z$ = .907, $p_{Holm}$ <.001), from 6 to 8 s ($Z$ = 1.307, $p_{Holm}$ <.001), and from 4 s to 8 s ($Z$ = 2.214, $p_{Holm}$ <.001). In other words, the drivers reduced their rate of deceleration when exposed to higher PTGA values. Finally, the interactions between PTGA values, the familiarity condition, and the presence of a mid-block layout were already elaborated in Sections 3.2.1 and 3.2.2.

## 4. Discussion

In this study, we investigated the impact of three familiarity conditions and type of crosswalk layout on driver behaviour when approaching uncontrolled mid-block crosswalks for different pedestrian time gap acceptance values. We adopted surrogate safety measures (MTTC, PET, MaxS, MaxD) to estimate changes in driver behaviour. Two main findings emerged regarding driver familiarity and crosswalk layout.

First, driver familiarity (with route and/or situation) impacted driver response when negotiating the unsignalized mid-block crosswalks. Results highlighted relevant differences between the route and situation familiarity conditions. We found that the route-familiarity condition resulted in a significantly higher degree of conflict severity (higher MaxS) and a higher probability of a collision (lower MTTC) involving pedestrians when compared to situation familiarity. For a PTGA equal to 4s, repeated DP interactions led to a significantly higher MTTC (*i.e.*, a lower probability of collision) than with other familiarity conditions. That is, the situation familiarity condition had a more evident effect on driver behaviour when the PTGA was 4 s (the drivers had less time to react). Finally, the data for drivers still unfamiliar show a significantly lower degree of conflict severity (lower MaxS) than that for drivers operating in the other familiarity conditions (repeated exposure to DP interactions and/or same road environment).

Second, the layout of the mid-block crosswalk affects driving behaviour. It is clear that the curb extension has a positive impact on conflict severity (lower MaxS and MaxD), collision probability, and on crash nearness (higher MTTC and PET).

### 4.1 Effect of familiarity

In this study we found that drivers familiar with the route were travelling at higher speeds in the 100 m preceding the crosswalk compared to situation familiar and still unfamiliar drivers. In real driving conditions, this behaviour leads to severe conflicts (Gettman *et al.*, 2008). This finding is consistent with literature which confirms the pronounced tendency of route-familiar drivers to drive at higher speeds (Charlton and Starkey, 2013; Charlton and Starkey, 2017; Colonna *et al.*, 2016; Martens and Fox, 2007; Rosenbloom *et al.*, 2007). Route-familiarity resulted in drivers delaying any evasive manoeuvre when compared to the other two protocols. Young and Stanton (2002) attributed this behaviour to a reduction in attention levels, while Rankin *et al.* (2009) attributed it to the application of the same environmental stimulus. Our outcomes are consistent with the findings of Yanko and Spalek (2013), who observed how route-familiar drivers, unlike unfamiliar ones, delayed their evasive manoeuvre in response to events occurring in the peripheral and central parts of the road.

In our study, we also tested the situation-familiar protocol for drivers who had also developed route familiarity. Results demonstrated that drivers who repeatedly interacted with pedestrians exhibited more cautious behaviour which was reflected in speed (MaxS) and minimum time to collision (MTTC) values. Being exposed to a certain type of interaction with pedestrians encourages the driver to maintain a safe driving style (Burdett *et al.*, 2018). The average MTTC values observed for situation familiar drivers are all above the threshold identifying a safer conflict event (*i.e.*, larger than 1.5 s). It indicates that the probability of a collision would be lower in the situation-familiar condition than in others. The MaxS model confirms that the situation-familiar condition is associated with a lower level of conflict severity than the route-familiar one. It can be argued that the greater attention paid to the presence of pedestrians (situation familiarity) compensates for the negative effects attributable to the pure route-familiarity condition such as a delayed response to hazardous events (Rosenbloom *et al.*, 2007). Another possible explanation is that situation familiarity prolongs the state of enhanced awareness that drivers experience following their first interaction with pedestrians at crosswalks.

However, drivers familiar with both the route and the situation approached the crosswalks at significantly higher speeds than unfamiliar drivers (see Figure 6). This may be the effect of the so called “kangaroo driving” that Elvik (1997) observed in the proximity of speed cameras, which consists of abrupt braking before the crosswalk and acceleration afterwards. In this study we observed that familiar drivers slow down at the crosswalk but drive faster before and after it.

Finally, the PET model revealed that drivers still unfamiliar drive more cautiously than drivers in route and situation familiarity conditions. We observed that unfamiliarity led to higher PET values in DP conflict scenarios. That is, in terms of crash nearness, drivers still unfamiliar experienced a larger PET during conflicts with pedestrians. Therefore, unfamiliar drivers perform their driving task in an appropriate manner and in compliance with traffic regulations.

### 4.2 Effect of mid-block crosswalk layout

No previous research investigated the effectiveness of this crosswalk layout when considering the familiarity factor in experimental design. Based on the outcomes of our study, the presence of a curb extension at an uncontrolled mid-block crosswalk (i) reduces the risk of pedestrians being hit by vehicles, (ii) increases the number of drivers yielding to pedestrians, as Johnson (2005) also found, and (iii) results in a significant decrease in the operating speed of vehicles approaching the crosswalk itself as seen in Figure 7. The observed outcomes relating to these SSMs are consistent with expected driver behaviour: the curb extension promotes a more cautious approach to the crosswalk than the linear layout, *i.e.* the baseline condition (Bella and Silvestri, 2015). The curb extension prompted a reduction in the maximum speed (MaxS) and an increase in the time gap before (MTTC) and after (PET) any potential conflict situations with pedestrians at the crosswalk. The presence of a curb extension results in longer time gaps (*i.e.*, larger MTTC and PET) for all the combinations, especially for PTGA equal to 4 s. The largest behavioural gap between the two layouts is observed with the MaxS model, meaning that the curb extension induced a lower maximum speed value. All these outcomes serve to confirm the positive effect of a curb extension on DP interactions under both route and situation familiarity protocols. This aspect is clear to see when we examine the MaxS observations associated with drivers operating in the unfamiliar state condition. Comparing the familiarity protocols and PTGAs, the success of the curb extension in reducing maximum speed values becomes evident.

**5. Conclusions**

Our research provides specific insights into the behaviour of drivers when approaching unsignalized mid-block crosswalks featuring a linear curb or curb extension layout and in the presence of pedestrians who have accepted one of three possible time gaps. In contrast with other studies, one strength of our research is the introduction of a situation-familiarity protocol in addition to the route-familiarity one, with the hypothesis that different "familiarity" protocols result in different driver behaviours. Surrogate safety measures were used to assess the impact of independent experimental factors on driver behaviour.

Our results support previous findings regarding the impact of route-familiarity, but also show that a different kind of familiarity (*e.g.*, situation familiarity) might affect driver behaviour or limit the effect of route-familiarity. Furthermore, our study provides road designers with information that should prove useful for the creation of effective speed enforcement systems, thus contributing to the diffusion of more pedestrian friendly urban environments.

Results confirm that different familiarity conditions lead to significant differences in behaviour and safety outcomes. The familiarity type impacts both conflict severity and the probability of a collision occurring. The results demonstrated that the route-familiarity condition led to higher maximum speeds and increased probability of a collision compared to the unfamiliar and situation-familiar conditions. Furthermore, the probability of a collision and the degree of severity of same would be lower in the situation-familiar condition than in the route-familiar one. The second main outcome of this study concerns the impact of a crosswalk layout on driver behaviour in different familiarity conditions. In accordance with previous findings, the curb extension layout has an effect (Bella and Silvestri, 2015), but our results serve to amplify the positive behavioural impact that this layout has on drivers by also considering the effects of familiarity. That is, this study provides a more comprehensive understanding of the implications of adopting this safety countermeasure in an urban environment and lends support to this design decision as promoted in manuals and guidelines (*e.g.*, Blackburn et al., 2018).

Finally, thanks to the relative behavioural validation achieved in previous investigations by the driving simulator used, the results of this study can be transferred to the field. It is worth considering that, in real driving conditions, any changes in the SSM will be in terms of magnitude but will, nonetheless, go in the direction evidenced in this study (Catani and Bassani, 2019; Bassani *et al.*, 2018).

Future investigations should consider driver familiarity as a three-level factor, carefully separating the effects attributable to prior knowledge of the road environment from those acquired after repeated interactions with other competing road users. However, further research is required to comprehend the driver learning process when subjected to different DP interaction sequences and the impact of different levels of driving experience (Groff and Chaparro, 2003).

This work does have some limitations. The inclusion of additional influencing factors such as environmental lighting conditions (daytime vs. night-time), interaction of the driver with other vehicles in the lane, and road geometric factors (*e.g.*, lane width, roadside treatments, alternative markings) would all help to provide a greater understanding of the operational and behavioural effects of different uncontrolled crosswalk layouts. Furthermore, driving simulation experiments with simulated pedestrians performing evasive manoeuvres (*i.e.*, stopping, backing up, or accelerating on the crosswalk to avoid collision with the oncoming vehicle) would serve to make the study of driver-pedestrian interactions more realistic.

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