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Effectiveness of smart LED strips at mid-block crosswalks under distracted driving conditions

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ABSTRACT

We investigated the effectiveness of an LED-based smart mid-block crosswalk system in mitigating the detrimental effects of driver engagement in non-driving-related tasks (NDRTs) with behavioural, performance, and subjective measurements. We designed a 2 (*Crosswalk*: smart vs conventional) by 2 (*Task complexity*: low vs. high NDRT) within-subjects experiment. Thirty-six drivers drove along four urban scenarios in a static driving simulator. We collected data on driving behaviour (speed, reaction distance), and safety (minimum time-to-collision [MTTC]), as well as subjective driver ratings on the perceived task load and their trust in the technology used, and performance levels achieved while performing the NDRTs.

Behavioural and performance observations showed that the smart mid-block crosswalk resulted in greater reaction distances and MTTC values when drivers interacted with pedestrians, thus indicating improved safety. Remarkably, the results also revealed that increased NDRT complexity does not negatively affect the smart crosswalk effectiveness in terms of driver-pedestrian collision prevention (i.e., MTTC does not decrease significantly). However, the NDRT complexity influenced driving performance in terms of speed and reaction distance at brake pedal pressure, with drivers exhibiting lower speeds and lower reaction distances with higher task loads. Moreover, the subjective ratings and performance levels while performing a NDRT reflected the experimental manipulation, with drivers perceiving higher task loads and performing worse in the higher NDRT complexity condition. Overall, the smart mid-block crosswalk led to a safer driver-pedestrian interaction compared to conventional crosswalks and achieved a good acceptance level both of which augur well for the widespread future installation of this technology.

1. Introduction

Pedestrian safety is of paramount public health and road safety importance, as pedestrian fatalities account for 36 % of total urban-road-related deaths in Europe [15]. A major factor in collisions involving pedestrians is driving distraction, which negatively affects drivers' ability to interact safely with other road users (e.g., pedestrians) or to anticipate and respond effectively to potential hazards [14]. Distraction is even more dangerous at night, when it can combine with fatigue and reduced visibility conditions and lead to an increase in crash frequency and severity [35,45,46]. A driver is considered distracted when engaged in non-driving related tasks (hereafter NDRTs) while driving (i.e., primary task), as NDRTs divert the driver's attention from the road and traffic conditions [13]. Crash statistics showed that distracted driving was the most common contributing factor in road collisions [26], and that in distraction-affected crashes many of the non-occupant victims were pedestrians [32]. In recent decades, several successful countermeasures have been developed, e.g. [3,29,38] to mitigate the adverse effects of NDRTs. Nevertheless, the incidence of fatalities among vulnerable road users remains a major road safety issue. Thus, it is imperative to find alternative strategies to address the problem. One of the latest strategies to enhance the driving experience and reduce driving risks involves the use of Smart on-Road Technologies (SRT) [2]. Specifically, in the context of driver-pedestrian interaction at mid-block crosswalks, previous naturalistic and simulated studies tested the effectiveness of different SRT in reducing the level of human error and

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improving road safety with results that were positive, but sometimes site-dependent [2]. For example, naturalistic studies revealed how the installation of smart LED-based crosswalk technologies on the road surface was effective in improving the drivers' longitudinal behaviour, as drivers slowed down to yield to pedestrians at significantly greater distances from the crosswalk [27] and significantly (20 %) reduced their speed compared to conventional pedestrian crossings [34]. Further driving simulation studies supported the effectiveness of smart LED-based crosswalks in improving drivers' yielding behaviour and inducing safer interactions with respect to conventional solutions [24,25,36].

Although existing literature has demonstrated the effectiveness of SRT at crosswalks, no study to date has examined their impact in the context of distracted driving. Among the types of distraction, cognitive distraction is of particular interest because it cannot be addressed by legislation, unlike in many countries where the Highway National Code does not allow the use of smartphones while driving. In simulation studies, cognitive distraction can be controlled by voice conversations [7] or by mnemonic computation ([18] and [12]).

Here, we investigated the effectiveness of smart LED red strips at a mid-block crosswalk on driving behaviour while drivers were simultaneously engaged in a NDRT (with the possibility of two different task loads). Participants drove in a static driving simulator undergoing four driving simulations with different mid-block crosswalk configurations and task loads. To assess the safety level of the driver-pedestrian interactions, we employed both surrogate safety measures (i.e., minimum time-to-collision (MTTC), maximum speed before the crosswalk; see, [1,20,36]) and longitudinal performance variables (i.e., speed and the reaction distance at brake pedal pressure; see [5]). Finally, we collected subjective ratings of the task load and trust in automation. We hypothesized that the smart mid-block crosswalk would induce safer driver-pedestrian interactions, and that the improvement would be modulated by the NDRT complexity (i.e., the smart solution would produce a greater improvement with a low complexity NDRT than it would with a high complexity one).

2. Method

2.1. Participants

Thirty-six drivers took part in the experiment (mean [M] age = 28 years ± standard deviation [SD] = 10.5, age range = 20–59 years; 19 males). Sample size was determined through an a priori power analysis using the *GPower* tool ([16]; version 3.1). We found that a minimum sample size of $n = 36$ was necessary to achieve the 90 % statistical power (α=.05) required to conclude that a result is significant with the variables under investigation.

All the participants held an Italian car driving license and they had normal or corrected-to-normal vision. We screened the participants for their level of arousal with the Stanford Sleeping Scale (SSS; [21]). All the participants scored lower than 4 (SSS = 1.55, 1-3 range) indicating no fatigue or drowsiness [11]. Finally, none of the drivers were aware of the hypotheses being tested.

2.2. Experimental design

We carried out a 2 (*Crosswalk*: smart vs. conventional) × 2 (*Task complexity*: low vs. high NDRT) within-participants experiment. Participants completed four driving sessions (~5 min each) in a virtual urban environment and under nighttime conditions. We considered nighttime driving to be the most critical condition due to limited driver visibility, which increases the likelihood of driving errors [45].

In each scenario, we presented a mid-block crosswalk configuration (smart or conventional) and the drivers performed a concurrent NDRT (see section below). The NDRTs (low or high) were administered for all the crosswalks to avoid giving participants any indication of the crosswalks being investigated. The distraction period (i.e., engagement in the NDRT) started 200 m before each crosswalk. The pedestrians always crossed from the right side and with a time gap acceptance (PTGA) of 4 s. The pedestrian started crossing the road and the red bar was illuminated when the vehicle was at a distance $d = S \cdot \text{PTGA}$ from the crosswalk, where S is the vehicle speed [1]. The order in which the scenarios were administered was varied to counterbalance any learning and order effects.

2.3. Non-Driving related tasks

We selected two NDRTs that involved vocal interactions between the driver and the researcher, with the former performing a number of mathematical operations ranging in complexity [10] to reproduce a cognitive distraction.

During the low complexity NDRT (Fig. 1a), participants performed a series of two-digit mental arithmetic operations involving additions without regrouping [18] while in the high complexity NDRT (Fig. 1b), they performed the same type of exercise but with regrouping. This task was combined with a memory component, in which participants were required to sum the number read aloud by the researcher with the second number read in the previous operation. The operations were randomly selected from a predetermined set, which was employed for all participants. For both tasks, we considered the total number of answers as the performance index.

2.4. Driving simulation and performance

We developed four two-lane (each 3.0 m wide) urban road scenarios using the SCANeR Studio® (version 1.9; AV Simulation, Boulogne-Billancourt, France). Each road scenario was 2.5 km long with a parking lane and sidewalks which were 2.5 m and 2 m wide, respectively. The smart mid-block crosswalk was simulated by installing red LED strips on the road surface before the crosswalk (Fig. 2b). We chose the colour red for its association with danger in signalling [37]. As soon as a pedestrian steps onto the road surface, the LED strip is activated and emits a fixed red light; when the pedestrian leaves the crossing area, the LED bar is disactivated and turned off. The carriageway was surrounded by several buildings to simulate a typical urban environment. Each scenario contained six crosswalks, three of which were used to acquire driver behaviour data. At these crosswalks, a pedestrian consistently crossed from the right side of the road. The other three crosswalks were designed to confuse the driver, create unpredictable situations, and limit the learning effect. To do this, we randomly included scenarios with no pedestrians or with one pedestrian crossing from the left side of the road. Throughout the scenario, we randomly placed parked cars to increase the verisimilitude of the scene. To deliberately create a critical situation for the driver, we consistently placed a parked car on the right side just before each crosswalk, effectively obscuring the pedestrian who was crossing. We included a low level of traffic in the opposite travelling direction, while no traffic was simulated in the direction of the ego-vehicle. This choice was made to neutralise the influence of traffic flow on driver behaviour and to increase the verisimilitude of the scenarios. Participants were asked to respect the traffic rules throughout the duration of the experiment, with the posted speed limit set to 50 km/h.

To perform the driving simulation task, we used a fixed-base driving simulator (model CDS650; AV Simulation, Boulougne-Billancourt, France). The simulation system was composed of three 32-inch monitors with a 130° × 20° field of view, a fully equipped driving position with seat, dashboard, steering wheel with force feedback, pedals, manual gearbox, and vibration pads to replicate pavement roughness, wheel rolling, and shocks. We reproduced the car cockpit on screen to ensure that driving conditions were as realistic as possible. A sound system reproduced the sounds of the engine and the surrounding environment. The simulator had previously been validated for longitudinal

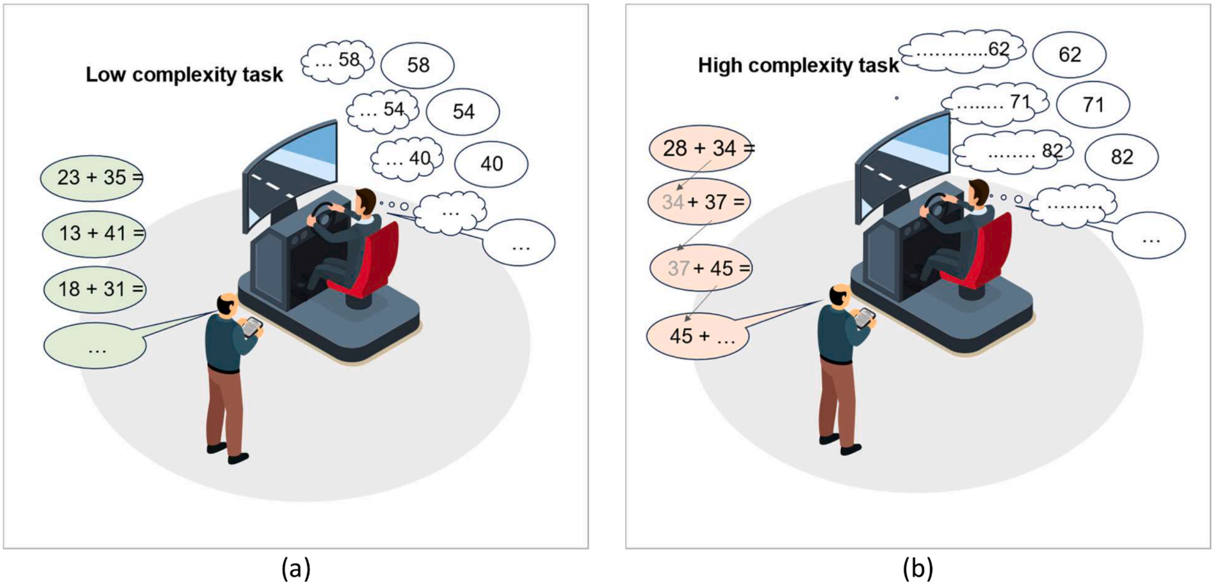

Fig. 1. Non-driving related task (NRDT) involving mathematical operations: (a) low complexity NDRT, with the summation of two-digit pairs of number without regrouping; (b) high complexity NDRT, with the summation of two-digit pairs of numbers with regrouping and memory task.

Fig. 2. (a) Conventional, and (b) smart mid-block crosswalks. In the smart crosswalk, the red LED light is activated when the pedestrian steps onto the crossing area.

[4], and transversal behaviour [6].

The driving performance indicators were recorded with a frequency of 100 Hz. Specifically, we measured the speed and the reaction distance between the car and the crosswalk when the driver pressed on the brake pedal to stop the car before the crosswalk, and the maximum speed and the MTTC in the 200 m before the crosswalk.

2.5. Questionnaires

We assessed the perceived workload produced by the NDRT combined with the crosswalk type for each scenario with the NASA Task Load Index (NASA-TLX; [19]). The NASA-TLX assesses task loads through six bipolar dimensions: mental, physical, and temporal demand, own performance, effort, and frustration, using a score between 0 and 100 (higher values indicate higher perceived task loads). Finally, we employed the Motion Sickness Assessment Questionnaire (MSAQ; [17]) to monitor self-reported symptoms of motion sickness, and a customized Trust in Automation (TiA) questionnaire to evaluate the level of trust in this SRT and drivers' willingness to rely on it. The MSAQ includes 16 brief statements describing the most common motion sickness symptoms (e.g., "I felt sick to my stomach"). The participants must respond to each statement on a Likert scale with the following 9 points: 1) No Symptoms at all, 2) Very Mild Symptoms, 3) Mild Symptoms, 4) Moderate Symptoms, 5) Moderate to Severe Symptoms, 6) Severe Symptoms, 7) Very Severe Symptoms, 8) Extremely Severe Symptoms, 9) Completely Debilitating Symptoms. The TiA questionnaire consisted of 7 brief statements and 3 questions reflecting drivers' opinions on the utility (or otherwise) and stressfulness of technology and their level of trust in it (partially readapted from [42]). Participants rated each item on a 7-point Likert scale, with points ranging from "Absolutely Agree" to "Absolutely Disagree", or from "Not at all" to "Extremely" or from "Extremely Harmful" to "Extremely Helpful" depending on the question.

2.6. Procedure

The study was conducted in compliance with the Code of Ethics of the World Medical Association [44]. The experiment took place in the Road Safety and Driving Simulation lab at the Politecnico di Torino (Italy). To recreate nighttime driving conditions, the experiment took place in a dark room, with the only source of light being the visual system (i.e., three screens).

First, participants were asked to fill out the SSS questionnaire to self-evaluate their scale of sleepiness. All participants were considered eligible for the experiment. Next, participants underwent a short (~5 min) training session to gain confidence with the driving simulator equipment. Before starting the first experimental scenario, the researcher (AP, the same for all the experimental sessions) explained the study's procedures and the NDRTs the participant would undertake. Afterward, the experiment began, with participants completing the four experimental scenarios and engaging in the NDRT when instructed to do so. After each scenario, participants filled out the NASA-TLX questionnaire and had a rest of 1 min before driving the next scenario. At the end of the experimental session participants completed the MSAQ and TiA questionnaires. Finally, participants were informed of the overall duration of the experiment (circa 30 mins), but they were unaware of the exact duration of the driving simulation to avoid the end-spurt effect [30].

2.7. Statistical analysis

To assess the effectiveness of the smart mid-block crosswalk on behavioural, performance, and subjective metrics we performed a separate 2 × 2 repeated measures ANOVA, with the *Crosswalk* (smart vs conventional) and *Task complexity* (low vs high) as independent variables. For the behavioural (i.e., maximum speed 200 m before the crosswalks, speed and reaction distance when pressure applied on brake pedal, and MTTC) variables, we averaged out the observed values for the three crosswalks in each experimental scenario for each participant. The significance level (α) was always set to 5 %.

3. Results

Our study used simulator-based technology to investigate the impact of a smart LED-based mid-block crosswalk on road safety in the context of distracted driving. To investigate how this technology affected driver behaviour, we analysed the driver's longitudinal behaviour and the driver-pedestrian interactions when vehicles approached the crosswalk. Finally, we presented the results of subjective measures related to the workload produced by the two NDRTs and the level of driver trust in the SRT used.

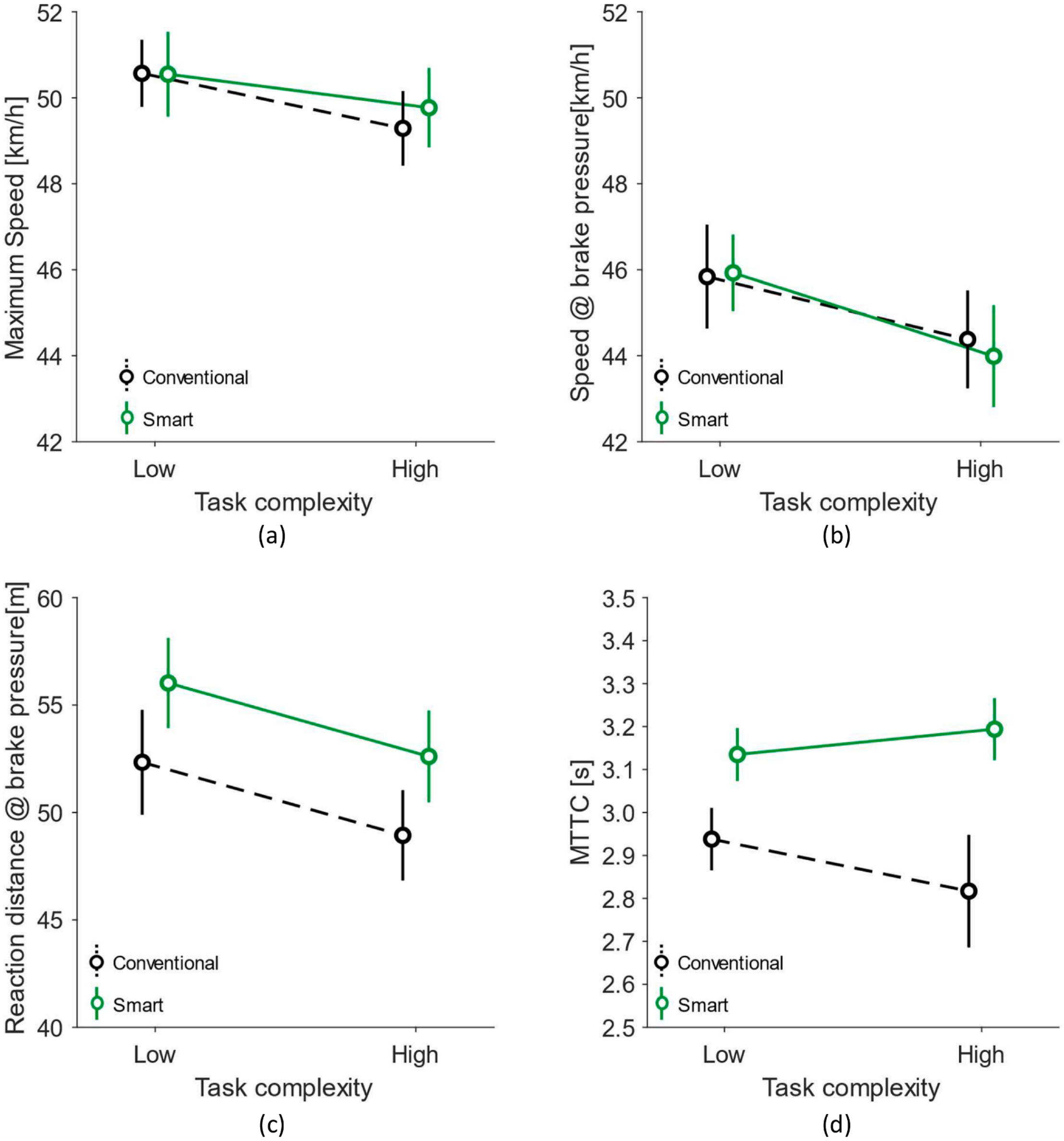

Fig. 3. (a) Average maximum speed recorded in the 200 m before the crosswalk; (b) Average speed when drivers engaged the brake pedal in response to the presence of a pedestrian at a conventional crosswalk, and to the red LED bar activation in the case of a smart crosswalk; (c) Average reaction distance; and (d) Average minimum time-to-collision (MTTC). Error bars on the graphs represent standard errors of the mean (SEM).

3.1. Behavioural measurements

We presented the results on driving behaviour when approaching the mid-block crosswalks, focusing on: (a) maximum speed 200 m before the crosswalks, (b) speed at brake pedal pressure, (c) reaction distance at brake pedal pressure, and (d) minimum time to collision, across the various experimental conditions (see Fig. 3).

The maximum speed recorded in the 200 m before the crosswalks was not significantly influenced by either the type of *Crosswalk* or the complexity of the NDRT. At the brake pedal pressure, the observed speed differed significantly across the NDRT conditions, $F(1{,}35) = 10.75$, $p = .002$, $\eta_p^2 = .235$ with drivers adopting higher speeds when performing a low complexity NDRT than they did with a high complexity one ($M = 45.9$ vs 44.2 km/h respectively). The effect of the *Crosswalk* on speed was not found to be significant at the brake pedal pressure moment. Considering the same instant, the reaction distance was significantly influenced by both the crosswalk, $F(1{,}35) = 7.02$, $p = .012$, $\eta_p^2 = .167$, and the NDRT, $F(1{,}35) = 5.33$, $p = .027$, $\eta_p^2 = .132$. The smart crosswalk was more effective than the baseline condition in making the drivers start the braking manoeuvre at a greater distance from the crosswalk ($M = 54.32$ vs 50.64 m). Moreover, drivers were found to react earlier while performing a low complexity NDRT than they did with a high complexity one ($M = 54.18$ vs 50.77 m). From our study, the smart mid-block crosswalk was also determined to have a significant effect on MTTC, $F(1{,}35) = 22.14$, $p < .001$, $\eta_p^2 = .387$.

The proposed smart countermeasure led to safer driver-pedestrian interactions, resulting in a higher MTTC with respect to the conventional solution ($M = 3.16$ vs 2.88 s respectively); while the same variable (MTTC) was not significantly affected by NDRT complexity. We were able to observe that the smart mid-block crosswalk was more effective than conventional ones in facilitating conflict free interactions between pedestrians and drivers. Finally, as a general outcome, we observed that the *Crosswalk* × *Task complexity* interaction term was not significant for the dependent variables investigated.

3.2. Performance and subjective measurements

For the performance of the concurrent task (Fig. 4a), we found the NDRT had a significant effect on the total number of answers, $F(1{,}35) = 69.29$, $p < .001$, $\eta_p^2 = .750$ resulting in a higher number of answers with the low complexity than with the high complexity NDRT ($M = 17.61$ vs 14.76 respectively). On the other hand, *Crosswalk* did not have a statistically relevant impact on the number of answers.

Concerning the perceived workload (Fig. 4b), the effect of the NDRT was deemed to be significant, $F(1{,}35) = 27.16$, $p < .001$, $\eta_p^2 = .437$. As hypothesised, drivers judged the driving tasks to be more demanding when they were undertaking a high complexity NDRT rather than a low complexity one ($M = 58.59$ vs 49.07 respectively). Neither *Crosswalk* nor *Crosswalk* × *Task complexity* interaction terms were found to be significant.

Regarding the level of trust in this smart solution (evaluated on a Likert scale with ratings ranging from 1 to 7 by participants), the drivers had to declare their level of trust in the technology (*Median [Mdn]* = 5) and whether it would help to improve their driving style (*Mdn* = 5). The general feedback on the system was positive since they suggested that the implementation of the smart mid-block crosswalk would be useful for road safety (*Mdn* = 6), and they classified this technology as effective (*Mdn* = 5) and useful (*Mdn* = 6). Finally, the drivers reported that the smart mid-block crosswalk did not evoke any high-level negative feelings (concern, *Mdn* = 2; stress, *Mdn* = 2), whilst it evoked a fair level of calmness (*Mdn* = 4).

4. Discussion

Driving while engaged in a secondary task is a well-known threat to road safety. The use of SRT may help to reduce or even eliminate the negative effects associated with this driver behaviour [2]. Thus, we carried out a driving simulation experiment to investigate the effectiveness of a mid-block smart crosswalk (*Crosswalk*: smart vs. conventional) on driver behaviour, performance, and subjective measures while performing a concurrent task (*Task complexity*: low vs. high) in nighttime driving conditions.

Examining longitudinal behaviour, our findings suggest that the maximum speed recorded in the 200 m before the crosswalk was not influenced by the type of mid-block crosswalk or engagement in a NDRT. This is a reasonable result, as the maximum speed was presumably recorded at the greatest distance from the crossing (around 200 m), and therefore, these factors did not play a key role in influencing driver speed. This is likely because the LED strips had not yet been activated, and distraction had just been triggered. Concerning the speed at the

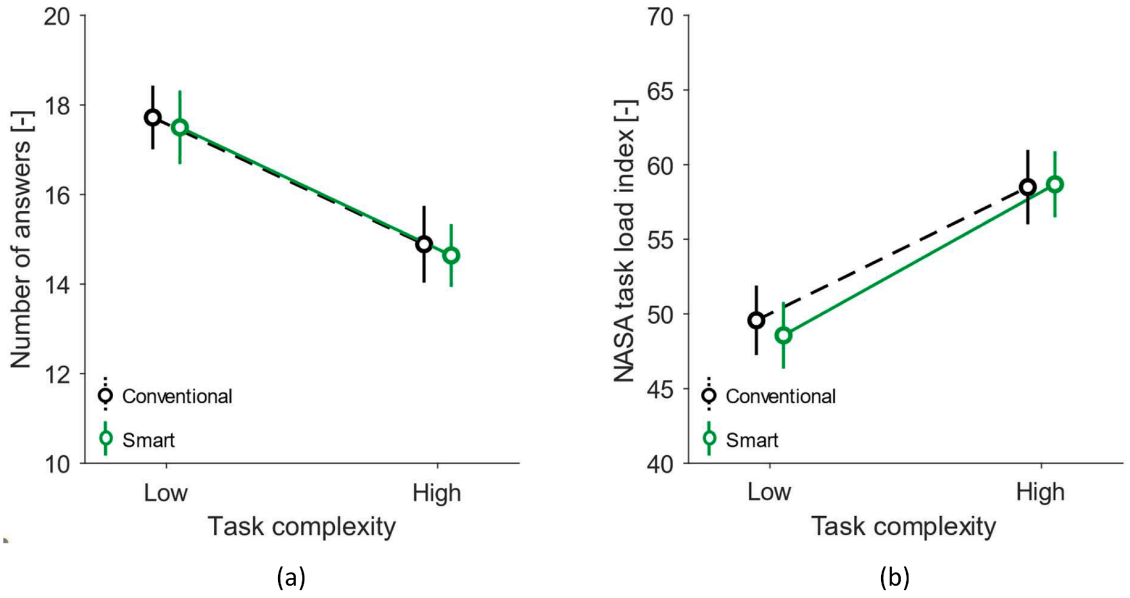

Fig. 4. (a) Mean number of answers, and (b) mean NASA Task Load Index. The green line refers to the smart mid-block crosswalk configuration, while the black one refers to the conventional configuration. Note that, for graphic purposes, the y-axis ranges from 40 to 70, while the variables were measured in a scale from 0 to 100. Error bars on the graphs represent the SEM.

moment in which drivers applied pressure to the brake pedal, the presence of the smart mid-block crosswalk did not alter longitudinal behaviour, and drivers maintained speeds similar to those at conventional crossings. However, the NDRT exerted a significant influence on the speed at the brake pedal, as the high-complexity NDRT led drivers to adopt lower speeds. This outcome could be explained by drivers' behavioural self-regulation (risk compensation strategy), which may occur when drivers recognise the increase in the situational complexity and risk (i.e., higher complexity of maths operation). It appears that drivers adjusted to the specific overloading situation by self-regulating their behaviour by decreasing the rate at which they processed driving-related information (i.e., reducing the driving speed) [10,22,28,33,43]. Furthermore, our results are supported by previous studies, in which driving performance still deteriorated while performing the secondary task despite the observed speed reductions [39–41].

According to our findings, the smart mid-block crosswalk elicited a safer driver-pedestrian interaction with respect to conventional configurations. With smart crosswalks, we measured higher reaction distance and higher MTTC values for both low and high complexity NDRTs, providing important insights into the safety benefits of the adoption of smart mid-block crosswalks [25,36]. The reaction distance significantly increased with the presence of smart mid-block crosswalks, allowing drivers to clearly see and react earlier to pedestrians. However, as expected, the complexity of the secondary task proved detrimental to driver perception [8] with drivers reducing the distance (from the crosswalk) at which they hit the brake pedal independently of the crosswalk configuration. Regarding the results obtained for MTTC, we observed that the smart crosswalk was instrumental in inducing conflict-free interactions between drivers and pedestrians (i.e., higher values of MTTC). Conversely, for conventional crosswalks the MTTC value was lower than that for smart crosswalks with a higher probability of leading to conflict events [47]. It might be concluded that the presence of conventional crosswalks tends to generate more conflicts, while smart mid-block crosswalks promote relatively safer pedestrian crossings even when drivers are engaged in a NDRT. Moreover, most importantly, this result was independent of the level of cognitive difficulty associated with the secondary task, indicating that even with a high distraction level the smart mid-block crosswalk induced a safer driver-pedestrian interaction (lower MTTC). This significant finding indicates that the adoption of smart mid-block crosswalks enabled drivers to mitigate the negative impact of tasks with high cognitive demands, bringing them to levels comparable to that of a low-complexity NDRT. This enhancement contributes to making pedestrian crossings safer even under conditions of elevated cognitive load.

From a subjective standpoint, the technology was positively accepted by participants, and the perceived workload did not increase with respect to the conventional configuration as already stated by Portera & Bassani [36]. This finding indicates that the installation of smart crosswalks did not increase the perceived workload of participants, thereby allowing drivers to maintain their perception and reaction capabilities. Conversely, NDRT complexity statistically influenced perceived workload, with the high complexity task being more challenging for drivers. This result is consistent with previous findings [18]. While this situation had a negative effect on driving performance at conventional crosswalks, the presence of smart crosswalks, despite the higher workload, did not compromise the safety of driver-pedestrian interaction as demonstrated by the values observed for MTTC. Finally, we found a good level of technology acceptance from the drivers. On average, drivers judged the technology as useful and satisfying to use, indicating that they were receptive to its use making the potential safety benefits of a smart mid-block crosswalk more attainable [23].

Notwithstanding the above, our results should be viewed in the context of three shortcomings. First, our testing focused exclusively on scenarios in which the ability to see pedestrians was obstructed by vehicles parked near the mid-block crosswalk. Our findings affirm the efficacy of smart on-road technologies within these specific contexts, while recognizing that outcomes might differ under alternative circumstances. Future research should aim to assess the technology's effectiveness by comparing scenarios involving both concealed and non-concealed pedestrians.

Second, the pedestrian always adopted a deterministic (non-dynamic) behaviour. Consequently, in this experiment, they crossed without considering the actual danger of the situation, meaning it was the sole responsibility of the driver to avoid potential collisions by taking the necessary evasive action. The lack of real decision-making by the virtual pedestrian introduces an element of artificiality that may not accurately reflect real-world pedestrian behaviour. To address this limitation in future research, one possible approach is to consider a co-simulation study, where drivers would engage in a driving simulation, and simultaneously, the same scenario would be replicated within a virtual reality headset for pedestrians [9].

Third, the effectiveness of the LED strip on pedestrian mid-block crosswalks was tested solely under nighttime conditions and its performance may differ in daytime scenarios due to varying perceptions of LED strip brightness. To address this limitation, future research should consider introducing daytime testing scenarios to assess the LED strip's effectiveness under different lighting conditions. Moreover, a subjective study assessing the LED strip's ability to capture the attention of drivers could be conducted using a full-scale LED strip in a controlled environment under varying lighting conditions. Therefore, the findings should be interpreted with caution and future studies should aim to address the limitations cited by reducing the impact of confounding variables. Finally, future studies might consider extending the analyses to other surrogate indicators of safety (e.g., the post-encroachment time, the distance-velocity model) to further deepen the understanding of driver behaviour.

5. Conclusion

Driver distraction while engaged in the performance of secondary tasks is a serious threat to road safety. The introduction of smart road technology may be crucial to combat the negative effects associated with this distraction [2,36]. Our study sheds light on the efficacy of a proposed smart mid-block crosswalk in mitigating the risks associated with driver cognitive distraction in driver-pedestrian interactions at mid-block crosswalks. The installation of a smart pedestrian crossing improves the safety of driver-pedestrian interaction under distracted driving conditions by increasing the reaction distance and MTTC. From a subjective point of view, our study reveals a significant level of technology acceptance by the drivers which is a key factor for the successful introduction of new technologies to the road environment [31]. Overall, these findings underscore the effectiveness of proactive measures, especially in scenarios where interventions, such as legal restrictions or educational campaigns, may prove insufficient due to the inherent nature of cognitive distraction activities that cannot be prohibited.

We offer relevant information and indications to road and transportation engineers regarding the effectiveness of an on road visual warning system useful for promoting safer driver behaviour and, hence, safer interaction with pedestrians at mid-block crosswalks. Moreover, from a subjective viewpoint, our study reveals a significant level of technology acceptance by drivers, which may serve to encourage (i) legislators to enable the use of these technologies through national highway codes, and (ii) local authorities to invest in these technologies as a key means of preventing or reducing the high number of fatal collisions involving pedestrians on our roads.

CRediT authorship contribution statement

Alberto Portera: Writing – review & editing, Writing – original draft, Visualization, Validation, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Francesco Angioi:** Writing

– review & editing, Writing – original draft, Visualization, Validation, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Leandro L. Di Stasi:** Writing – review & editing, Writing – original draft, Validation, Supervision, Resources, Methodology, Investigation, Funding acquisition, Formal analysis, Conceptualization. **Marco Bassani:** Writing – review & editing, Writing – original draft, Validation, Supervision, Resources, Methodology, Investigation, Funding acquisition, Conceptualization.

Declaration of competing interest

The Authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

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