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Illusion of safety? Safety-related perceptions of pedestrians and car drivers around 3D crosswalks

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ABSTRACT

Facilitating safe pedestrian road crossings is a major prerequisite for safe urban environments. In multiple cities around the world, 3D crosswalks have been painted, which provoke an optical illusion, of e.g., a crosswalk floating above the road, in car drivers who approach the crosswalk. However, to date, no detailed study of road users' safety related perceptions on 3D crosswalks has been conducted. Hence, we investigated car drivers' and pedestrians' perceptions of a 3D crosswalk, and how they rate its safety in comparison to traditional (non-3D illusion) crosswalks. In an on-site questionnaire survey, we interviewed 201 pedestrians and 102 car drivers in the direct vicinity of a newly painted 3D crosswalk located in Yangon, Myanmar. Our results show that only 53.9 % of the car drivers report to have consciously perceived the 3D effect of the crosswalk. Nonetheless, both, pedestrians and car drivers rate the 3D crosswalk as safer for road crossing than a traditional crosswalk. A high share of pedestrians (43.3 %) report taking a detour to use the 3D crosswalk for road crossing. Approximately one third (31.3 %) of pedestrians and 48.0 % of car drivers interviewed have talked to their friends about the 3D crosswalk, indicating a high potential for using 3D crosswalks as a marketing tool for road safety actors to generate attention for pedestrian safety. Unrelated to our main research question, we found that pedestrians prefer to cross in groups, as it increases the perceived likelihood of cars yielding to them. Overall, the data points to significant increases in the perceived safety of drivers as well pedestrians around the 3D crosswalk. Future studies need to investigate how these perceptions translate to actual safety related behavior.

1. Introduction

The Global Status Report on Road Safety identifies pedestrian safety as one of the key issues in reducing the number of road related fatalities and injuries (World Health Organization, 2018). Since pedestrians do not have a protective barrier around them, their risk of heavy injury is significantly higher compared to car-occupants, and thus they are characterized as *vulnerable road users* (Otte, Jäntsch, & Hasper, 2012). Pedestrian safety is an especially important issue in large urban centers, where pedestrians frequently cross roads, resulting in a high potential for conflicts with other road users (Zegeer & Bushell, 2012). Globally, pedestrian safety has been one of the focus points for road safety efforts in low-income countries, as fatality numbers for pedestrians are increasing in many low-income

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countries (World Health Organization, 2018; Yasin, Grivna, & Abu-Zidan, 2020). The design and structure of road crossings presents one potential way to decrease the risk of injuries for pedestrians (Bunn et al., 2003; Stoker et al., 2015), and the general design of road infrastructure to minimize the risk for road users is a main pillar of the safe system approach, which requires a comprehensive assessment of risk factors in the road system (Johansson, 2009).

Through good crosswalk design, the visual attention of car drivers can be guided towards pedestrians, preventing crashes, and the speed of vehicles can be lowered, decreasing the severity of crashes (Vignali et al., 2019; Vignali et al., 2020; Zegeer & Bushell, 2012). This increase in perceived safety can increase the frequency of walking as a means of transport (Basu et al., 2022). Physical infrastructure, e.g., traffic lights and raised medians (traffic islands) reduce vehicle–pedestrian collision frequency and severity (King, Carnegie, & Ewing, 2003; Stipancic, Miranda-Moreno, Strauss, & Labbe, 2020). But although physical crossing infrastructure that increases pedestrian safety can be implemented relatively cost-efficiently during the initial building of roads, the associated costs for the retroactive installation of physical road crossing infrastructure often leads to a preference for painted crosswalk markings (Stoker et al., 2015).

In comparison to physical infrastructure, traditional, painted crosswalks can be installed with little resources. However, studies show that traditional marked crosswalks have little positive impact on pedestrian safety (Retting, Ferguson, & McCartt, 2003), and even increase pedestrian crash rates for some road environments (Zegeer, Stewart, Huang, & Lagerwey, 2001). In contrast to traditional crosswalks, innovative crosswalk designs have more positive effects on pedestrian crash risk. High-visibility crosswalks, which use larger painted areas significantly increase pedestrian safety (Feldman, Manzi, & Mitman, 2010; Fitzpatrick, Chrysler, Iragavarapu, & Park, 2011; Guo, & Boyle, 2022; Pulugurtha, Vasudevan, Nambisan, & Dangeti, 2012; Sarwar et al., 2017).

1.1. 3D crosswalks

The “3D zebra crossing” / “3D crosswalk” is a relatively new category of crosswalks which has not been investigated in depth for its effect on safety perceptions by road users. This type of crosswalk uses optical illusions to provoke the perception of a three-dimensional crosswalk from a vehicle driver’s perspective, even though the crosswalk markings are painted flat on the road. I.e., there is a difference between the visual percept of road users (what they perceive) and the visual stimuli (reality). 3D crosswalks have been painted in several pilot projects around the world (e.g., in Aarhus, Denmark (Eurocities, 2021); Chiang Mai, Thailand (Pichayapan, Kaewmoracharoen, Peansara, & Nanthavisit, 2020); Ísafjörður, Iceland (Iceland Magazine, 2017); or Montréal, Canada (Woods, 2018)).

The 3D illusion can take the form of the crossing lines, seemingly floating above the road, or an illusionary cliff can be painted, giving the illusion of a trench in the road. A visualization of a *trench* illusion crosswalk is presented in Fig. 1. The evocation of depth through the painting of a flat, two-dimensional picture is categorized as a *trompe l’oeil illusion* (English: *deceive the eye illusion*) (Wade, & Hughes, 1999). This type of illusion utilizes monocular pictorial depth cues, i.e., visual cues that provide depth information even when

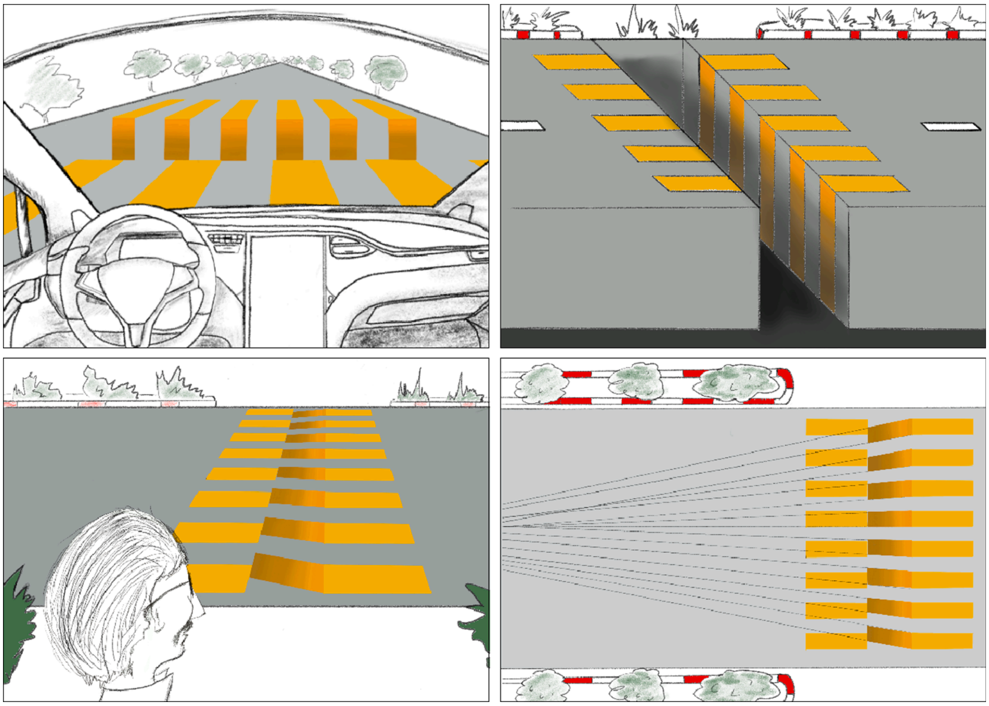

Fig. 1. Visualization of perspectives on a 3D crosswalk with a *trench illusion* (top left: car driver’s perspective when approaching the crosswalk; bottom left: pedestrian’s perspective of the crosswalk; top right: visualization of the crosswalk if the percept matched reality; bottom right: top-down perspective with added linear perspective lines).

an observer closes one eye. Historically, the illusion has been used by artists in paintings, to invoke e.g., the perception of looking into a room, although the painting is flat. In the trench illusion visualized in Fig. 1, three depth cues are used, *linear perspective, overlay*, and *shading*.

Linear perspective is used to give car drivers the impression, that the stripes which go down the illusionary trench are vertical towards the driver (Fig. 1, top left). This is achieved by angling the trench-stripes so that they converge towards the point of view of the driver approaching the crosswalk (Fig. 1, bottom right). In addition, the width of the trench-stripes is slightly distorted to support this perception of vertical stripes. On a traditional crosswalk, all stripes are painted with the same width, i.e., drivers approaching a traditional crosswalk will perceive crosswalk stripes at the far end of the crosswalk as more narrow than those on the closer end, and use this information to understand that the crosswalk stripes are flat on the ground and extending along the road away from them (Grondin, 2016). On the trench illusion crosswalk, the trench-stripes are slightly trapezoidal, i.e., slightly wider on the far end than on the near end. This produces the perception of even width for the trench-stripes, which supports the perception of them being vertical in relation to the observer.

To give the impression that the stripes in the illusionary trench are going vertically down from the road, overlay and shading are used. Overlay is used to give the illusion of one part of the painted surface being in front of another, producing the perception of depth. In the car driver's perspective (Fig. 1, top left), the crosswalk stripes closer to the driver appear to overlap the stripes that go down the illusionary trench. Shading is used to amplify this effect, the stripes that appear to go down the trench are increasing in shading, as if they would be darker because there is less direct light within the illusionary trench. From a pedestrian perspective, the illusion does not work, as the perspective of the trench-stripes is not correct (Fig. 1, bottom left).

While knowledge about the human visual perception is frequently used to investigate car drivers' behavior in the road environment, e.g., by analyzing speed choices in relation to road design features (Charlton et al., 2010) and road markings (Ding et al., 2013), visual illusions and specifically the trompe l'oeil illusion has been explored less. Westerhuis, Jelijs, Fuermaier, and de Waard (2017) investigated whether trompe l'oeil cycling path boundaries would increase cyclists' distance to cycle path curbs, finding that cyclists' distance to the curb actually decreased, contrary to their expectations. Potentially, 3D crosswalks could increase pedestrian safety, through a decrease in the speed of vehicles, as drivers perceive the 3D effect, recognize that they are approaching a special type of crosswalk, and slow down. In addition, 3D crosswalks have the potential for increasing interest in pedestrian safety and could present a public relation outreach tool for road safety actors to generate attention for pedestrian safety, as the news media is likely to publicize the painting of 3D crosswalks (e.g., Eurocities, 2021; Iceland Magazine, 2017; Woods, 2018). Despite the relatively frequent installation of 3D crosswalks around the world, there is only a very limited number of studies on the topic (e.g., using static images: Rebelo, Cerqueira, Freixinho, & Noriega, 2018). In the only available empirical field study on car speed and 3D crossings, an initial decrease in vehicle speeds was found after the crosswalk was painted. Over the span of three months, speeds increased again to earlier levels, which was attributed to faded paint and a related loss of the 3D effect and a hypothesized familiarity of car drivers with the novel crossing (Pichayapan, Kaewmoracharoen, Peansara, & Nanthavisit, 2020). As this study was observational, no data is available on car drivers' and pedestrians' subjective safety related perceptions around 3D crosswalks. In addition, no data was collected comparing traditional and 3D crosswalks.

Apart from the direct relation between crosswalk design and safety, there is a more indirect relation between the availability of crossing facilities and their use by pedestrians. Studies show that the sole presence of safe pedestrian crossing facilities does not automatically facilitate their use, as pedestrians are likely to cross roads at unmarked locations, if the safer crossing facility is too far away or to inconvenient to use (Demiroz, Onelcin, & Alver, 2015; Oviedo-Trespalacios & Scott-Parker, 2017; Sisiopiku, & Akin, 2003). Hence, the willingness of pedestrians to take a detour to use a dedicated crossing facility needs to be factored into potential safety benefits of road crossings (Cantillo, Arellana, & Rolong, 2015). Pedestrian group size at road crossings has also been identified to have an indirect relation to pedestrian safety. Katz, Zaidel, and Elgrishi (1975) report that car drivers are significantly more likely to stop at a road crossing, if there is a group of pedestrians waiting to cross. From a pedestrian perspective, Faria, Krause, and Kraus (2010) found that individual pedestrians were 1.5–2.5 times more likely to start crossing when another pedestrian had begun to cross the road. Similarly, Hamed (2001) found pedestrian group size to be a significant predictor of decreases in waiting time before crossing. Hence, the willingness to take a detour to cross at a given painted crosswalk can also influence pedestrian crossing behavior, as grouping would occur naturally at crosswalks in the road system.

1.2. Research aims

As little is known about pedestrians' and drivers' subjective experience with 3D crosswalks, this research was conducted to learn about road users' perceptions of this novel type of crosswalk. This study aims to investigate the potential of 3D crosswalks to influence both, pedestrians' and car drivers' perceptions of safety as well as their self-reported behavior. Consequently, pedestrians' and drivers' perceptions of risk are assessed, and respondents self-reported and observed behaviors of drivers and pedestrians are compared. In addition, this study contrasts perceptions of a 3D crosswalk with road sections without crosswalks. The survey further assesses the willingness of pedestrians to make a detour to use the new crosswalk, and how pedestrians crossing in groups or alone relates to drivers' behavior. The overall aim of the study is to better understand safety related perceptions of road users around 3D crosswalks. The following research questions are investigated:

1. Is the *3D effect* / optical illusion of the 3D crosswalk registered by the car drivers passing the crosswalk?

2. Does the 3D crosswalk increase perceived safety of road crossing in pedestrians and car drivers compared to traditional crosswalks?

3. Do pedestrians take a detour to use the 3D crosswalk?

4. How does group crossing relate to drivers' stopping frequency?

2. Method

2.1. Data collection location

To assess perceptions and safety related reported behaviors around a 3D crosswalk by pedestrians and car drivers, an on the road survey study was conducted in Yangon, Myanmar. In Myanmar, pedestrians constitute between 14 % and 26 % of road users fatally injured in traffic (Ministry of Health Myanmar, 2014; World Health Organization, 2018). And while the main form of motorized transportation in the country consists of motorcycles (World Health Organization, 2018), they are banned in the commercial capital Yangon, where all motorized transport consists of cars and busses (Siebert, Albers, Naing, Perego, & Santikarn, 2019). In November 2018, a 3D crosswalk was painted on *Pyay Road* in Yangon, between the *Practising High School* of the *Yangon University of Education* and the shopping center *Junction Square*. The 3D crosswalk is designed to generate the illusion of a small trench on the road for drivers that approach the crosswalk while pedestrians do not see this effect (Fig. 2). There had not been a crosswalk at this location before the 3D crosswalk was painted. However, there are two existing traditional crosswalks located approximately 150 m from the 3D crosswalk.

At the point of the road where the crosswalk is located, the road has six lanes (three lanes in each direction), with a raised median between traffic directions. The raised median's primary function is to prohibit U-turns, but pedestrians frequently use it to wait in the middle of the road. On both sides of the road, signs with the word "SLOW" are installed right next to the crosswalk (visible on the top right frame in Fig. 2). There is a high frequency of pedestrian traffic due to the nearby high school, the shopping center, and a bus stop on each side of the road. According to the Myanmar Motor Vehicle Law (Government of the Union of Myanmar, 1989), drivers need to approach pedestrian crosswalks "cautiously" and stop at crosswalks when pedestrians are crossing the road.

2.2. Data collection

A questionnaire survey with 201 pedestrians and 102 car drivers was conducted on three days in December 2018, one month after

Fig. 2. The 3D crosswalk painted in urban Yangon (top left: drivers' perspective; top right: bird's eye view; bottom: top view).

the 3D crosswalk had been painted. All participants were approached between 9 am and 5 pm in the vicinity of the crosswalk and interviewed by three trained interviewers of Kantar TNS Myanmar. Participants from all age groups above 16 years were approached and asked if they'd like to take part in a questionnaire survey. All participants (drivers and pedestrians) answered the questionnaire in Burmese. Response rates were not registered.

Pedestrians and car drivers received different questionnaires, depending on how they arrived at the survey location. All participants answered questions on their demographic background. Pedestrians answered questions on their perceptions of car drivers' behavior and reported their own behavior in crossing scenarios, e.g., phone use while crossing a street. Car drivers answered questions on their behavior and their attitude towards different crossing scenarios, e.g., the perceived safety impact of crosswalks. As 3D crosswalks are a novel concept, no existing questionnaire was used, but explorative single items on 5-point Likert-scales were prepared in English and Burmese. Both questionnaires and survey responses are available in the repository of the Open Science Framework (Siebert, Møller, Lwin, & Albers, 2022).

2.3. Sample

201 pedestrians were surveyed (49.8 % female, 50.3 % male). Mean age of pedestrians was 26.09 years ($SD = 11.59$), ranging from 16 to 82 years. 75.6 % of all respondents received some kind of road safety education in school, while 24.4 % report no prior road safety education. 102 drivers were surveyed (40.2 % female, 59.8 % male). Mean age of drivers was 38.49 years ($SD = 10.56$), ranging from 19 to 67 years.

2.4. Analysis

For both participant groups the demographics and general traffic behavior are described. Wilcoxon rank-sum tests are applied for statistical analysis of the non-parametric 5-point Likert Scale item data. The reported effect size is r and interpreted after Cohen (1992).

3. Results

An overview of the most important findings is presented in this chapter.

3.1. Participants' reported traffic behavior at the investigated road section

The large majority of the surveyed pedestrians is familiar with the surveyed road, crossing it daily (50.8 %) or occasionally (42.8 %). Pedestrians generally report safe behavior for distractions while crossing the road. Only one in ten pedestrians (10.0 %) reports to at least sometimes using the phone or listening to music when crossing the road. Only 9.0 % report running across the road without looking when in a hurry. Of all pedestrians, 62.7 % often (24.9 %) or always (37.8 %) cross the first half of the road and wait in the middle of the roadway between the concrete barriers of the median to cross the second half. Two thirds of pedestrians report to always (18.9 %) or often (40.3 %) cross between vehicles stopped on the roadway in traffic jams.

More than half of the interviewed pedestrians rate the speed of cars at this road section as normal (58.7 %). The pedestrians' perception generally is that cars only sometimes (57.2 %) slow down or stop to let them pass. Most of pedestrians agree (53.7 %) or strongly agree (17.4 %) that cars only slow down or stop on this street if there is a traffic jam. When crossing the road alone, almost half of the pedestrians report that cars slow down or stop rarely (24.4 %) or never (22.9 %). Only 3.0 % report that cars always slow down for individuals. When crossing the road in groups, more than half of the pedestrians report that cars slow down or stop often (34.8 %) or

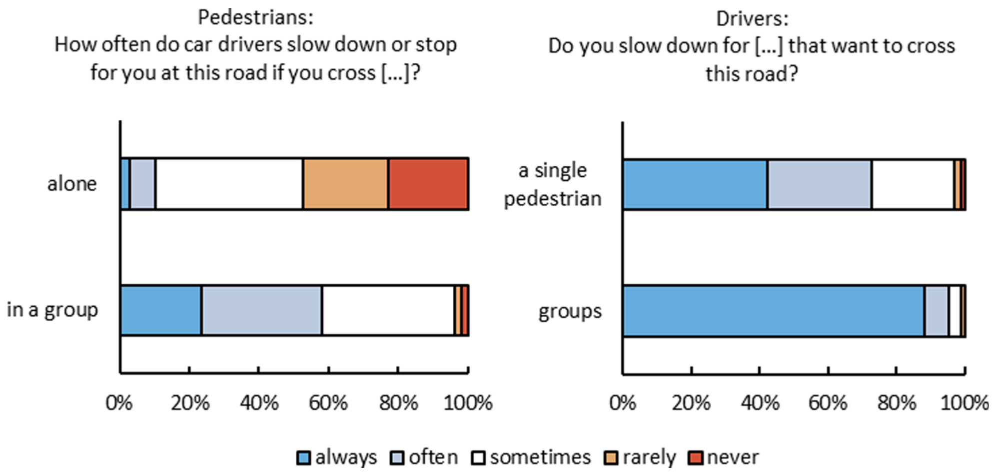

Fig. 3. Stopping frequency for individual pedestrians and groups, reported by pedestrians (left; $N = 201$) and car drivers (right; $N = 102$).

always (23.4 %). Only 4.0 % report that cars rarely (2.0 %) or never (2.0 %) slow down for groups. Fig. 3 illustrates the pedestrians' perceptions of the drivers' yielding behavior for different crossing settings. Pedestrians report that drivers are significantly more likely to stop for groups (*Mdn* = 2; *often*) than for individuals (*Mdn* = 3; *sometimes*), V = 11,573, p <.001, r = -0.51. Consequently, the majority of pedestrians try to cross this road in a group of people often (35.8 %) or always (27.9 %). Only 12.9 % of pedestrians perceive crossing the road as safe or very safe, 11.4 % report that crossing this road section is very risky.

Almost all drivers use the surveyed street daily (57.8 %) or occasionally (40.2 %). All interviewed drivers except one (99.0 %) knew about the nearby school. About half of the drivers (43.1 %) were in the area to pick up their children from school. Most drivers (77.5 %) report to drive normal speeds at this part of the road while 9.8 % state to drive fast speeds and 11.6 % report driving slow speeds. Almost all drivers report to slow down always (75.5 %) or often (16.7 %) to let pedestrians cross this road. For crosswalks, drivers report to slow down always (80.4 %) or often (14.7 %) to let pedestrians pass. When there is heavy traffic on this street, 95.1 % of drivers report to let pedestrians pass always (82.4 %) or often (12.8 %). If pedestrians are already on the road, most drivers report to always (69.6 %) or often (17.7 %) let them pass. Drivers report to be more likely to slow down for groups ("always" = 88.2 %) than for single pedestrians ("always" = 42.2 %). Fig. 3 illustrates the drivers' reported behavior for different crossing settings. Drivers report to significantly stop more often for groups (*Mdn* = 1; *always*) than for individuals (*Mdn* = 2; *often*), V = 1,275, p <.001, r = -0.45. When asked to judge how risky it is for pedestrians to cross the surveyed road in general, drivers report that it is risky (44.1 %) or very risky (26.5 %) to cross for pedestrians. Half of the drivers (51.0 %) report that crosswalks in general enhance pedestrian safety. However, a quarter of the interviewed drivers indicate that crosswalks generally make pedestrians less safe (20.6 %) or even much less safe (5.9 %).

3.2. Participants' perception of the 3D crosswalk

Most pedestrians agree (66.7 %) or strongly agree (6.0 %) that the new crosswalk is special. 31.3 % report to have talked with their friends about it. Approximately half of the pedestrians (46.8 %) report that car drivers are now more likely to slow down due to the new 3D crosswalk. 61.7 % report that drivers are now more likely to stop if the pedestrian is already crossing. In traffic jams, pedestrians report that only few drivers tend to leave the space of the new crosswalk free for people to cross always (5.5 %) or often (8.0 %).

A majority of pedestrians report that crossing the road is now safer (59.2 %) or much safer (3.5 %) with the new 3D crosswalk. 35.8 % report that there is no difference, and only 3 out of 201 pedestrians (1.5 %) perceive crossing the road as less safe than before (without any crosswalk). When asked to generally compare the 3D crosswalk to a traditional crosswalk, more than half of the pedestrians rate the 3D crosswalk as safer (52.7 %) or much safer (5.0 %) than a traditional crosswalk. Only 2.0 % of pedestrians rate it as less safe (Fig. 4). Regarding a change in traffic behavior, 43.3 % of pedestrians report to always (22.4 %) or often (20.9 %) take a detour to use the new 3D crosswalk when they want to cross the surveyed road (Fig. 5).

Of all 102 drivers interviewed, about three-quarters (73.5 %) noticed the new crosswalk ("Did you notice a new crosswalk on your way here?"). The drivers which had noticed the crosswalk had passed it close to 30 times on average (M = 29.11, SD = 30.00, Min = 2, Max = 99). All drivers that had noticed the new crosswalk also identified it as special. Asked what made the crosswalk special in a single choice item (*different color* | *bigger* | *3D crosswalk* | *other*) a majority of drivers (73.3 %) indicated the 3D illusion of the crosswalk, followed by a bigger size (16.0 %), and different color (10.7 %). About half of the drivers (48.0 %) report to have talked with their friends about the new crosswalk.

A majority of drivers report that pedestrian crossing at the road is now safer (56.0 %) or much safer (5.3 %) with the new 3D crosswalk. 37.3 % report that there is no difference, and only 1 out of 75 drivers that had noticed the crosswalk perceive crossing the road as less safe than before (1.3 %). When asked to generally compare the 3D crosswalk to a traditional crosswalk, more than half of

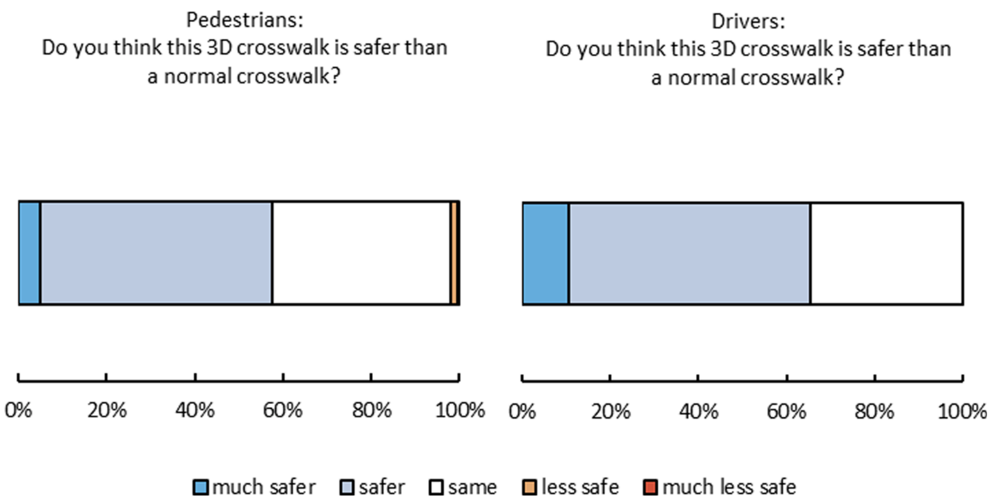

Fig. 4. Pedestrians' (left; N = 201) and car drivers' (right; N = 102) perceived safety of the 3D crosswalk compared to a traditional crosswalk.

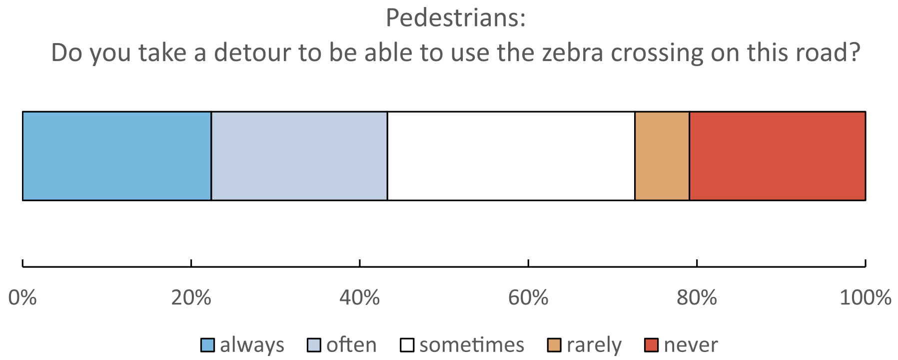

Fig. 5. Pedestrians' ($N = 201$) reported frequency of taking a detour to use the new 3D crosswalk.

the drivers rate the 3D crosswalk as safer (54.7 %) or much safer (10.7 %) for pedestrians than a normal crosswalk. None of the drivers rate it as less safe (Fig. 4). 6.7 % of drivers that noticed the new crosswalk think it is dangerous (5.3 %) or very dangerous (1.3 %) for drivers. Regarding a change in driving behavior, three-quarters (73.3 %) of drivers report that they are more likely (61.3 %) or much more likely (12.0 %) to slow down for pedestrians due to the new crosswalk. In traffic jams, most drivers report to leave the space of the new crosswalk free for people to cross always (61.3 %) or often (16.0 %).

4. Discussion

The goal of this study was to learn more about drivers' and pedestrians' safety related perceptions of a novel 3D crosswalk, which is painted to produce an optical illusion in car drivers approaching the crosswalk. While multiple 3D crosswalks have been painted globally, their impact on road users' safety-related perceptions had not been assessed. This study is the first to collect subjective data of pedestrians and drivers around a 3D crosswalk. The 3D crosswalk painted in Yangon, Myanmar represents a new type of painted crosswalk, which has not been extensively investigated for safety related perceptions of road users so far.

In our first research question, we investigated whether car drivers perceive the intended optical illusion, i.e., if they correctly identify that the crosswalk is special, because it evokes a *3D effect* in drivers. Of 102 drivers that were interviewed, approximately 75 % generally noticed the new crosswalk, of which approximately 75 % identified the *3D effect*. That is of the 102 drivers interviewed, 53.9 % reported to have perceived the optical illusion. As the 3D effect represents a novel type of road infrastructure which could potentially be used to promote road safety of pedestrians, our finding that 48.0 % of drivers have talked to friends about the 3D crosswalk is promising. For interviewed pedestrians, who do not perceive the optical illusion from their perspective, this number was lower, with only approximately one third of pedestrians reporting to have talked with friends about the 3D crosswalk. One potential reason for the relatively low conspicuity of the general crosswalk and the 3D effect for car drivers could be visual occlusion during traffic jams, where cars obstruct the view on the crosswalk. In addition, the relatively low recall rate of the 3D crosswalk in drivers, could be due to inattentional blindness, an effect found for drivers that frequently drive a similar route (Charlton, & Starkey, 2013, 2018). However, the 3D effect of the crosswalk should generally lead to a higher conspicuity of the pedestrian crossing and should be strong enough to disrupt the driving without awareness effect. Hence, our results on a relatively low conspicuity of the 3D crosswalk need to be investigated further.

In our second research question, we investigated whether the 3D crosswalk increases the perceived safety of pedestrian road crossings from pedestrians' as well as car drivers' perspectives. Our results indicate that safety perceptions are positively influenced, as the majority of pedestrians (57.7 %) rate the 3D crosswalk as safer or much safer for crossing, compared to a traditional crosswalk. Car drivers have similar perceptions, with 65.3 % rating the 3D crosswalk as safer or much safer for pedestrian crossing in comparison to a traditional crosswalk. It is important to note that the perceived level of safety, does not necessarily correspond to the actual level of safety (Cho et al., 2009), and that road users might compensate for a higher level of perceived safety, by showing riskier behavior (Wilde, 1982). In this study, only the perceptions of road users were investigated, which does not allow a direct transfer to actual behavior.

For road users' perceptions of increased safety of road crossings on the 3D crosswalk in comparison to traditional crosswalks, there are a number of potential reasons. Unrelated to the 3D effect of the crosswalk, road users could perceive the painted area of the 3D crosswalk as larger compared to traditional crosswalks. The drawing pattern used to produce the optical illusion of the 3D crosswalk (Fig. 2) breaks apart the straight lines that make up a traditional crosswalk, which could lead to a perceived increase of the painted area, and thereby the perceived visibility of the 3D crosswalk. Related to this, road users might compare the visibility of the *newly* painted 3D crosswalk to the average visibility of *older* traditional crosswalks that they encounter in the road system. As the majority of traditional crosswalks that road users encounter will be considerably older than the 3D crosswalk, their paint will have faded more, potentially decreasing objective as well as perceived visibility of traditional crosswalks in comparison to the new 3D crosswalk. Increased safety perceptions due to a perceived larger painted area and higher color intensity of the 3D crosswalk would be in line with research that shows a relation between the visibility of a crosswalk and pedestrian safety (Feldman, Manzi, & Mitman, 2010; Fitzpatrick, Chrysler, Iragavarapu, & Park, 2011; Guo, & Boyle, 2022; Pulugurtha, Vasudevan, Nambisan, & Dangeti, 2012; Sarwar et al., 2017). However, our data on car drivers' perception of the crosswalk indicates that there is at least a partial effect of the optical illusion on safety related perceptions, as the majority of drivers (73.3 %) who report to have noticed the new crosswalk, mention the 3D effect as the reason for its *'specialness'*.

In our third research question, we investigated whether pedestrians report to take a detour to use the 3D crosswalk to cross the street. In our survey, we found that a large share of pedestrians (43.3 %) always or often take a detour to use the new 3D crosswalk when they want to cross the surveyed road. This result is especially interesting considering the two existing traditional crosswalks located approximately 150 m from the 3D crosswalk. Hence, our findings indicate, that the 3D crosswalk could be preferred for road crossings, over the available traditional crosswalks. As before, it is not only the 3D effect of the novel crosswalk that could potentially relate to this result. A higher perceived general visibility of the 3D crosswalk, either due to the new paint, or a perceived larger painted area could potentially explain this effect. In addition, pedestrians might be more prone to use the 3D crosswalk due to its novelty, an effect that might wear off after some time. In light of research that the ease of use and willingness to take a detour significantly relates to the use of dedicated crossing facilities (Cantillo, Arellana, & Rolong, 2015; Demiroz, Onelcin, & Alver, 2015; Oviedo-Trespalacios & Scott-Parker, 2017; Sisiopiku, & Akin, 2003), our results indicate a relatively high willingness for detours to use the 3D crosswalk.

In our fourth research question, we investigated how group crossing relates to car drivers' stopping behavior. We found a significant difference in car drivers' stopping frequency perceived by pedestrians. Pedestrians report that drivers are significantly more likely to stop for groups than for individual pedestrians. This perception could potentially relate to the majority (63.7 %) of pedestrians in the survey trying to cross in groups often or always. Car drivers report a similar perception and report to slow down significantly more often for pedestrian groups than for individual pedestrians that want to cross. These findings are consistent with earlier research, which found a significant relation between group size and car stopping frequency / pedestrian waiting times (Faria, Krause, & Kraus, 2010; Hamed, 2001; Katz, Zaidel, & Elgrishi, 1975). While these results are not specific to 3D crosswalks, i.e., this effect has been observed for road crossing in general, there is a potential benefit of a 3D crosswalk. Our data indicates that pedestrians perceive the 3D crosswalk as safe, and take detours to use it (our third research question), hence the 3D crosswalk could help to facilitate pedestrian grouping, which in turn would increase the likelihood of car drivers yielding, to let pedestrians cross.

While our questionnaire survey of pedestrians and car drivers revealed multiple positive perceptions relating to the 3D crosswalk, there are a number of limitations and future research needs, that need to be taken into account when interpreting the study results. One limitation is the retrospective nature of the data collection. At the time of the survey, the 3D crosswalk had already been painted. Hence, participants were asked to retrospectively report the impact of the newly painted crosswalk, potentially leading to an imprecise recall of e.g., earlier perceived safety at this part of the road. Future studies should include a pre-survey that can be used as a baseline measurement for safety judgements of roads before 3D crosswalks are painted. Although the Myanmar traffic law stipulates the right of way of pedestrians on crosswalks, studies have found that additional variables such as social norms (Schneider & Sanders, 2015) and law compliance (Britt, Bergman, & Moffat, 1995) relate to vehicle stopping rates. I.e., in a road environment with e.g., a high level of law compliance, the potential added safety benefit of a 3D crosswalk might only be incremental, as general compliance is already high.

An additional major limitation of this study is the lack of observational data on pedestrian and car driver behavior. This lack of observational data could be critical, as the only available study on behavior around 3D crosswalks indicates that a short-term decrease in car speeds could disappear after a small number of weeks (Pichayapan, Kaewmoracharoen, Peansara, & Nanthavisit, 2020). As a related limitation, the data collection over a short timeframe could potentially lead to an incorrect assessment of the safety related perceptions of road users for longer time spans. Future studies should therefore plan for multiple perception assessments, which would take into account longer-term effects. Due to the stated limitations, this study should not be used to make a general argument for or against the installation of 3D crosswalks, as the data collection was limited in the temporal scope, and no observed behavioral data was collected.

In light of the global efforts to decrease injuries and fatalities in the road system, there is a general limitation in aiming to increase road safety mainly through influencing road users' behavior. As researchers have correctly pointed out, eliminating crash risks through separated road infrastructure is a much more effective way to increase road users' safety (McLeod & Curtis, 2020), which is why structured approaches to road safety such as the *safe system approach* place safe infrastructure in the center of road safety efforts (Johansson, 2009). Still, the perceptions of road users in regard to this infrastructure need to be investigated.

Overall, the investigated 3D crosswalk painted in Yangon has a positive impact on the perceived safety of drivers and pedestrians. It further presents a tool, to publicize efforts that are aimed at improving pedestrian safety. Further studies need to be conducted to investigate how these perceived safety benefits translate to actual safety related behavior.

CRediT authorship contribution statement

Felix Wilhelm Siebert: Conceptualization, Formal analysis, Methodology, Project administration, Visualization, Writing – original draft, Supervision. **Mette Møller:** Conceptualization, Writing – review & editing. **Aye Moe Moe Lwin:** Conceptualization, Methodology, Writing – review & editing. **Deike Albers:** Data curation, Formal analysis, Methodology, Visualization, Writing – original draft.

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

The data used in this study is available in the repository of the Open Science Framework (OSF), accessible under this link: https://www.doi.org/10.17605/OSF.IO/6G8VS

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References

Basu, N., Oviedo-Trespalacios, O., King, M., Kamruzzaman, M., & Haque, M. M. (2022). The influence of the built environment on pedestrians' perceptions of attractiveness, safety and security. *Transportation Research Part F: Traffic Psychology and Behaviour, 87*, 203–218.
Britt, J. W., Bergman, A. B., & Moffat, J. (1995). Law enforcement, pedestrian safety, and driver compliance with crosswalk laws: Evaluation of a four-year campaign in Seattle. *Transportation Research Record, 1485*, 160–167.
Bunn, F., Collier, T., Frost, C., Ker, K., Roberts, I., & Wentz, R. (2003). Traffic calming for the prevention of road traffic injuries: Systematic review and meta-analysis. *Injury Prevention, 9*(3), 200–204.
Cantillo, V., Arellana, J., & Rolong, M. (2015). Modelling pedestrian crossing behaviour in urban roads: A latent variable approach. *Transportation Research Part F: Traffic Psychology and Behaviour, 32*, 56–67.
Charlton, S. G., Mackie, H. W., Baas, P. H., Hay, K., Menezes, M., & Dixon, C. (2010). Using endemic road features to create self-explaining roads and reduce vehicle speeds. *Accident Analysis & Prevention, 42*(6), 1989–1998.
Charlton, S. G., & Starkey, N. J. (2013). Driving on familiar roads: Automaticity and inattention blindness. *Transportation Research Part F: Traffic Psychology and Behaviour, 19*, 121–133.
Charlton, S. G., & Starkey, N. J. (2018). Memory for everyday driving. *Transportation Research Part F: Traffic Psychology and Behaviour, 57*, 129–138.
Cho, G., Rodríguez, D. A., & Khattak, A. J. (2009). The role of the built environment in explaining relationships between perceived and actual pedestrian and bicyclist safety. *Accident Analysis & Prevention, 41*(4), 692–702.
Cohen, J. (1992). A power primer. *Psychological Bulletin, 122*(1), 155–159.
Demiroz, Y. I., Onelcin, P., & Alver, Y. (2015). Illegal road crossing behavior of pedestrians at overpass locations: Factors affecting gap acceptance, crossing times and overpass use. *Accident Analysis & Prevention, 80*, 220–228.
Ding, H., Zhao, X., Rong, J., & Ma, J. (2013). Experimental research on the effectiveness of speed reduction markings based on driving simulation: A case study. *Accident Analysis & Prevention, 60*, 211–218.
Eurocities (2021, September 30). Managing urban traffic: 3D zebra crossings spread across Europe. https://eurocities.eu/stories/managing-urban-traffic-3d-zebra-crossings-spread-across-europe/.
Faria, J. J., Krause, S., & Krause, J. (2010). Collective behavior in road crossing pedestrians: The role of social information. *Behavioral Ecology, 21*(6), 1236–1242.
Feldman, M., Manzi, J. G., & Mitman, M. F. (2010). Empirical Bayesian evaluation of safety effects of high-visibility school (yellow) crosswalks in San Francisco, California. *Transportation Research Record, 2198*(1), 8–14.
Fitzpatrick, K., Chrysler, S. T., Iragavarapu, V., & Park, E. S. (2011). Detection distances to crosswalk markings: Transverse lines, continental markings, and bar pairs. *Transportation Research record, 2250*(1), 1–10.
Government of the Union of Myanmar. (1989). 1989 Motor Vehicle Rules, Appendix F. Retrieved from: https://www.myanmarrtad.com/?q=my/node/118.
Grondin, S. (2016). Depth Perception. In *Psychology of Perception* (pp. 103–122). Cham: Springer.
Guo, H., & Boyle, L. N. (2022). Driving behavior at midblock crosswalks with rectangular rapid flashing beacons: Hidden Markov model approach using naturalistic data. *Accident Analysis & Prevention, 165*, Article 106406.
Hamed, M. M. (2001). Analysis of pedestrians' behavior at pedestrian crossings. *Safety Science, 38*(1), 63–82.
Iceland Magazine (2017, September 25). Photos, Video: 3D crosswalk in Ísafjörður helps slow down speeding motorists. https://icelandmag.is/article/photos-video-3d-crosswalk-isafjordur-helps-slow-down-speeding-motorists.
Johansson, R. (2009). Vision Zero-Implementing a policy for traffic safety. *Safety Science, 47*(6), 826–831.
King, M., Carnegie, J., & Ewing, R. (2003). Pedestrian safety through a raised median and redesigned intersections. *Transportation Research Record: Journal of the Transportation Research Board, 1828*, 56–66.
Katz, A., Zaidel, D., & Elgrishi, A. (1975). An experimental study of driver and pedestrian interaction during the crossing conflict. *Human Factors, 17*(5), 514–527.
McLeod, S., & Curtis, C. (2020). Integrating urban road safety and sustainable transportation policy through the hierarchy of hazard controls. *International Journal of Sustainable Transportation*, 1–30.
Ministry of Health Myanmar. (2014). Injury Surveillance Report. Retrieved from: http://www.searo.who.int/entity/disabilities_injury_rehabilitation/country_experiences/isreport2010-2013mmr.pdf.
Otte, D., Jänsch, M., & Haasper, C. (2012). Injury protection and accident causation parameters for vulnerable road users based on German in-depth Accident Study GIDAS. *Accident Analysis & Prevention, 44*(1), 149–153.
Oviedo-Trespalacios, O., & Scott-Parker, B. (2017). Footbridge usage in high-traffic flow highways: The intersection of safety and security in pedestrian decision-making. *Transportation Research Part F: Traffic Psychology and Behaviour*, *49*, 177-187.
Pichayapan, P., Kaewmoracharoen, M., Peansara, T., & Nanthavisit, P. (2020). Urban school area road safety improvement and assessment with a 3D piano-keyboard-styled pedestrian crossing approach: A case study of chiang mai university demonstration school. *Sustainability, 12*(16), 6464.
Pulugurtha, S., Vasudevan, V., Nambisan, S., & Dangeti, M. (2012). Evaluating effectiveness of infrastructure-based countermeasures for pedestrian safety. *Transportation Research Record: Journal of the Transportation Research Board, 2299*, 100–109.
Rebelo, F., Cerqueira, D., Freixinho, I., & Noriega, P. (2018, July). Evaluation of 3d crosswalks design. In *International conference on applied human factors and ergonomics* (pp. 89-96). Springer, Cham.
Retting, R. A., Ferguson, S. A., & McCartt, A. T. (2003). A review of evidence-based traffic engineering measures designed to reduce pedestrian–motor vehicle crashes. *American Journal of Public Health, 93*(9), 1456–1463.
Sarwar, M. T., Fountas, G., Bentley, C., Anastasopoulos, P. C., Blatt, A., Pierowicz, J., … Limoges, R. (2017). Preliminary investigation of the effectiveness of high-visibility crosswalks on pedestrian safety using crash surrogates. *Transportation Research Record, 2659*(1), 182–191.
Schneider, R. J., & Sanders, R. L. (2015). Pedestrian safety practitioners' perspectives of driver yielding behavior across North America. *Transportation Research Record, 2519*(1), 39–50.

Siebert, F. W., Albers, D., Naing, U. A., Perego, P., & Santikarn, C. (2019). Patterns of motorcycle helmet use–A naturalistic observation study in Myanmar. *Accident Analysis & Prevention, 124*, 146–150.

Siebert, F. W., Møller, M., Lwin, A. M., & Albers, D. (2022). Illusion of safety? Safety-related perceptions of pedestrians and car drivers around 3D crosswalks. *Data Repository Open Science Framework*. https://doi.org/10.17605/OSF.IO/6G8VS

Sisiopiku, V. P., & Akin, D. (2003). Pedestrian behaviors at and perceptions towards various pedestrian facilities: An examination based on observation and survey data. *Transportation Research Part F: Traffic Psychology and Behaviour, 6*(4), 249–274.

Stipancic, J., Miranda-Moreno, L., Strauss, J., & Labbe, A. (2020). Pedestrian safety at signalized intersections: Modelling spatial effects of exposure, geometry and signalization on a large urban network. *Accident Analysis & Prevention, 134*, Article 105265.

Stoker, P., Garfinkel-Castro, A., Khayesi, M., Odero, W., Mwangi, M. N., Peden, M., & Ewing, R. (2015). Pedestrian safety and the built environment: A review of the risk factors. *Journal of Planning Literature, 30*(4), 377–392.

Vignali, V., Cuppi, F., Acerra, E., Bichicchi, A., Lantieri, C., Simone, A., & Costa, M. (2019). Effects of median refuge island and flashing vertical sign on conspicuity and safety of unsignalized crosswalks. *Transportation Research Part F: Traffic Psychology and Behaviour, 60*, 427–439.

Vignali, V., Pazzini, M., Ghasemi, N., Lantieri, C., Simone, A., & Dondi, G. (2020). The safety and conspicuity of pedestrian crossing at roundabouts: The effect of median refuge island and zebra markings. *Transportation Research Part F: Traffic Psychology and Behaviour, 68*, 94–104.

Wade, N. J., & Hughes, P. (1999). Fooling the eyes: Trompe l'oeil and reverse perspective. *Perception, 28*(9), 1115–1119.

Westerhuis, F. F., Jelijs, L. B., Fuermaier, A. A., & de Waard, D. D. (2017). Using optical illusions in the shoulder of a cycle path to affect lateral position. *Transportation Research Part F: Traffic Psychology and Behaviour, 48*, 38–51.

Wilde, G. J. (1982). The theory of risk homeostasis: Implications for safety and health. *Risk Analysis, 2*(4), 209–225.

Woods, A. (2018, July 11). Montreal 3D crosswalk experiment messing with drivers' minds to increase pedestrian safety. Toronto Star. https://www.thestar.com/news/canada/2018/07/11/montreal-tries-out-3d-crosswalks-in-bid-to-improve-pedestrian-safety.html.

World Health Organization (2018) Global Status Report on Road Safety 2018. World Health Organization. Retrieved from: https://www.who.int/violence_injury_prevention/%20road_safety_status/2018/en/.

Yasin, Y. J., Grivna, M., & Abu-Zidan, F. M. (2020). Reduction of pedestrian death rates: A missed global target. *World Journal of Emergency Surgery, 15*(1), 1–6.

Zegeer, C. V., & Bushell, M. (2012). Pedestrian crash trends and potential countermeasures from around the world. *Accident Analysis & Prevention, 44*(1), 3–11.

Zegeer, C. V., Stewart, J. R., Huang, H., & Lagerwey, P. (2001). Safety effects of marked versus unmarked crosswalks at uncontrolled locations: Analysis of pedestrian crashes in 30 cities. *Transportation Research Record, 1773*(1), 56–68.