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The estimation of vehicle speed and stopping distance by pedestrians crossing streets in a naturalistic traffic environment

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ABSTRACT

The ability to estimate vehicle speed and stopping distance accurately is important for pedestrians to make safe road crossing decisions. In this study, a field experiment in a naturalistic traffic environment was conducted to measure pedestrians' estimation of vehicle speed and stopping distance when they are crossing streets. Forty-four participants (18–45 years old) reported their estimation on 1043 vehicles, and the corresponding actual vehicle speed and stopping distance were recorded. In the speed estimation task, pedestrians' performances change in different actual speed levels and different weather conditions. In sunny conditions, pedestrians tended to underestimate actual vehicle speeds that were higher than 40 km/h but were able to accurately estimate speeds that were lower than 40 km/h. In rainy conditions, pedestrians tended to underestimate actual vehicle speeds that were higher than 45 km/h but were able to accurately estimate speeds ranging from 35 km/h to 45 km/h. In stopping distance estimation task, the accurate estimation interval ranged from 60 km/h to 65 km/h, and pedestrians generally underestimated the stopping distance when vehicles were travelling over 65 km/h. The results show that pedestrians have accurate estimation intervals that vary by weather conditions. When the speed of the oncoming vehicle exceeded the upper bound of the accurate interval, pedestrians were more likely to underestimate the vehicle speed, increasing their risk of incorrectly deciding to cross when it is not safe to do so.

1. Introduction

1.1. Background

With the increasing use of automobiles worldwide, pedestrian safety is quite a problem to be solved. According to a report issued by WHO (World Health Organization, 2013), approximately 270,000 pedestrians worldwide were killed in 2010, accounting for 22% of the total fatalities caused by traffic accidents. During the year of 2010 in Germany, nearly 500 pedestrians were killed, accounting for 13% of the road traffic fatalities; France has similar pedestrian fatality rates to Germany. The African region has the highest road traffic fatality rate, and 38% of these fatalities are pedestrians (World Health Organization, 2013). In the United States, 4280 pedestrians were killed and nearly 70,000 were wounded in traffic

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accidents in 2010 (National Highway Traffic Safely Administration, 2012). In China (Traffic Administration Bureau, 2010), the total fatalities caused by road traffic accidents have decreased slowly during the past ten years. However, the number of pedestrians killed in traffic accidents remains huge. In 2010, 16,281 pedestrians were killed in automobile accidents, accounting for 24.96% of the total traffic accident fatalities, while 44,629 pedestrians were injured, accounting for 17.57% of the total traffic accidents injuries. It requires great efforts to improve pedestrian safety and decrease the pedestrian fatalities. To some extents, knowing more about the crossing behaviors of the pedestrians may be helpful to figure out the causes of the accidents and improve pedestrian safety.

Although accidents may result from unsafe behaviors of the vehicle drivers, unsafe behaviors of the pedestrians due to poor judgments of the distance away and/or speed of approaching vehicles (Hunt, Harper, & Lie, 2011) has also been shown to play a role. Street-crossing is a continuous interaction between pedestrians and oncoming vehicles (Svensson & Hyden, 2006). A pedestrian makes a crossing decision based on the judgment of whether a gap in the traffic is large enough to pass safely. Gap judgment is a complex task that involves accurate perception and integration of distance and speed information (Oxley, Ihsen, Fildes, Charlton, & Day, 2005). By means of either simulated experiments (Oxley et al., 2005; Simpson, Johnston, & Richardson, 2003) or field surveys (Yannis, Papadimitriou, & Theofilatos, 2013), previous research has showed that pedestrians' gap selections were primarily based on vehicle distance and less so on the corresponding time gap.

In general situations, as a simulated study showed (Oxley et al., 2005), pedestrians tend to make more positive crossing decisions (press the "YES" key representing they would cross the street) when the distance gap is large, ignoring the increased vehicle speed. It seems that pedestrians sometimes do not take vehicle speeds into account when making crossing decisions. Hence pedestrians will probably choose insufficient time gaps, which are inversely proportional to the vehicle speeds especially when vehicles travel at high speed. Another explanation may be that although pedestrians do consider the vehicle speed, the speed they considered was not judged accurately due to insufficient estimation ability. In this case, inaccurate estimation of vehicle speed may lead to more dangerous street-crossing decisions, thus it is important to explore the ability of pedestrians to accurately estimate vehicle speed while crossing streets.

Pedestrian judgments of vehicle gaps are usually conservative in most occasions: First, pedestrians have already left a buffer in their critical gaps, as evidenced by the safety margin in Zhuang and Wu (2012). That is, vehicles usually arrived after pedestrians had passed for some time t. In the most extreme case, t equals zero, which means that pedestrians have made a highly risky decision that will put them in a near miss. Second, to ensure safety, pedestrians usually assume that drivers do not change speed after seeing them. If the driver yields, the available gap becomes larger. The two conservative estimations, acting as buffer mechanisms, ensure that pedestrians can cross safely in most cases, even when they unintentionally misjudged the gap. In emergent situations, pedestrians who are urgent to cross the street could use up this buffer zone to cross with the minimum gap: the gap allows them to pass with a safety margin of zero ($t = 0$) if the vehicle brakes for them. Obviously, this gap presented in distance is the vehicle's stopping distance. Therefore, the ability to make safe estimations (accurate or overestimations) of vehicle stopping distances is also important. As no studies were available on this topic, it is included in the study to explore the relationship of pedestrian-estimated and actual stopping distance.

1.2. Speed estimation

Pedestrian speed estimation is under explored in literature; The only study we found was Troscianko's work (Troscianko, Wright, & Wright, 1999). In that study, ten participants were asked to estimate the vehicle in real traffic from an interior site that generally eliminated nonvisual cues. The results showed that participants significantly underestimated vehicle speed (Troscianko et al., 1999). Although the experimental control is rigorous, the observation site is not the natural site where most pedestrians estimate vehicle speed, and the sample size is not big enough, which decreased its external validity. Therefore, this study will conduct a field study to investigate the speed estimation of pedestrians. Besides the natural context of study, this work also explored how different environmental factors related with speed estimation.

Since previous work on pedestrian speed estimation is rare, related studies were reviewed here to find possible factors that might affect pedestrians' speed estimation. An analysis of speeding records conducted by Cherry and Andrade (2001) indicates that brightly colored vehicles regularly receive tickets for comparatively lower speeds, meaning that bright color may lead to overestimations of speed. Horswill and Plooy (2008) investigated the effect of reducing image contrast on speed estimation in a simulated experiment and found vehicle speeds were perceived to be slower in reduced contrast condition. A common weather condition that may reduce the contrast is a rainy condition, as the heavy sky is gloomy and the raindrops block the line of sight. Therefore, rainy conditions, as compared with sunny ones, may have a different effect on how pedestrians estimate speed. Besides the two factors borrowed from driver studies, a factor peculiar to pedestrian is that they need to estimate speed at different positions. As shown by Zhuang and Wu (2011), pedestrians crossing a wide road usually cross it in halves separately. It was also found that pedestrian crossing the second stage is more risky in making decisions than when they are at the roadside (Li & Fernie, 2010). It may be possible that their estimations of vehicle speed are not the same at the two positions. Therefore, the experiment included view position as one possible factor and set two levels for it: at the roadside, and on the traffic island (the middle of the road).

Consequently, we have three factors (weather, vehicle color, view position) that should be incorporated into the current work when addressing pedestrians' speed estimation of the approaching vehicle.

Basic psychological studies on visual perception of velocity can provide the current work with some ideas about other factors that may affect the estimation. Brown (1931) carried out a series of experiments to investigate the phenomenal speed