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Effects of mobile phone distraction on pedestrians' crossing behavior and visual attention allocation at a signalized intersection: An outdoor experimental study

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ABSTRACT

With the rapid growth in mobile phone use worldwide, traffic safety experts have begun to consider the impact of mobile phone distractions on pedestrian crossing safety. This study sought to investigate how mobile phone distractions (music distraction, phone conversation distraction and text distraction) affect the behavior of pedestrians while they are crossing the street. An outdoor-environment experiment was conducted among 28 college student pedestrians. Two HD videos and an eye tracker were employed to record and analyze crossing behavior and visual attention allocation. The results of the research showed that the three mobile phone distractions cause different levels of impairment to pedestrians' crossing performance, with the greatest effect from text distraction, followed by phone conversation distraction and music distraction. Pedestrians distracted by music initiate crossing later, have increased pupil diameter, and reduce their scanning frequency, fixation points and fixation times toward traffic signal area priorities. In addition to the above effects, pedestrians distracted by phone conversation cross the street more slowly, direct fewer fixation points to the right traffic area, and spend less fixation time and lower average fixation duration on the left traffic area. Moreover, pedestrians distracted by texting look left and right less often and switch, distribute and maintain less visual attention on the traffic environment. These findings may inform researchers, policy makers, and pedestrians.

1. Introduction

As the prevalence of mobile phones has increased, the number of pedestrians who use mobile phones while crossing the street has risen globally. According to a recent observational study in China, approximately one-third of pedestrians displayed mobile-phone-distracted activity while crossing the street (Zhao et al., 2015). An authoritative poll in the United States even indicated that approximately 60% of adults admitted using mobile phones while crossing the street (Liberty Mutual Insurance, 2013).

Pedestrians' mobile phone use behavior while crossing, which is a typical multi-tasking activity like distracted driving, requires them to complete two complex tasks simultaneously. First, pedestrians must observe the surrounding traffic environment carefully, including approaching vehicles, traffic signs, and signals, and must assess vehicles' traveling speed, distance and arrival time to ensure their crossing safety. Second, pedestrians are compelled to pay visual, auditory and cognitive attention to check and operate their mobile phones to keep in touch with their social circle. Thus, mobile phone use distracts pedestrians' attention from the complex traffic environment, which may cause pedestrians to miss critical traffic information and to make incorrect assessments and be exposed to a higher risk of collision (Bungum et al., 2005; Tabibi and Pfeffer, 2007). However, mobile phone use behavior while crossing is not always considered an imminent threat by most pedestrians. This behavior has received less social attention and fewer legal restraints than mobile phone use behavior while driving.

Despite being often overlooked, mobile phone distraction has become recognized in the academic field as one of the major contributors to fatal and non-fatal pedestrian crashes. Injury data from the US Consumer Product Safety Commission indicates that the number of mobile-phone-related injuries among pedestrians increased during the period from 2005 to 2010, and in 2010, it even exceeded the number of injuries for drivers (Nasar and Troyer, 2013).

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Meanwhile, the negative effects of mobile phone distraction on pedestrians' crossing performance have been examined by numerous studies, including observational surveys and virtual-environment experiments. Mobile phone distraction was reported to have a significant effect on pedestrians' gait quality according to a gait analysis device (Mcdonough et al., 2008; Lamberg and Muratori, 2012; Kim et al., 2014; Sammy et al., 2015; Nakamura et al., 2016). Participants engaged in cell phone use presented significant reductions in gait velocity and cadence as well as step and stride lengths; they also showed a tendency to increase step width and step time. These changed gait characteristics would have further impacts on pedestrians' walking stability and variability. Furthermore, mobile phone distraction impairs pedestrians' crossing behavior and increases their vulnerability to conflicting traffic streams. For example, pedestrians distracted by mobile phones walk more slowly (Hatfield and Murphy, 2007; Hyman et al., 2010; Schabrun et al., 2014), change directions more often (Hyman et al., 2010), take longer to initiate crossing (Stavrinos et al., 2009; Neider et al., 2010, 2011; Byington and Schwebel, 2013), miss more safe opportunities to cross (Neider et al., 2010; Stavrinos et al., 2011; Byington and Schwebel, 2013), are more likely to cross unsafely into oncoming traffic (Nasar et al., 2008; Stavrinos et al., 2009, 2011; Schwebel et al., 2012; Byington and Schwebel, 2013; Dalibor et al., 2016), and make more errors (Bellows et al., 2012) than pedestrians who are not distracted. Additionally, mobile phone distraction draws pedestrians' attention away from the crossing task and affects their visual attention distribution. Numerous studies have examined how mobile phone distraction impairs pedestrians' visual attention through the observation of participants' head movements. For example, pedestrians distracted by mobile phones are less likely to look at traffic before crossing (Hatfield and Murphy, 2007; Stavrinos et al., 2009, 2011; Byington and Schwebel, 2013; Dalibor et al., 2016), look left and right less while crossing (Hatfield and Murphy, 2007; Dalibor et al., 2016), spend more time looking away from the road (Schwebel et al., 2012; Byington and Schwebel, 2013) and show a decreased perceptual visual field (Alejalil and Davoodi, 2017) compared to those who are not distracted. With the advancement of science and technology, eye-tracking systems can be successfully applied to explore pedestrians' visual search strategies in road crossing tasks (Tapiro et al., 2014, 2015; Tapiro et al., 2016a; Lin and Huang, 2017; Lu and Lo, 2017). Tapiro et al. (2016b) also conducted a semi-immersive virtual environment simulation to assess how mobile phone conversations affect visual attention distribution. The data derived from recordings of pedestrians' eye-movements have shown that participants distracted by mobile phone conversations spend relatively more time looking at the center area and less time looking at the periphery where unseen threats may emerge. In brief, these unsafe crossing behaviors and the impaired visual attention caused by mobile phone distraction may increase pedestrian vulnerability and risk of accident.

However, the distraction level of previous observational experiments was uncontrolled, and the degree of perceived risk in virtual-environment experiments may be different from outdoor-environment experiments. Furthermore, pedestrians' visual search performance under other conditions of distraction, such as when listening to music or when texting, has not been examined or compared in previous studies (Tapiro et al., 2016b). Additionally, the total fixation time was used as the only eye movement indicator to describe pedestrians' visual attention distribution, so other eye movement indicators, such as fixation points and fixation duration, should be considered to enhance the measurement of and better understand pedestrian distraction.

Therefore, the present study conducted an outdoor-environment experiment to explore the effect of mobile phone distraction among college student pedestrians. The size of the effects between different uses of mobile phones while crossing (listening to music, talking on the phone, and texting) were compared. As dependent variables, three crossing behavior indictors and five eye movement indicators were recorded together to quantify the effects of mobile phone distraction on pedestrians' crossing performance.

2. Method

2.1. Participants

Interested participants were recruited from Hefei University of Technology in China. A total of twenty-eight college students, 17 male and 11 female, participated in the study. The twenty-eight participants ranged in age from 17 to 25 years old with a mean age of 20.6 years (SD = 2.23), and all of them owned smart phones. This group was chosen since college students are known to cross streets more frequently and to use mobile phones with greater frequency than other groups. According to the preliminary questionnaire survey (Jiang et al., 2017), approximately 40% of 405 college students reported having used mobile phones while crossing, and 5.4% of the respondents had even been involved in a crossing accident due to mobile phone distractions. The principal inclusion criteria in the study were that participants did not wear glasses (so that eye movement could be properly tracked) and had the ability to walk unimpaired and at a standard pace. After finishing an approximately 30-minute experiment, the participants received nearly $8 as compensation for their effort.

2.2. Experiment scenario

To better simulate the effect of mobile phone distraction on pedestrians' crossing behavior and visual attention allocation, an outdoor-environment experiment was conducted. The experiment was conducted from December 28, 2016, to January 10, 2017, during sunny weather. Considering the greater possibility that pedestrians would use their mobile phones at such an intersection in everyday life and for greater security during our experiment, a two-phase traffic-signal-controlled intersection with a 40-km/h speed limited was selected as the experimental intersection. The intersection was located near a residential area with rater complete necessary street furniture and was relatively quiet and separated from busy urban areas. Because the experiment time (9:00–11:00 a.m. and 2:00–4:00 p.m.) avoided peak hour and weekends, the experimental intersection had a low level of traffic, particularly in the right lane, and the number of vehicles per minute was fewer than 5 based on our observation. The 14-meter-wide experiment crosswalk with zebra crossing provided twenty-one seconds of green light time during which pedestrians were given a crossing signal; this green interval alternated with a 39-s red phase during which pedestrians were forbidden from crossing. As shown in Fig. 1, for each direction, there was a lane designed for both through traffic and left-turn traffic and a lane designed for both through traffic and right-turn traffic.

2.3. Apparatus

In the current study, pedestrians' crossing behaviors were captured and recorded by two Sony video HD cameras mounted on tripods. The cameras were placed in secret hiding places facing pedestrians to ensure they would not draw attention and distract the crossing pedestrians, thereby confounding the study results. Because eye movement recording has been considered an appropriate research tool to identify drivers' visual attention in terms of distracted driving research (Garrison, 2011; Garrison and Williams, 2013), Tobii Pro Glasses 2 were used to record the pedestrians' eye movements. 50-HZ Tobii Pro Glasses 2 with a wearable eye-tracker apparatus can capture objective data and allow insights into human behavior in any real-world environment by measuring a variety of eye movement and attentional behaviors. They can also record and store eye-tracking data, sounds, and footage on a removable SD memory card for further analysis. Considering the influence of different mobile phones, the Huawei P9 with an Android system and a 5.2 inch screen was selected as the only

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