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A vibrotactile wristband to help older pedestrians make safer street-crossing decisions

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ABSTRACT

Introduction: Older pedestrians are overrepresented in fatal accidents. Studies consistently show gap-acceptance difficulties, especially in complex traffic situations such as two-way streets and when vehicles approached rapidly. In this context, the present research was aimed at assessing the effectiveness of a vibrotactile device and study older pedestrian's behavior when wearing the wristband designed to help them make safer street-crossing decisions.

Method: Twenty younger-old participants (age 60–69), 20 older-old participants (age 70–80) and 17 younger adults (age 20–45) carried out a street-crossing task in a simulated two-way traffic environment with and without a vibrotactile wristband delivering warning messages.

Results: The percentage of decisions that led to collisions with approaching cars decreased significantly when participants wore the wristband. Benefits tended to be greater particularly among very old women, with fewer collisions in the far lane and when vehicles approached rapidly when they wore the wristband. But collisions did not fall to zero, and responses that were in accordance with the wristband advice went up to only 51.6% on average, for all participants. The wristband was nevertheless considered useful and easy to use by all participants. Moreover, behavioral intentions to buy and use such a device in the future were greater in both groups of older participants, but not among the younger adults.

Practical applications: This haptic device was able to partly compensate for some age-related gap-acceptance difficulties and reduce street-crossing risks for all users. These findings could be fruitfully applied to the design of devices allowing communication between vehicles, infrastructures, and pedestrians.

1. Introduction

1.1. Accident risk among older pedestrians

Older people are among the road users most vulnerable to pedestrian fatalities. French accident statistics indicate a higher incidence of pedestrian accidents, particularly at a very old age (age 75 or older). In 2014, for example, pedestrians over 75 accounted for more than 36% of fatalities although they represent less than 9% of the population (ONISR, 2015). International data show the same trends (e.g. DFT, 2011).

The higher number of fatalities in older pedestrians is often explained by an increased physical frailty, by greater exposure effects, and by gap-acceptance difficulties. When involved in an accident, older people generally recover less well from physical injuries, making collisions more likely to result in serious injury or death (for more details, see e.g., Dunbar et al., 2004). But since walking is reported to be their preferred mode of travel in urban areas, ranked above individual cars and public transportation (Holland and Hill, 2007; ITF, 2012; Tournier et al., 2016), older pedestrians are also subject to greater exposure effects. It seems that older women are the most affected by these risks reflected by a slightly higher percentage of pedestrian accidents (i.e., 56%, ONISR, 2015). Some laboratory studies have also highlighted gender differences in unsafe crossing decisions (Geraghty et al., 2016; Holland and Hill, 2010). With increasing age, women are known to make more unsafe crossing decisions and become poorer at estimating

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their walking speed (Holland and Hill, 2010). However, these age effects in older women seem to be lessened by driving experience, underlying possible differences in visual searching (Underwood et al., 2002) and judging vehicle arrival times (Carthy et al., 1995). When driving, women have also been shown to drive fewer kilometers than men in similar age groups (Sirén et al., 2001) and to be more likely to give up driving sooner (Hakamies-Blomqvist and Wahlström, 1998) and thereafter travel as car passengers (Oxley et al., 2004). This generation effect is tending to disappear today, however, because young and middle-aged women now drive as much as men.

The overrepresentation of older pedestrians in crash statistics could also be explained by their altered decision-making and gap-acceptance processes in situations where no helping signals or markings are provided (see e.g., Dommes et al., 2015, 2014, 2013; Dommes and Cavallo, 2011; Holland and Hill, 2010; Oxley et al., 1997, 2005). Observational studies (Oxley et al., 1997; Zhuang and Wu, 2011, 2012) and accident analyses (Fontaine and Gourlet, 1997; Dunbar, 2012) have shown that aging brings on greater street-crossing difficulties, especially in complex infrastructure and traffic situations such as two-way streets. Older pedestrians have been found to be more likely to be hit during the second half of the crossing, i.e., on the far side of a two-way street (Fontaine and Gourlet, 1997; Oxley et al., 1997). Whereas young participants consider the time gaps available in both lanes in deciding whether or not to cross a two-way street, older participants base their decisions mainly on the gap available in the near lane and thus neglect the far lane (Dommes et al., 2014). These non-optimal choices could be compensated for by faster walking, but, only if the pedestrian is able to do so, and if she/he watches for traffic while crossing the street. However, older pedestrians are known to pay more attention to watching their step as they cross, causing them to at least partly disregard approaching traffic (Avineri et al., 2012).

Studies about the characteristics of the oncoming traffic have also shown that aging leads to more unsafe street-crossing decisions when the speed of approaching vehicles is high (Dommes and Cavallo, 2011; Lobjois and Cavallo, 2007, 2009). Because an approaching vehicle is farther away at a high speed than at a low one for a given available time gap, older people more often choose to cross with shorter safety margins when the speed of the approaching vehicle is high. The use of such distance-based heuristics by older pedestrians (i.e. "the vehicle is far away, I can cross" *versus* "the vehicle is close, I can't cross") is actually related to their misperception of the time available for crossingpredicting unsafe crossings in both one-way (Dommes and Cavallo, 2011) and two-way (Dommes et al., 2013) traffic situations.

1.2. Older pedestrians' need to improve their safety on the road and why the haptic modality can be beneficial

Beyond these street-crossing difficulties, older people are known to be less efficient and less confident in their overall walking skills (for a recent review see e.g., Tournier et al., 2016). Assisting mobility, developing advanced new technologies, and improving older pedestrians' safety on the road is becoming an urgent issue that must be addressed by going beyond the existing pedestrian navigation aids and providing users with safety information and warnings (e.g., about approaching vehicles, the presence of marked crosswalks).

Existing pedestrian-assistance devices provide navigation and orientation information to users to help them find their way in unknown cities. Current commercial navigation systems in mobile phones are mainly based on screen interaction combined with visual or spoken turn-by-turn instructions. But these perceptual modalities are already largely called upon during walking and may therefore trigger interference effects. Another limitation is that they do not allow for safer itineraries, although some prototypes with this capability have been developed in research laboratories (see e.g. Garvey et al., 2016; Kim et al., 2014). Wang et al. (2016) for example recently proposed a pedestrian system that uses acceleration, orientation, and GPS data on smartphones to enrich its map with the presence of crosswalks and detect traffic lights and obstacles to warn pedestrians of danger. But to our knowledge, no marketed device or prototype provides assistance to pedestrians that can help them adopt safer street-crossing behaviors and make safer crossing decisions. This could be very useful particularly for older pedestrians However, receiving additional visual/auditory feedback during their main task of walking can be a danger in itself, due to their cognitive limitations and their difficulty switching between different cognitive processes and information sources (see e.g., Salthouse et al., 2003). Using a sensory modality other than vision or hearing is currently an alternative means of guaranteeing pedestrian safety.

In this context, wearable haptic devices can be useful since they can provide information while freeing the user's hands, ears, and eyes. Haptics is a feedback technology that takes advantage of the human sense of touch by applying forces, vibrations, and/or motions to the user through a haptic-enabled device that is worn or held, such as a smartphone (Jacob et al., 2012). Several haptic prototypes have already been developed to assist people in navigating via vibrotactile directional messages or warnings (Bosman et al., 2003; Dobbelstein et al., 2016; Jacob et al., 2012; Heuten et al., 2008; Piateski and Jones, 2005; Pielot et al., 2011, 2012; Tsukada and Yasumura, 2004). Some of them appear to be effective to alert a driver for a danger in the visual scene (Ho et al., 2005), or to guide a pedestrian without requiring a long reaction time or producing distraction (Pielot et al., 2011, 2012). Whereas haptic-aided navigation has already proven useful for younger individuals (Pielot et al., 2012; Bosman et al., 2003) and visually impaired individuals (Amemiya and Sugiyama, 2008), the situation is different for older adults whose specific need for a haptic navigation aid has seldom been investigated. Some rare initiatives have been undertaken to support wayfinding in older users with memory problems (Rassmus-Gröhn and Magnusson, 2014), but the effectiveness of using vibrotactile information for improving pedestrian safety on the road-by providing street-crossing advice, for example, − has never been studied, in the young or old people.

1.3. Aims of the study

In this context, the present study was aimed at testing the effectiveness of a prototypal alert system based on vibrotactile feedback that was specifically designed with older pedestrians' needs and difficulties in mind. The goal was also to study older pedestrians' behaviors when they wore a vibrotactile wristband designed for helping them make safer street-crossing decisions, in preventing them to cross in situations where they would experience difficulties, i.e. in two-way traffic situations and when vehicles approach rapidly (see e.g., Dommes et al., 2014). Haptics was thought to be a good means to warn the pedestrians of a danger because of its capacity to orient attention towards critical events (see e.g., Ho et al., 2005). Another objective was to assess users' perceptions of this prototype in terms of their behavioral intention to buy and use it if it were to be marketed.

To allow pedestrians to cross the street in a safe and controlled environment, tests were run on a virtual platform. A simulator was also useful for testing the device's ability to accurately emulate all of the necessary communication between the infrastructure, the vehicles and the pedestrians required for such a prototype (e.g., localization with millimeter precision). This is not yet available with current technologies, but could become possible in the near future with increasing research and development of connected objects and autonomous vehicles.

We hypothesized that the vibrotactile wristband would be a beneficial street-crossing aid for all young and old participants. The benefits would be greater for older participants than for younger ones, and in older-old women especially because of their difficulties observed in previous street-crossing studies (Geraghty et al., 2016; Holland and Hill, 2010). A decrease of decisions that led to collisions could be particularly hypothesized in the far lane and when vehicles approached