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***ELDERLY PEDESTRIANS' VISUAL TIMING STRATEGIES
IN A SIMULATED STREET-CROSSING SITUATION***

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Summary: The purpose of the present experiment was to investigate the effect of age and of the approaching vehicle's speed on crossing behavior in an interactive street crossing simulation. Seventy-eight subjects aged from 20-30, 60-70 and 70-80, took part in the experiment. Half of them were female and half were male. The participants were asked to cross between two approaching cars if they judged crossing possible. Vehicle speed (40 and 60 km/h) and time gap between cars (from 1 to 7s) were varied. The results show that the accepted time gap increased with age, but that the adopted safety margins, as well as the rates of unsafe crossings and missed opportunities were globally comparable for all groups of participants. However, the speed of the approaching vehicles was identified as an important risk factor for elderly pedestrians. Unlike younger pedestrians, seniors exhibited more risky behaviors at higher speeds. Results are discussed in relation to the visual information used, and with respect to the validity of judgment and crossing tasks in the study of pedestrian behavior.

INTRODUCTION

Crossing a road is a highly difficult task for elderly pedestrians. Accident statistics in France actually show that 51% of pedestrian fatalities in 2004 concerned people more than 65 years old (ONISR, 2005). International accident studies indicate the same tendency and alert on the fact that seniors are at particular high risk when crossing the street. In spite of the important safety problem, very few experimental studies have investigated the elderly pedestrians' street-crossing behavior.

The most critical aspect in street-crossing is the selection of a safe gap between the approaching vehicles: the pedestrians have to visually judge whether there is enough time to cross before a vehicle arrives and to relate the available time gap to the time needed to cross. This task involves the sensory, perceptual and cognitive functions of the pedestrians as well as their locomotor capacities. However, existing work (Lobjois & Cavallo, 2007; Oxley, Fildes, Ihsen, Charlton, & Day, 1997; Oxley, Ihsen, Fildes, Charlton, & Day, 2005) studied senior pedestrians' gap acceptance only by using judgment tasks that did not involve any locomotor behavior. Typically, the pedestrians were sitting (Oxley et al.) or standing (Lobjois & Cavallo) in front of a screen displaying traffic scenes and had to estimate, by pressing a button, whether or not they could safely cross the street.

The ecological validity of this paradigm has to be questioned for several reasons. A number of recent studies have shown dissociations between judgement and action measures of perceptual performance. Young adults in a simulated street crossing situation made more unsafe decisions in an estimation task than in an actual crossing task (te Velde, van der Kamp, Barela, & Savelsbergh, 2005). Gray & Regan (2005) obtained similar findings in a driving simulator study when comparing overtaking manoeuvres and judgments. More generally, according to the ecological approach, perception and action are interdependent, and perception should be studied when coupled with action. This view is supported by Goodale & Milner (1992) who suggest that there are two anatomically distinct visual systems which also differ in their functions: the *perception* system responsible for recognition and awareness of what one is seeing, and the *perception-action* system engaged in the visual control of motor behavior. A judgment task therefore may not reliably represent actual road-crossing behavior.

The present study used a simulated interactive road-crossing situation in order to examine age-related effects on road crossing behavior. Previous experiments (Lobjois & Cavallo, 2007) have shown that elderly pedestrians based their crossing decisions to a large extent on the current distance of the oncoming vehicle while neglecting speed information. This led to shorter accepted time gaps and more risky decisions at higher speeds, and longer accepted time gaps and more missed opportunities at lower speeds. Younger pedestrians, on the contrary, operated in a constant-time mode regardless of speed. One of the objectives of this study was to determine whether these age-related differences were due to characteristics of the estimation task or whether they also pertain to actual crossing tasks. Unlike estimation tasks, in actual crossing tasks pedestrians can calibrate their perceptions with their actions and thus improve their crossing decisions. This possibility of perception-action calibration, especially in a virtual environment, should be beneficial for all participants, but we expect it to be particularly helpful for seniors who regularly need to reassess their movement speed to properly compensate for reduced perceptual and motor capacities (Lee, Young, & McLaughlin, 1984).

Another advantage of the interactive road-crossing task is to allow one to study crossing behavior itself which, to our knowledge, has never been done before.

METHOD

Participants

Seventy-eight participants aged from 20-30, 60-70 and 70-80, took part in the experiment. Half of them were female and half were male. The elderly participants underwent a medical examination to insure the absence of severe physical or mental pathologies.

Experimental Setup

The street-crossing simulation device (Cavallo, Lobjois, & Vienne, 2006) was based on the INRETS Sim² driving simulator (Espíe, 1999). The device included a portion of an experimental road (4.2 m wide, materialized on the ground), an image-generation system, a three-screen projection, a 3D sound-rendition system and a recording system. The images (refreshed at 30 Hz) were calculated and projected according to the participants' eyes height. Scenes were updated

interactively by a movement-tracking system that recorded the participant's positions via a cable attached to the participant's waist. The scenes represented a one-way street 4.20 m wide sidewalk-to-sidewalk. Traffic consisted of a motorcycle followed by two cars moving at a constant speed from the left to the right in reference to the participant standing on the sidewalk. At the beginning of each scene, the motorcycle was 1.5 s away from the pedestrian and the first car was 1 s away from the motorcycle.

Experimental task, Design and Procedure

The participants were positioned at the edge of the sidewalk facing the experimental road and had to look left to the simulated road environment and the approaching vehicles. Participants were instructed to cross the street between the two cars when they thought it was safe to do so, by walking at any pace but not running. The participants' decision to cross or not to cross and their motion until the end of the visual sequence were recorded.

Vehicle speed (40 and 60 km/h) and time gap between the two cars (1 to 7 s, in 1-s increments) were varied. The number of repetitions per time gap differed according to their probability of being accepted for crossing. As a matter of fact, the shortest gaps are systematically refused and the longest gaps systematically accepted (e.g., Lobjois & Cavallo, 2007). Therefore, the time gaps of 1 and 7 s were presented once, the time gaps of 2 and 6 s twice, and the time gaps of 3, 4, and 5 s three times, equaling a total of 15 trials. The combination of these 15 trials and 2 speeds resulted in 30 trials presented in random order. Between the trials the visual scene was replaced by a blue screen. The experiment started with some practice trials and lasted about 30 min.

Data Analysis

All trials were scored on whether the participant accepted or not the available gap to cross the street. The participants' motion was computed every time when crossing was accepted. Among the computed indicators derived from these data, the following measures are presented here:

Medium accepted time gap. For each participant and each speed, the medium accepted time gap was computed using a logistic regression analysis on the raw data. This metric determined the transition point between the decision not to cross and the decision to cross (see Lobjois & Cavallo, 2007, for more details).

Crossing behavior. From the pedestrian's position on the experimental road and the vehicle's position on the virtual road, initiation time (IT), crossing time (CT), and safety margin (SM) were calculated for each participant and each accepted crossing. *Initiation time* was equal to the time between the moments when the rear end of the first car passed in front of the pedestrian and when the participant started to walk (IT was negative when the participant started crossing before the first car passed his line). *Crossing time* was equal to the time between the moments when the pedestrian started to walk and when he was completely over the curb of the opposite sidewalk. *Safety margin* was referred to the time between the moments when the participant reached the finishing sidewalk and when the front end of the second car reached the participant's crossing line.

Decision categories. For the accepted crossings, an *unsafe decision* was counted when the SM was less than 1.5 s. This variable was expressed as a percentage of the total number of crossings accepted by the participant. For rejected crossings, a *missed opportunity* was counted when the participant refused to cross although she/he would have had enough time to cross safely considering her/his mean IT and CT. This variable was expressed in percentage of the total number of crossings refused by the participant.

These measures were subjected to ANOVA with age group as a between-participant factor and vehicle speed as within-participant factor. The significance level was set at 0.05 for all statistical analyses. Significant effects were examined by Scheffé post hoc tests.

RESULTS

Median accepted time gap. The ANOVA revealed a main effect of Speed, $F(1,72)=81.86$, $p<.0001$, with greater accepted gaps at 40 ($M=3.74$ s) than at 60 km/h ($M=3.18$ s), as well as an interaction between Age and Speed, $F(2,72)=6.14$, $p>.005$. The post hoc test on this interaction yielded significant speed differences for the two elderly age groups, but not for the young pedestrians (see Fig. 1).

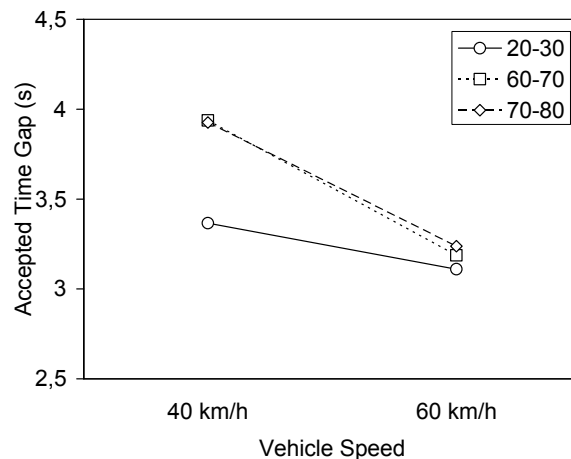


Figure 1. Median accepted time gap (s) as a function of age and speed of approaching vehicles

Initiation Time. A main effect of speed was found, $F(1,72)=156.50$, $p<.0001$, indicating an earlier crossing initiation at 40 ($M=-1.17$ s) than at 60 km/h ($M=-0.94$ s).

Crossing Time. The findings indicate a main effect of Age, $F(2,72)=6.86$, $p<.0025$, with significant lower crossing times for young pedestrians ($M=4.06$ s) compared to the 60-70 group ($M=4.31$ s) and to the 70-80 group ($M=4.56$ s).

Safety Margin. The ANOVA revealed a main effect of Speed, $F(1,72)=270.70$, $p<.0001$: the SM was greater at 40 ($M=2.08$ s) than at 60 km/h ($M=1.51$ s), as well as an interaction between Speed and Age, $F(2,72)=12.90$, $p<.0001$. Post hoc investigation of this interaction showed significant differences between the two speeds for all three age groups, but the decrease of SM from 40 to 60 km/h was notably more pronounced in the seniors than in the young pedestrians (see Fig. 2).

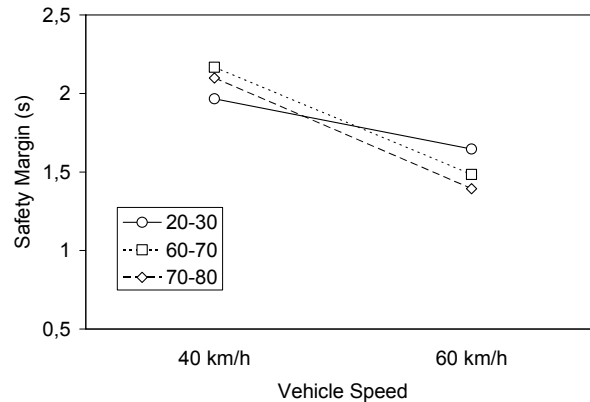


Figure 2. Safety margins (s) as a function of age and speed of approaching vehicles

Unsafe Decisions. A main effect of Speed was found, $F(1,72)=108.00$, $p<.0001$, with fewer unsafe decisions at 40 (M=29.9%) than at 60 km/h (M=51.1%). The significant interaction between Age and Speed indicated that this speed effect was observed only for elderly pedestrians, but not for younger ones (see Fig. 3).

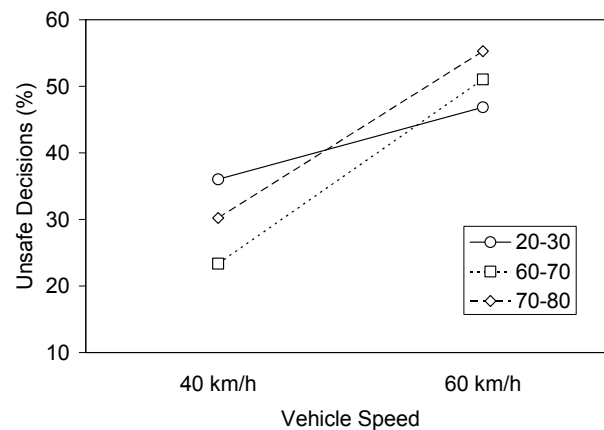


Figure 3. Unsafe decisions (%) as a function of age and speed of approaching vehicles

Missed Opportunities. The analysis revealed a significant main effect of Speed, $F(1,72)=48.39$, $p<.0001$, with a higher rate of missed opportunities at 40 (M=25.9%) than at 60 km/h (M=8.5%).

DISCUSSION AND CONCLUSION

The findings of this experiment showed that the only main effect of age was related to the lower walking speed of elderly pedestrians. The resulting increase of crossing times (by 0.25 and 0.50 s for the 60-70 and 70-80 age groups respectively, compared to young pedestrians) were partially compensated by longer accepted gaps (increase of 0.32 and 0.34 s for the 60-70 and 70-80 age groups respectively, compared to the young pedestrians, although this difference was not significant), so that similar safety margins and unsafe-decision rates were found for the three populations of pedestrians.

At the first glance, these global results cannot explain the high rate of fatal accidents incurred by the elderly pedestrians. However, the similar safety margins do not mean that the elderly pedestrians are exposed to the same levels of risk than the younger pedestrians. Seniors most likely need greater safety margins to compensate for their diminished ability to manage perilous situations (stumbling, etc.).

Furthermore, the systematically observed interaction between age and speed indicates that elderly pedestrian had specific difficulties to safely handle situations when vehicles approached at high speed. As a matter of fact, speed only influenced the older groups, leading them to accept shorter gaps (-0.72 s), to adopt reduced safety margins (-0.76 s) and to make more unsafe decisions (26%) at 60 km/h compared to 40 km/h. Thus, high vehicle speed is undeniably a safety-critical factor for senior pedestrians. It not only affects decision-making and increases the probability of collision, but also worsens its consequences for a population that is particularly vulnerable.

The influence of speed on the elderly pedestrians' crossing decisions was already observed earlier by studies using judgment tasks (Lobjois & Cavallo, 2007; Oxley et al., 2005). It can be explained by the use of simplifying heuristics based on vehicle distance. For a given available time gap, the distance of the approaching vehicle is greater at high speed than at low speed. Using preferably distance gap instead of time gap, senior pedestrians accepted gaps of the same size more frequently at higher speeds than at lower ones. Younger pedestrians, on the contrary, operated in a constant-time mode independently of vehicle speed.

The use of distance-based heuristics by the elderly pedestrians can be considered as a means of accommodating sensory and cognitive limitations. Information on distance-gap may have been obtained easier and faster than time-gap information in the studied situation where the angular velocity of far-away vehicles was extremely slow. The age-related decline of visual motion sensitivity (e.g., Sekuler, Hutman, & Owsley, 1980), especially for slow movements (Snowden & Kavanagh, 2006), as well as the increase in processing speed (e.g., Salthouse, 1996), may have caused the seniors to ignore the vehicle's visual movement. It is very likely that too much time would have been needed to get a reliable information on motion and time-gap before being able to make a crossing decision, while the available gap was constantly reducing.

The present findings, obtained in a street crossing task involving actual walking, globally confirmed previous results observed in estimation tasks (Lobjois & Cavallo, 2007). Although a strict comparison of the results and the observation of fine differences would require a specific design with identical populations and experimental conditions, we note that the observed patterns of results (especially the age and speed interactions) are clearly related. We therefore can say that the decision characteristics observed in the estimation task were largely reflected in the crossing task. Yet, the crossing task not only allows to study crossing decisions, but presents the advantage to enable the analysis of crossing behaviour itself and thus to study adaptive strategies, such as the adjustment of crossing initiation and crossing speed to available time. The crossing task also makes possible the precise measurement of safety margins. For all these reasons the crossing task seems preferable to the estimation task and should be used whenever possible.

There are however situations where only estimation tasks can be utilized, for instance in real-world settings to exclude physical risk, but also in laboratory settings when no portion of road is available. Our findings suggest, as far as crossing decisions are considered, that the estimation task quite well represents the actual crossing task. Moreover, the similarity of crossing decisions obtained by judgment and action measures of performance is not only interesting in methodological terms, but also raises stimulating questions regarding the underlying visual systems of perception and action, questions that deserve to be further explored.

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