The beneficial effects of a simulator-based training on the elderly pedestrian safety

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THE BENEFICIAL EFFECTS OF A SIMULATOR-BASED TRAINING ON THE ELDERLY PEDESTRIAN SAFETY

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SUMMARY

International accident statistics indicate that elderly pedestrians make up an extremely vulnerable road-user group. Past research has shown that older adults have trouble taking the speed of approaching vehicles into account in deciding whether or not to cross the street: contrary to younger pedestrians, older adults make many unsafe decisions when vehicles are approaching at high speeds and miss safe opportunities to cross when vehicles approach slowly. Although for many seniors, walking is the major way of getting around, there are surprisingly no studies on improving the safety of elderly pedestrians through training. The present study was aimed at contributing to this issue. Our objective was to develop and assess the effectiveness of a training program that combined educational and behavioral interventions. To this end, 20 seniors were enrolled in a simulator-based street-crossing training program and 20 other seniors were assigned to the control group (internet-use training). Before the training, immediately after it, and 6 months later, the street-crossing decisions of the 40 older participants were assessed using a simulated street-crossing task. Twenty younger participants performed the same task to serve as a baseline against which the performance of the older trained group was compared. The results showed that the training produced significant short- and long-term benefits and enhanced the overall safety of the experimental participants' street-crossing decisions. In view of applying our method, it would be important to separate the effects of educational training (explicit feedback; training instructions) and repeated practice in crossing the street on the simulator. A partial answer to this question can be found by looking at the results of the control group, whose performance improved with task repetition in such a way that on the long-term follow-up test, no significant difference was found between the two groups. More generally, these findings suggest that combining repeated simulator-based street-crossing practice with enhanced awareness (acquired explicitly or implicitly) of street-crossing dangers has a positive effect. When compared with the younger participants, the older participants of the experimental group considerably improved their behavior so that age-related differences in the mean safety-related indicators were no longer observed after training. However, the older participants' ability to take the oncoming car's speed into account in their decisions did not improve with training. This finding may reflect age-related sensory and cognitive difficulties that cannot be remedied by a behavioral or educational method. Further studies are therefore required to identify the sensory, perceptual, and cognitive abilities involved in street-crossing decision-making. A better understanding of these skills would be useful in designing future cognitive training programs likely to improve the behavior of senior pedestrians.

Key Words: street-crossing; aging; training; simulator

PURPOSE OF THE STUDY

International accident statistics indicate that elderly pedestrians make up an extremely vulnerable road-user group. In France, more than half of all pedestrians killed on the road (51%) are over 65 years old, whereas this age group represents less than 15% of the population [ONISIR, 2006]. In French urban areas, the percentage of elderly pedestrians killed on the road even reaches 63%. Developing countermeasures for improving the safety of street crossing among older adults is therefore becoming an urgent problem.

Past research [Lobjois & Cavallo, 2007, 2009; Oxley, et al., 1997, 2005] has highlighted some of the age-specific characteristics of road-crossing behavior: slowing of decision-making, decreased walking speed, difficulty in selecting safe gaps and adopting sufficient safety margins. More specifically, these studies showed that older adults have trouble taking the speed of approaching cars into account in deciding whether to cross the street: contrary to younger adults, who accepted constant time gaps, older pedestrians were found to accept shorter and shorter time gaps as the car's speed increased, putting them at a higher risk at high speeds. They also tended to miss safe opportunities to cross in front of cars approaching at low speeds. These behaviors are thought to reflect age-related difficulties in processing information about the approaching car's speed and integrating it into the decision-making process. With aging, distance gap seems to become the overriding parameter for deciding whether or not to cross [Lobjois & Cavallo, 2007].

Walking is essential to the mobility of elderly road users, not only for carrying out daily living tasks, but also for social insertion and physical exercise. Although the number of pedestrian zones continues to increase, and urban planning had been updated with pedestrians in mind, walkers in the city are still far from being perfectly safe. Surprisingly, there doesn't seem to be any research on behavior-based safety measures, i.e., training programs to teach older adults to adopt safer street-crossing behaviors. The present study was aimed at contributing to this issue. Our objective was to develop and assess the effectiveness of a training program that combined educational and behavioral interventions. To our knowledge, the only street-crossing training programs that have been developed were aimed at child pedestrians [e.g., Thomson, et al., 2005) or brain damaged pedestrians [e.g.,Weiss, et al., 2003], but not seniors pedestrians. And yet, data from laboratory studies clearly indicate that elderly adults can improve their performance with practice and training. A new research trend on retraining older adults in the perceptual, motor, and/or cognitive skills of daily activities emerged about twenty years ago and has been growing ever since [e.g., Edwards, et al., 2005]. In this line, some studies focused on older drivers and how they handle their difficulties [for a review see Korner-Bitensky, et al., 2009]. The training method we used specifically addresses rehabilitation of the behavioral component of street crossing by providing simulator-based training. Simulators and virtual reality have already proven to be powerful training devices to prevent child pedestrian injury [e.g., Schwebel, et al., 2008], rehabilitate brain damage deficits [e.g., Akinwuntan, et al., 2005] or learn basic driving skills [e.g., Kappé & Emmerik, 2005]. Some other advantages of simulators are that they provide feedback, allow for graduated levels of task difficulty, and make it possible to adapt the training to each individual's abilities, in such a way that effective and personalized skill learning or relearning can be achieved [Weiss, et al., 2003].

The validity of the interactive street-crossing simulator we used in the present study has already been demonstrated [see Cavallo, et al., 2006]. With a high level of immersion and presence sensation, it allows for safe street crossing as well as a perfect control over the characteristics of the traffic (i.e., in our case, vehicle speed and time gaps). The simulator-based training method we developed promoted not only individual sensory-motor practice, but also addressed elderly adults' ways of thinking about the task and the strategies they bring into play. Through explicit online and offline behavioral feedback (about safety margins and median accepted time gap, respectively), the training was aimed at modifying older adults' street-crossing strategies. More specifically, one of our objectives was to improve the way seniors process the speed information and use it in their decisions and behaviors. In particular, pedestrians were encouraged to assess the approaching car's speed before crossing rather than considering its distance only, even if this meant starting to cross later. They were also encouraged to observe the approaching traffic as they crossed and to increase their pace if the car was arriving faster than expected. In sum, by means of repeated practice and a better understanding of the task constraints, our training program was aimed at improving the overall safety of elderly adults when crossing the street, and also at helping them take the approaching car's speed into account in a safer way. In addition, by recruiting younger adults, we also examined to what extent age-related differences in street-crossing safety could be reduced after older pedestrians participated in the street-crossing training program.

METHOD

1. Participants

Twenty elderly participants (11 women and 9 men) ranging in age from 65 to 83 (*M* = 73.05 years, *SD* = 4.44) were enrolled in the street-crossing training program. A control group of twenty elderly participants (12 women and 8 men) ranging in age from 61 to 82 (*M* = 71.35 years, *SD* = 5.78) was pre- and post-tested at the same time as were participants in the experimental group. Instead of the street-crossing training, the control group participants were given an internet-use training course. The 40 seniors were retired individuals living on their own. They all underwent a medical examination (which included sight and hearing acuity and current medication) to ensure study eligibility (i.e., absence of major cardiac, neurological, and visual disorders or diseases). All seniors obtained a score over 27 (*M* = 28.96, *SD* = 0.93) on the Mini-Mental State Examination [Folstein, et al., 1975], which indicated that they were not affected by cognitive impairments.
Twenty younger participants (10 women and 10 men) ranging in age from 20 to 30 (*M* = 25.15 years, *SD* = 3.28) were also recruited. They did not receive any training.

2. Experimental Setup

The street-crossing simulation device was based on the INRETS Sim^2 driving simulator [Espié, 1999] and adapted to the street-crossing situation [Cavallo et al., 2006]. The device included a portion of experimental road (4.2-m wide, materialized on the ground), an image-generation system, three-screen projection (2.70 x 1.90 m), a 3D sound-rendition system, and a recording system. The setup provided the participant with a horizontal visual field between 90° (at the starting point) and 140° (in the middle). The vertical visual field was 40°. The images (30 Hz refresh rate) were calculated and projected at the participant's eye height. Scenes were updated

interactively by a movement-tracking system that recorded the participant's motion via a cable attached to her/his waist.
The visual scene represented a one-way street 4.20 m wide sidewalk-to-sidewalk. Traffic consisted of a motorcycle followed by two identical cars moving at a constant speed from left to right (with respect to the participant standing on the sidewalk).

3. Street-Crossing Task

The 40 seniors and the 20 younger participants individually performed a simulated street-crossing task which served as pre- and post-tests. On each trial, participants were asked to stand at the edge of the sidewalk, facing the experimental road. They had to look left at the visual scene, paying attention to the approaching vehicles, and decide whether or not to cross between the two cars. If they thought there was not enough time, they were to remain on the sidewalk. If they thought it was safe to cross (without running), they had to walk (at any pace) over to the sidewalk on the other side of the street. The participant's crossing decisions and motion were recorded on each trial.
Vehicle speed (30, 40, 50, 60, and 70 km/hr) and time gap between the two cars (1 s to 7 s, in 1-s increments) were crossed. The number of repetitions per time gap differed according to their probability of being considered acceptable for crossing. In fact, it has been shown that the shortest gaps are always refused and the longest gaps always accepted [Lobjois & Cavallo, 2007]. For this reason, the 1- and 7-s time gaps were presented once, the 2- and 6-s time gaps twice, and the 3-, 4-, and 5-s time gaps, three times. This combination of 15 trials and 5 speeds resulted in a total of 75 trials. The 75 trials were randomized and divided up into 2 blocks, with a break for the participants between the blocks.
Before beginning the street-crossing task, the experimenter presented the basic principles of the study. Then the participants performed practice trials (vehicle speeds of 30, 50, and 70 km/hr and time gaps of 1, 4, and 7 s) until they fully understood the task. The complete test session lasted approximately 30-45 min.
The younger participants group performed the task only once to assess their street-crossing behaviors and serve as a baseline. The older participants groups performed the simulated street-crossing task three times, before they were trained, immediately after and 6 months later.

4. Older Training

4.1 Street-Crossing Training: The Older Experimental Group

The training program comprised two 1.5-hour sessions, which were separated by approximately one week. The first training session began with a discussion (approximately 30 min) about what information should be taken into account in order to cross the street safely and what safety-conscious behaviors should be adopted.
The participant was then asked to do three street-crossing training modules. The presentation order of the three modules was counterbalanced over the two training sessions. The modules presented the same visual scene as the one used in the test session. The task was also identical. Vehicle speed (Module A: 30 vs 50 km/hr; Module B: 40 vs 60 km/hr; Module C: 50 vs 70 km/hr) and time gap (1 to 7 s) were varied, making for a total of 42 randomly presented trials per module. Each module was repeated immediately, so the participants did each module twice in a row.
During and after each module, the experimenter gave the participant two kinds of feedback. The first concerned the safety margin, which was computed online for

each trial. If the participant's safety margin was above 1.5 s [criterion set on the basis of Simpson, et al., 2003], the crossing was scored as safe. The experimenter then initiated the next trial. If the safety margin was below 1.5 s, the experimenter informed the participant about its value. Then, they discussed about what made this behavior risky (time gap too short, initiation time too long, high speed of approaching car, etc.). When the experimenter felt the participant did not fully understand, the trial was repeated. The second kind of feedback pertained to the median accepted time gap. At the end of each training module, the experimenter and the participant looked together at the effect of the approaching car's speed on her/his median accepted time gap. For each trained speed, the participant's median accepted time gap was computed via a logistic function on the raw data [for more details see Lobjois & Cavallo, 2007]. If the participant's decisions exhibited a speed effect (i.e., the median accepted time gap decreased as speed increased), the experimenter stressed the importance of paying better attention to the speed of the approaching car before deciding whether or not to cross the street.

4.2 Internet-Use Training: The Older Control Group

Participants in the control group were given computer and internet-use training so that they could experience the same amount of social contact and have the same number of sessions as the experimental group. Participants received an introduction to the computer and instruction in how to use and access websites. They carried out information search exercises on topics that interested them (e.g., health, etc.).

RESULTS

For each accepted crossing, safety margin was calculated from the respective positions of i) the pedestrian on the experimental road and ii) the second car on the virtual road. Safety margin was the time between the moments when the participant reached the opposite sidewalk and when the front end of the second car reached the crossing line; safety margin was negative if the participant was still on the road when the front of the second car passed the crossing line. From the safety margins, two categories of decisions were defined: a crossing was scored as a safe decision when safety margin was greater than 1.5 s and the crossing was scored as an unsafe decision when safety margin was negative. These two variables were expressed as percentages of the total number of crossings accepted by the participant.
Two types of analyses were performed. The first examined the short- and long-term effects of the street-crossing training program by comparing the performances of the experimental and control older groups. The second analysis examined age-related differences before and after street-crossing training by comparing the performances of the older experimental group with those obtained by the younger group.

1. Short- and Long-Term Effects of Street-Crossing Training

For each of the two variables (safe and unsafe decisions), an ANOVA was performed with group (experimental, control) as a between-participant factor, and with testing point (pre-test, immediate post-test, and 6-month post-test) and speed of the approaching car as within-participant factors. The significance level was set at .05. Partial η^2 was used as an index of the relative effect size. Significant effects were further examined using Tukey's post-hoc tests.

1.1 Safe decisions
The results yielded a significant group x testing point interaction $F(2,76) = 10.9$, $p < .001$, $\eta^2 = .22$. The post-hoc analyses indicated significant group differences on the immediate post-test only ($p < .05$), where the experimental group made more safe decisions than the control group. The experimental group exhibited a significant increase in the percentage of safe decisions between the pre- and the immediate post-tests ($p < .001$), which was maintained on the 6-month post-test ($p < .001$). The control group also exhibited a significant increase of safe decisions between the pre- and immediate post-tests ($p < .001$) that persisted on the 6-month post-test ($p < .001$). The results also yielded a significant effect of speed, $F(4,152) = 440.1$, $p < .001$, $\eta^2 = .86$, with safe decisions decreasing as speed increased.

1.2 Unsafe decisions
Given that there were no unsafe decisions when the vehicle was travelling at 30 km/hr, the ANOVA only pertained to speeds of 40, 50, 60, and 70 km/hr. The results yielded a significant group x testing point x speed interaction, $F(6,228) = 2.9$, $p < .01$, $\eta^2 = .07$ (see Figure 1). Post-hoc tests for the experimental group revealed a significant decrease in the mean percentage of unsafe decisions between the pre-test and the immediate post-test ($p < .05$), which was maintained on the 6-month post-test ($p < .05$) when the vehicle was approaching at 50, 60, or 70 km/hr, whereas no significant differences appeared between the three testing points when the car was approaching at 40 km/hr. The control group also exhibited a significant decline in the mean percentage of unsafe decisions between the pre-test and the both post-tests but only when the car was approaching at 70 km/hr ($p < .001$). The two groups did not differ significantly from each other on the immediate or 6-month post-test at any speed. However, while on the pre-test both groups made significantly more unsafe decisions at 70 than at 40 km/hr ($p < .001$), the speed effect was no longer observed in the experimental group on the immediate post-test. In contrast, the control group still made significantly more unsafe decisions at 70 than at 40 km/hr ($p < .01$). But, the reduction in the number of unsafe decisions at the high speed in the experimental group did not last: on the 6-month post-test, both groups made significantly more unsafe decisions at 70 km/hr than at 40 km/hr ($p < .05$).

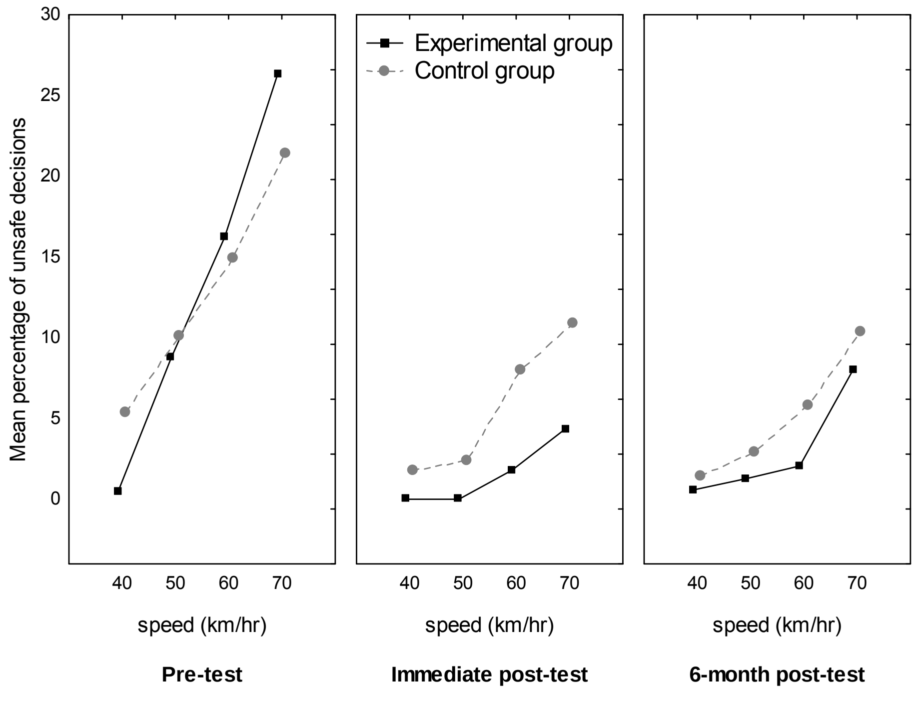

Figure 1. Mean percentage of unsafe decisions, by group, speed, and testing point.

2. Age-Related Differences Before and After Street-Crossing Training

For each of the two variables (safe and unsafe decisions), an ANOVA was performed with age (younger, older) as a between-participant factor, and with comparison point (before, immediately, and 6 months after older training) and speed of the approaching car as within-participant factors.

1.1 Safe decisions

The results yielded a significant age x comparison point interaction $F(2,76)=49.1$, $p<.001$, $\eta^2=.56$. Post hoc tests showed that the two age groups differed significantly before older training ($p<.05$) with older participants making fewer safe decisions than the younger ones. Significant age-related differences were no longer observed immediately after ($p>.09$) and 6 months after older training ($p>.70$).

The results also yielded a significant age x comparison point x speed interaction $F(8,304)=2.4$, $p<.05$, $\eta^2=.06$. Before training, older participants made less safe decisions than the younger ones when the car was approaching at high speeds (i.e., at 60 and 70 km/hr, see Figure 2, $p<.05$). Immediately and 6 months after older training, significant age-related differences were no longer observed at high speeds; age-related differences appeared only at low speed where older participants made significantly more safe decisions than the younger ones (i.e., at 30 km/hr, $p<.05$).

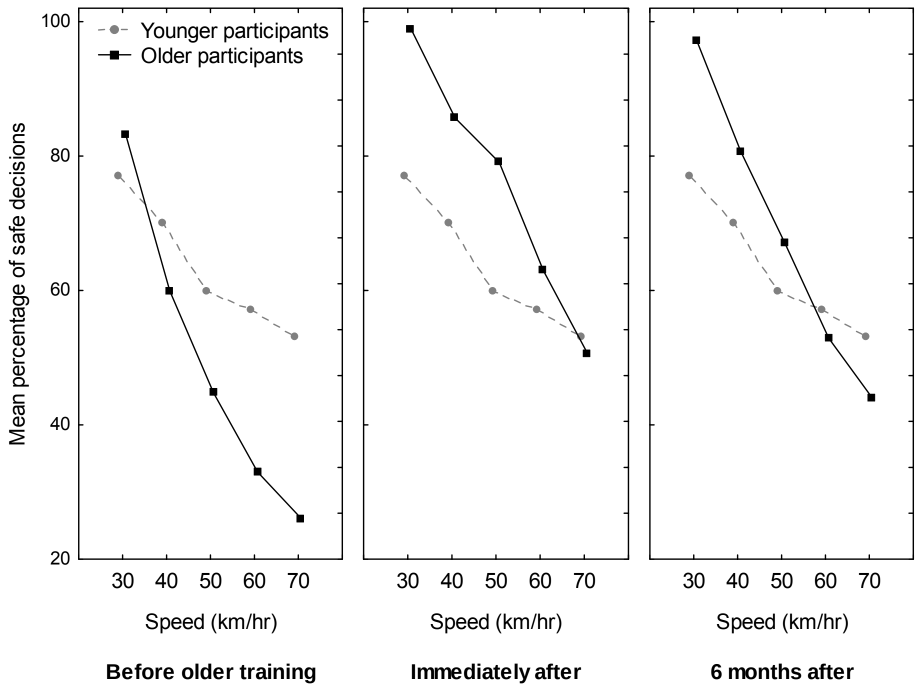

Figure 2. Mean percentage of safe decisions in function of age group, speed of the approaching car and comparison points.

1.2 Unsafe decisions

The results indicated a significant age x comparison point interaction $F(2,76)=34.9$, $p<.001$, $\eta^2=.48$. Post-hoc analyses showed significant age-related differences only before older training ($p<.001$) where the older participants made more unsafe decisions than the younger ones. Immediately and 6 months after older training, significant age-related differences were no longer observed ($p>.60$).

The results also showed a significant age x comparison point x speed interaction $F(8,304)=16.4$, $p<.001$, $\eta^2=.30$ (see Figure 3). While the younger participants showed no speed effect, the older participants made significantly more unsafe decisions as speed of the approaching car increased before they undertook the training program ($p<.001$ between each of the speeds excepts between 30 and 40 km/hr). They made more unsafe decisions than the younger participants when the car was approaching at high speeds (i.e., at 50, 60 and 70 km/hr, $p<.001$). Immediately after training, the speed effect was no longer observed in the older participants' unsafe decisions, and no age-related differences appeared at any speed of the approaching car. However, 6 months after training, older participants' decisions showed again a speed effect: they made more unsafe decisions when the car was approaching at 70 km/hr than at 60, 50, 40 and 30 km/hr ($p<.001$). Whereas older participants made more unsafe decisions than the younger ones when the car was approaching at 70 km/hr ($p<.01$), no significant age-related differences were observed at 30, 40, 50 and 60 km/hr.

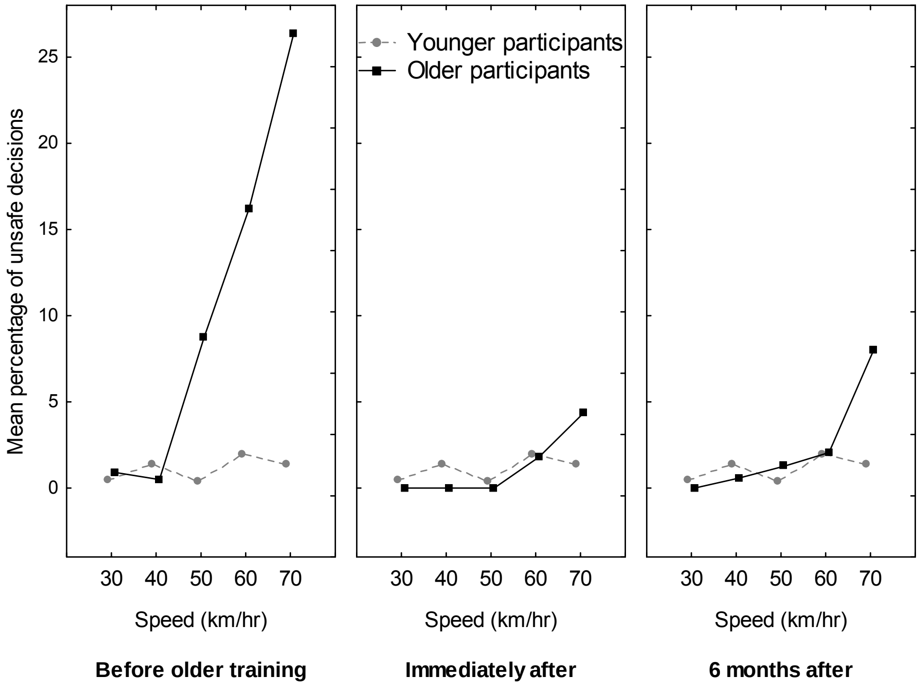

Figure 3. Mean percentage of unsafe decisions in function of age group, speed of the approaching car and comparison point.

DISCUSSION

The participants who benefitted from the street-crossing training program exhibited a significant improvement in the safeness of their street-crossing decisions. Immediately after the training, more safe and fewer unsafe decisions were observed. The benefits were still present six months after training. These results suggested that a combination of repeated practice and educational training can lead to safer street-crossing decisions among elderly pedestrians.

Two possible explanations can be formulated. The first is that participants may have taken advantage of the explicit and educational feedback given them during the training program, i.e., online safety margins and offline median accepted time gaps.

The second is that participants may have made better use of the implicit continuous visual feedback available in the interactive street-crossing task: the simulator provided a perception-action coupling that enabled participants to adapt their actions to their visual perceptions. Although a study by Lobjois and Cavallo [2009] showed that elderly participants did not take advantage of the adjustment possibilities offered by the simulator, the results of the present study are compatible with the idea that the training program promoted better use of visual feedback. The fact of having attracted the participants' attention to the availability of this information may have helped them better adjust their actions to what they were perceiving and therefore make safer decisions as they repeated the task. In view of applying our method, it would be important to separate the effects of educational training (explicit feedback and instructions) and repeated practice in crossing the street on the simulator.
A partial answer to this question can be found by looking at the results of the control group, whose performance improved with task repetition. On the final post-test, no significant difference was found between the two older groups suggesting that the control group had progressed just about as much as the experimental group. The progress of the control group could be ascribed to enhanced awareness of street-crossing dangers acquired implicitly over task repetition. Over time, they could also have benefitted from the perception-action coupling offered by the simulator.
The progresses made by both older groups suggest that combining repeated simulator-based street-crossing practice with enhanced awareness (acquired explicitly or implicitly) of street-crossing dangers can have a positive effect. When compared with the younger participants, the older participants of the experimental group considerably improved their behavior so that age-related differences in the mean safety-related indicators were no longer observed after training. However, the older participants' ability to take the oncoming car's speed into account in their decisions did not improve with training. Contrary to the younger ones, older participants made more unsafe decisions when cars were approaching at high speeds than at low speeds. These age-related differences appeared before, as well as 6 months after training. This finding may reflect age-related sensory and cognitive difficulties that cannot be remedied by a simulator-based behavioral method.

CONCLUSION

The results of this study showed that training can improve the safety of elderly pedestrians and provided a basis for developing future programs adapted to their difficulties. The lack of effectiveness of our training program in the way older pedestrians used the approaching car's speed in their decisions may reveal age-related sensory and cognitive difficulties that the simulator-based educational and behavioral method could not alleviate. Further studies are therefore required to identify the sensory, perceptual, and cognitive abilities involved in street-crossing decision-making. A better understanding of these skills would be useful in designing cognitive training programs likely to improve the behavior of senior pedestrians.

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