Street-crossing workload in young and older pedestrians

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A B S T R A C T

Although several studies have sought to identify both gap-acceptance difficulties with aging and gait differences, few have examined the extent to which crossing the street is physically and cognitively demanding for older pedestrians, in such a way that street crossing can be seen as a dual task. To gain insight into this issue, this study reports an experiment with 15 young (ages 19–26), 19 younger-old (ages 60–72), and 21 older-old (ages 73–82) adults. The participants carried out three tasks: (i) a simple walking task, (ii) a dual task involving walking while scanning (walking while pressing a button as soon as a visual or sound stimulus appeared), and (iii) a street-crossing task with vehicles approaching from two directions. The results indicated more street-crossing collisions in older-old than in younger-old and young participants. Longer reaction times were observed in the dual walking-scanning task for both old groups, especially for visual stimuli. Walking-speed comparisons yielded nonsignificant differences between the dual task and the street-crossing task in young participants, suggesting a correspondence in terms of demands and task priority. In contrast, old participants walked significantly faster in the street-crossing task than in the dual task, suggesting that they placed priority on walking rapidly than on scanning traffic. Finally, whereas the participants estimated the perceived workload to be greater when they were crossing the street than while simply walking or responding to the dual task, young participants gave the highest rating to the mental and physical demands, perhaps due to a lack of awareness of task demands among old participants.

1. Introduction

Crossing the street can be regarded as a challenging and demanding task because it requires several processes, decisions, and actions to be performed quickly, sometimes in parallel. After selecting a place to cross, the pedestrian has to approach the curb and look for oncoming vehicles. If there is no traffic light to guide the decision-making process, or when pedestrians deliberately choose to cross against the light, they have to decide when to cross by estimating the available gaps in the traffic and relating them to their own degree of mobility. After initiating a crossing, pedestrians also have to continue observing oncoming vehicles, update the estimates of their time-to-arrival, and adjust their walking speed and trajectory if necessary (Butler et al., 2016).

The complexity of this task shows up in the characteristics of pedestrian accidents. Crash statistics indicate that French pedestrians are more often killed when crossing the street at a distance of 50 m or more from a zebra crossing (37%, Observatoire National Interministériel de Sécurité Routière ONISR, 2017), i.e., in situations where no helping signals or markings are provided and pedestrians must perform gap-acceptance processes. Crash statistics also show that older people make up an extremely vulnerable road-user group. In 2016, about 40% of

pedestrians killed in traffic accidents were over the age of 75, although this age group only accounts for 9% of the French population (Observatoire National Interministériel de Sécurité Routière ONISR, 2017). The same issues can be observed in several countries (National Highway Traffic Safety Administration NHTSA, 2001; ITF, 2012).

1.1. Aim of the present study

Although several studies have sought to identify both gap-acceptance difficulties and gait differences with aging, few have examined the extent to which crossing the street is physically and cognitively demanding for older pedestrians, in such a way that street crossing can be seen as a dual task. The goal of the present experiment was not to add a task to that of crossing the street (others have already done so, e.g., Butler et al., 2016; Neider et al., 2011), but to study whether the street-crossing task can be considered as a dual task involving walking while scanning the environment. To our knowledge, no previous paper has investigated the extent to which this second part of the street-crossing task (i.e., after the decision-making process), like many dual tasks, is physically and cognitively demanding for older pedestrians. Vieira et al. (2015) showed that older adults' street-crossing speed was

higher than their preferred walking speed on a treadmill. But in that study, participants crossed at a virtual zebra crosswalk based on a pedestrian light right in front of them. That experimental situation is not as difficult as crossing the street without any help (i.e., without crosswalk or lights), which is when most accidents take place (see e.g.,Observatoire National Interministériel de Sécurité Routière ONISR, 2017).

To gain insight into this issue, the present study reports an experiment that was conducted in a simulator. Three tasks were performed (i) a simple walking task (walking in the simulator room with no approaching virtual cars), (ii) a dual task of walking while scanning (walking while pressing a response button as soon as a visual or sound stimulus appeared in the urban environment, with no approaching virtual cars), and (iii) a street-crossing task in a simulated and complex two-way traffic environment. Behavioral indicators such as reaction time on the dual walking-while-scanning task and collisions on the street-crossing task were measured. Mean walking-speed comparisons were made across tasks, and participants also answered a questionnaire after performing each task to measure workload. Finally, several age groups of participants were considered (young and older adults).

1.2. Age-related difficulties in street crossing

Many studies have shown that aging pedestrians have difficulty selecting safe gaps to cross the street (Holland and Hill, 2010; Lobjois and Cavallo, 2007, 2009; Oxley et al., 1997, 2005). The first characteristic linked to these gap-acceptance difficulties is that older pedestrians appear to base their decisions on the distance of the approaching car, contrary to younger adults who mainly use time-gap information (see e.g., Petzoldt, 2014). Several experimental protocols using virtual reality (see e.g., Dommes and Cavallo, 2011; Oxley et al., 2005) have shown that the use of distance-based heuristics unfortunately leads to unsafe crossing behaviors in case of high speeds. Another well-established particularity of older pedestrians is their difficulty handling challenging traffic situations such as two-way streets. Whereas their street-crossing safety is significantly greater on one-way streets, observational studies have shown that older pedestrians are more likely to get hit by a car during the second half of the crossing, i.e., on the far side of the street (Oxley et al., 1997; Fontaine and Gourlet, 1997). Simulator studies explain this by suggesting visual strategies that are biased towards the near lane, with older pedestrians mainly checking for vehicles approaching in the near lane before crossing and sometimes reaching the middle of the street without looking at the far-side traffic at all (Dommes et al., 2014).

These gap-acceptance difficulties with aging appear to be linked to normal age-related declines (Dommes et al., 2015b, 2013, 2011), such as perceptual impairments (see e.g., Poulter and Wann, 2013; Snowden and Kavanagh, 2006) and cognitive difficulties (Salthouse et al., 2003). The well-known processing-speed slowing and attention decrements may cause older pedestrians to have trouble rapidly exploring and processing visual information coming from the environment, thus impairing their street-crossing decision-making process and leading them to wrongly identify an available time gap. Compared to young adults, they have trouble estimating the time-to-arrival of moving vehicles (Butler et al., 2016; Dommes et al., 2013). Another issue is that, due to their declining motor abilities, older people may not be able to compensate for their non-optimal choices by walking faster, increasing their step length, or running (see e.g., Salzman, 2010; Shkuratova et al., 2004).

A reorganization of gait pattern is often observed with aging, to avoid falling and stumbling. The walking-speed reduction is the most obvious and well-known feature of age-related declines (see e.g., Prince et al., 1997). A decrease in step length is also commonly observed (Espy et al., 2010). Gait variability (step-to-step fluctuations), moreover, is characteristic of gait performance with aging (see e.g., Lord et al., 2011), as are falls and fears of falling (e.g., Scheffer et al., 2008).

Balance adjustments are also observed during walking (Woollacott and Tang, 1997). But another important point is that to keep their balance and maintain a safe gait (i.e., without falling), older people appear to undergo greater cognitive demands than young adults (Beauchet and Berrut, 2006). Dynamic motor activities, such as walking, seem to become cognitively costly with aging (e.g., Lindenberger et al., 2000; Woollacott and Shumway-Cook, 2002). In older people, gait performance cannot be conceived of as a series of identical and automatic steps. Instead, walking becomes a complex task that places demands on sensory and cognitive systems (Sheridan and Hausdorff, 2007). In this line, the field study by Avineri et al. (2012) noted many downward head pitches in older pedestrians while crossing. More recent simulator studies have argued that after deciding when to cross and initiating the crossing, older pedestrians allocate their attention to watching their path as they walk (Tapiro et al., 2016) and neglect active visual control during the street-crossing phase (Zito et al., 2015). This may be why the second part of the street-crossing task, i.e., after the decision-making process, is physically and cognitively demanding for older pedestrians. The present experiment was aimed at contributing to this research question by comparing the street-crossing task to a simple walking task and to a dual task involving walking while scanning the environment using a simulator.

1.3. Street-crossing workload

Whereas some studies have asked to participants to perform an additional task while crossing the street on a simulator (Neider et al., 2011) or while waiting to cross (Butler et al., 2016), to our knowledge, no study has looked at whether walking while scanning approaching traffic during street crossing can be seen as a dual task likely to exceed available resources in older pedestrians. Most of the time, authors state that street crossing is a dual task (see e.g., Vieira et al., 2015) without providing any empirical evidence.

Several papers have used the dual-task paradigm to investigate the allocation of attentional resources among older people during walking. The famous Lundin-Olsson et al. study (1997), for example, showed that most old frail adults stop walking when they start a conversation with someone, presumably because attentional constraints exceed their resources. In this line, some researchers have also studied dual-task effects on street-crossing behavior with aging. Neider et al. (2011), for example, asked their participants to cross simulated streets of varying difficulty (using a treadmill) while either remaining undistracted, listening to music, or conversing on a cell phone. The results showed that the older adults were more vulnerable to dual-task impairments than were the younger adults when the crossing task was difficult, with older adults being less likely to successfully complete a crossing and tending to take more time to start crossing. More specifically, Butler et al. (2016) examined dual-task interferences on the decision-making phase of the street-crossing task in a controlled laboratory environment. While waiting to cross in front of an approaching vehicle, 85 older participants had to move as many white balls as possible from a jar of mixed red and white balls into another container using one hand. The participants were facing away from the road while doing this but they could easily turn to view an approaching car. The results showed that while some participants were able to prioritize and cross successfully, others did not prioritize and could not cross safely. This divided-attention crossing task had a negative impact on many of the older participants, maybe because performing a concurrent task requiring vision results in task switching or in "*the equivalent of 'missing frames' (as in a vintage film with a slow frame rate) with regard to the observation of the approaching vehicle*" (Butler et al., 2016, page 11).

Multiple resource theory (Wickens, 1984, 2008) postulates that when several tasks require common attentional resources (and resources using the same channel, e.g., vision), the workload increases and task performance will depend on how resources are allocated to the tasks. Task priority is what determines how attentional resources are

allocated, and plays the greatest role when tasks are difficult and share resources. Various measures, including behavioral and subjective ones, are available to researchers, not only to assess workload and how attentional resources are allocated, but also to assess task priority. Behavioral measures include a wide variety of performance indexes such as error rate or task-completion time. The dual-task paradigm is the one most often used: participants are subjected to two concurrent tasks and reaction time on the secondary task is taken as a measure of workload (Wickens, 1984). The rationale behind using reaction time is that the amount of resources required by the primary task determines reaction time on the secondary task. Subjective measures using self-report ratings, such as the NASA Task Load Index (NASA-TLX, Hart and Staveland, 1988), can also be collected immediately after task performance. Six subscales are used, respectively, to assess mental demand, physical demand, temporal demand, performance, effort, and frustration level.

To reach our goal of examining the extent to which crossing the street is physically and cognitively demanding for older pedestrians, as dual tasks are, the present simulator experiment compares performance (reaction times, walking speed, etc.) across three more or less complex tasks, i.e., a simple walking task, a dual walking-while-scanning task, and a street-crossing task. The NASA-TLX Questionnaire was used to assess subjective workload after each task.

2. Method

2.1. Participants

A total of 55 participants took part in the experiment: 15 young adults ranging in age between 19 and 26 years (M = 23.5, SD = 1.82), 19 younger-old adults ranging in age between 60 and 72 years (M = 65.89, SD = 3.29), and 21 older-old adults ranging between 73 and 82 years (M = 75.57, SD = 2.36). The two old groups were formed *a posteriori* on the basis of the median age (73) and mean age (M = 70.97, SD = 5.64) of all old participants. The young group of participants was comprised of 8 women and 7 men, the younger-old group, of 9 women and 10 men, and the older-old group, of 11 women and 10 men, in such a way that each group contained approximatively 50% women and 50% men.

The criteria for including participants in the younger-old and older-old groups were that they had to be: (i) older than 60, (ii) living independently, and (iii) able to get out regularly without help. These participants were also required to take the Mini-Mental State Examination (MMSE, Folstein et al., 1975) to ensure the absence of severe cognitive impairments; only those participants who had a score of above 27 (out of 30) were included.

The sample was composed of volunteers who answered advertisements containing instructions about how to participate in the study. The instructions stated that the study was about understanding decision-making processes during street crossing across the lifespan, but no reference was made to age-related difficulties. The study was approved by our ethics committee. All participants signed an informed consent form before the study began.

2.2. Procedure, materials, and tasks

Participants were tested individually on a simulator. They carried out three tasks in the following order: (i) a simple walking task, (ii) a dual walking-while-scanning task, and (iii) a street-crossing task.

2.2.1. Street-crossing simulator

The virtual environment used in the present study (see Fig. 1), including hardware and software specifications, is detailed elsewhere (see e.g., Cavallo et al., 2019). Briefly, the simulated environment replicates an actual street of 5.7 m wide. The participants can walk a distance of 5.7 m. The visual scenes are updated interactively by a movement-

tracking system (Vicon®, Oxford Metrics, London, UK). This system also records the participant's movements using reflective markers placed on her/his head (see Fig. 1).

The visual scene represents a two-way urban street 5.70 m in width. The sidewalks were flat, and participants did not have to step up or down. The pedestrian's initial position was such that she/he was standing on the sidewalk.

2.2.2. Simple walking task

The first task asked participants to walk 10 times along the experimental street, from sidewalk-to-sidewalk, with no approaching virtual cars, at a normal-to-fast walking pace. Each individual's walking speed (average of the 10 trials) was calculated and was then entered into the street-crossing scenario for later purposes. This task also allowed walking speed comparisons (in m/s) with the other tasks (i.e., the dual walking-while-scanning task and the street-crossing task).

2.2.3. Dual walking-while-scanning task

The second task performed by the participants was a dual task involving walking while scanning. It was composed of two sub-tasks.

First, participants performed a simple reaction-time task. Participants were standing at the edge of the sidewalk. They were instructed to stay in this position and to press a response button (see Fig. 2a) as soon as they either heard a loud beep (played for 100 ms at 44100 Hz throughout the simulator room, thanks to the 3D sound-rendition system) or saw a visual stimulus (a 55-cm wide red circle, see Figs. 2b and c) in the urban environment. Four trials were proposed to familiarize participants with the task. The familiarization trials involved two sound stimuli and two visual stimuli (one on the right and one on the left side of the participant's visual field when s/he was standing at the edge of the sidewalk, i.e., see Fig. 2b and c). The experimental task involved a total of 14 trials. Among these, 6 involved a sound stimulus. The other 8 involved a visual stimulus that could appear in one of two positions, i.e., on the participant's right or left side when s/he was standing at the edge of the sidewalk (see Fig. 2b and c). Inter-stimulus time varied between 3 and 5 s. Reaction times for pressing the button after stimulus presentation (14 trials) were collected.

After this simple reaction time task, participants performed the dual task of walking while scanning the environment. Participants had to walk in the simulator room, from one sidewalk to the opposite sidewalk, with no approaching virtual cars. While they walked, they were asked to press the response button as soon as the visual or sound stimulus appeared in the urban environment. Participants were instructed to walk at a normal-to-fast walking pace, as in the simple walking task. The dual task involved a total of 30 trials. Stimuli appeared in different walking positions. The 12 sound stimuli were presented in one of three of the participant's walking positions, i.e., when the participant was in the middle of the first lane (4 trials), in the middle of the street (4 trials) and in the middle of the far lane (4 trials). Visual stimuli appeared in one of two of the participant's walking positions, when the participant was in the middle of the near lane (8 trials, see Fig. 2d) or in the middle of the two-way street (4 trials, see Fig. 2e). Table 1 summarizes the stimuli proposed in the dual task. Six trials did not include any visual or sound stimuli. Reaction times for pressing the button after stimulus presentation (24 trials) were collected.

Ten trials were proposed to familiarize participants with the task, four with sound stimuli, four with visual stimuli, and two with no stimuli.

To evaluate workload, reaction times (in seconds) were compared between the simple reaction-time task and the dual walking-while-scanning task.

2.2.4. Street-crossing task

The third task was a street-crossing task. The participant stood on the sidewalk and could see the traffic coming from both directions (see

Fig. 1. The simulator room and the visual scene.

Fig. 3). The traffic was comprised of motorcycles and cars (between 5 and 10) that were approaching at a constant speed, from the left of the pedestrian in the near lane (2.85-m wide), and from the right in the far lane (2.85-m wide).

The experimenter began the third task by describing the task and

allowing the participant to observe the approaching traffic on the simulated two-way street. The participant then performed 18 practice trials. The experimental street-crossing task was composed of two blocks of 20 trials, with a break between the two blocks. The third task took about 30 min to complete. No participants reported simulator
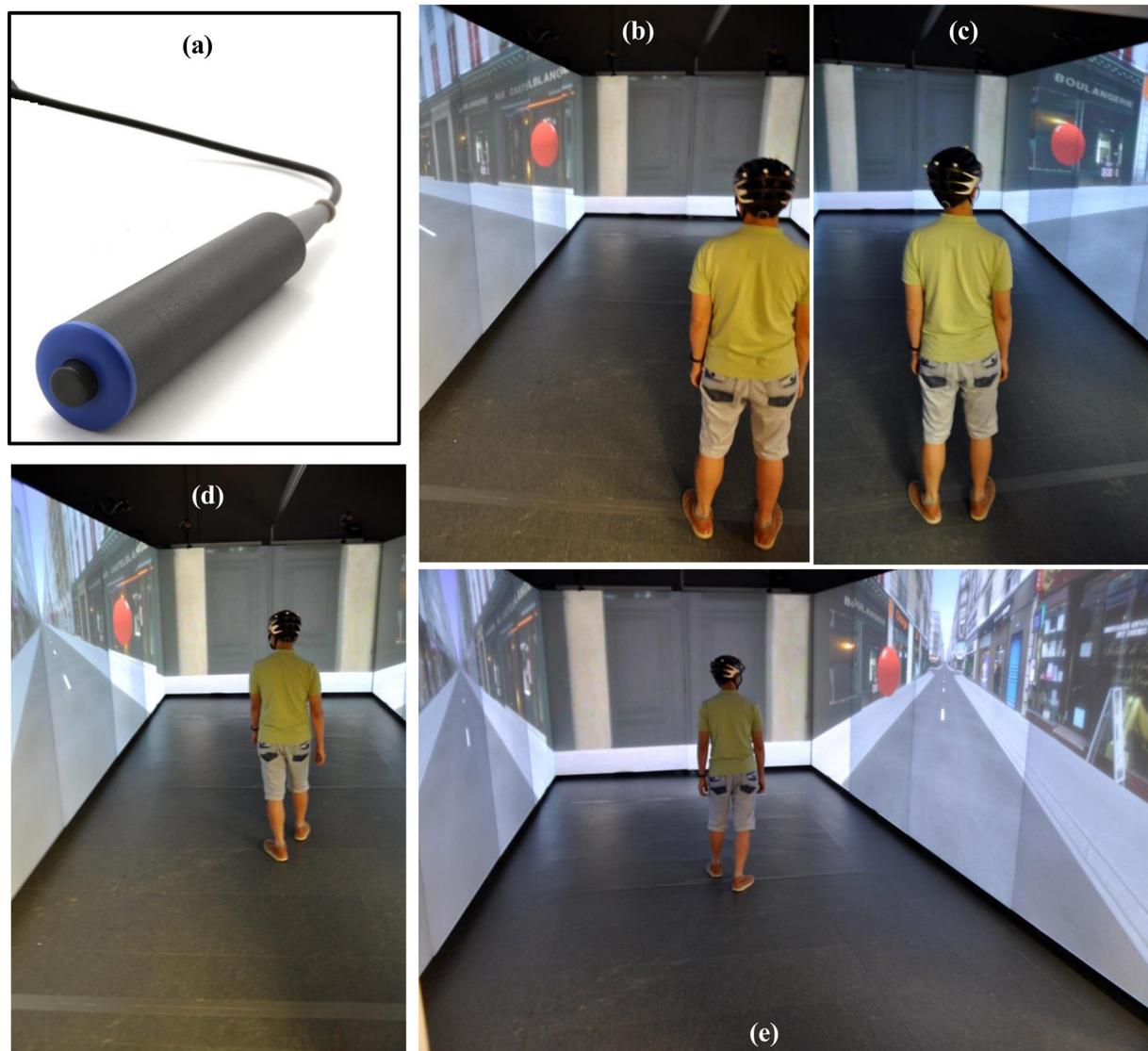

Fig. 2. (a) The response button used by participants. (b) The red circle presented on the left side of the participant's visual field when s/he was standing at the edge of the sidewalk during the simple reaction-time task. (c) The red circle presented on the right side of the participant's visual field when s/he was standing at the edge of the sidewalk during the simple reaction-time task. (d) The red circle on the left side of the participant's visual field when s/he was in the middle of the near lane during the walking-while-scanning task, and (e) the red circle on the right side of the participant's visual field when s/he was in the middle of the street during the walking-while-scanning task (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article).

Table 1
The 30 trials proposed in the walking-while-scanning dual task.

	Participant in middle of near lane	Participant in middle of two-way street	Participant in middle of far lane
Sound stimuli (12)	Beep (4 trials)	Beep (4 trials)	Beep (4 trials)
Visual stimuli (12)	- Red ball on right side (4 trials) - Red ball on left side (4 trials)	- Red ball on right side (2 trials) - Red ball on left side (2 trials)	X
No stimuli (6)	Nothing happened, and the participant did not have to press the response button		

sickness symptoms, maybe thanks to the interactive system that allows an active walk of 7 m (see Cavallo et al., 2019).

For each trial, experimenters instructed participants to cross the two-way street if they thought it was safe to do so without running and/or stopping in the middle. If the available gaps seemed too short for crossing the entire street, participants were told to wait until the next trial. Decisions to cross and participants' locomotion until they reached the opposite sidewalk were recorded.

Vehicle speed was varied across the 40 experimental trials: 20 trials involved vehicles that approached at a constant speed of 40 km/h, while the other 20 trials involved vehicles approaching at a constant speed of 60 km/h. Across trials, the available time gaps between two approaching cars in the traffic flows were also varied, but in such a way that all participants had the same number of opportunities to cross the street, as a function of their own walking speed (WS). Again during the first task (simple walking), WS across the width of the simulated street had been measured on 10 trials at a normal-to-fast walking pace. Each individual's WS (the average of the 10 trials) was entered into the street-crossing scenario and used for the present task. Participants were instructed here to walk at a normal-to-fast speed, but they were also advised that they could walk faster or slower if they wanted or needed to. Rather than proposing fixed gaps (e.g., 1, 2, 3, 4 s), and so as to ensure that younger and older participants had comparable crossing opportunities, the temporal values of the gaps proposed were adjusted to each individual's WS (for more details, see Dommes et al., 2015b; Maillot et al., 2017). The modification could be negative, and the available gap was then shorter than the individual's WS. When it was positive, the gap was longer. Combinations of gaps in each lane resulted in three different situations: (i) gaps were the same in each lane (5 possible time gaps for each speed of approaching cars, for a total of 10 trials), (ii) time gaps were shorter in the near lane than in the far lane (6 trials for each speed, for a total of 12 trials), and (iii) gaps were shorter in the far lane than in the near lane (9 trials for each speed, for a total of 18 trials). These varying time gaps, however, were always synchronized, so they were simultaneously available in the two lanes (bearing in mind that time-gap durations could be different in each lane for some trials). The manipulated gaps always appeared 6 s after trial onset, providing a view of the scenes for 6 s before participants could cross. All other vehicles in the traffic groups were separated by about 1.5 s so that participants could not cross between them.

The behavioral indicator used for this task was the percentage of collisions. A crossing was scored as a collision when the participant was 'hit' by the approaching car, i.e., s/he was in front of the approaching car (somewhere between the right and left sides of the car) when it passed the crossing line. This variable was calculated for the near and far lanes of the two-way street and was expressed as a percentage of the total number of crossings actually made by the participant.

2.2.5. NASA-TLX questionnaire

Measures of perceived workload were collected after each task (the simple walking task, the dual walking-while-scanning task, and the street-crossing task) using the NASA-TLX (Hart and Staveland, 1988). Participants gave their ratings on six subscales assessing mental demand, physical demand, temporal demand, performance, effort and frustration level respectively. Ratings were given on a scale ranging from 0 to 100 for each dimension. Mean NASA-TLX subscale scores (based on the unweighted scoring procedure, see e.g., Nygren, 1991) were used.

2.3. Data analyses

Analyses of variance (ANOVAs) were conducted to examine all dependent measures obtained from the three tasks. Statistical significance was set at a p-value of .05. The computation of relative effect size (η^2) and post-hoc comparisons (Tukey HSD) completed the analyses.

3. Results

We compared walking speeds and NASA-TLX scores across the three tasks after analyzing the behavioral indicators collected on the second task involving walking while scanning the environment, and on the third task involving crossing the street.

3.1. Dual walking-while-scanning task: reaction times, errors, and omissions

Fig. 4 plots mean reaction times on the second task. Reaction time was the time taken to press the button in response to a sound or visual stimulus presented in (a) the simple reaction-time task with participants standing at the edge of the sidewalk, and (b) the dual task of walking and pressing the response button.

The 3 (age group: young, younger-old, and older-old participants) × 2 (task: simple RT or dual task) × 2 (stimulus type: sound or visual) ANOVA revealed a significant main effect of age group on mean reaction time, $F(2,52) = 8.81$, $p < .001$, $\eta^2 = .25$. Post-hoc tests indicated that the time taken to press the response button was significantly
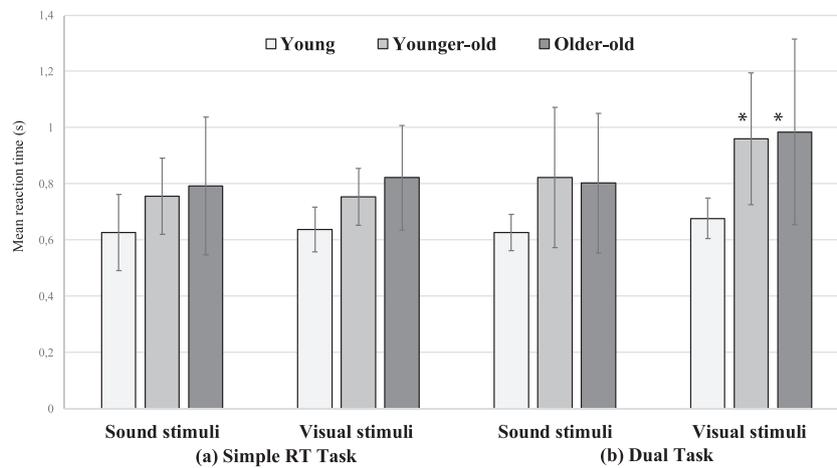

Fig. 3. Street-crossing task.

Fig. 4. Mean reaction time (s) in young, younger-old, and older-old participants for pressing the button in response to sound and visual stimuli in (a) the simple reaction-time (RT) task and (b) the dual task. Vertical bars represent standard deviations. An asterisk indicates a significant value < .05 at Tukey HSD post-hoc tests.

greater ($p < .01$) in both older-old participants ($M = 0.85$, $SD = 0.28$) and younger-old participants ($M = 0.82$, $SD = 0.21$) than in young participants ($M = 0.6$, $SD = 0.10$). The difference between the older-old and younger-old participants was not significant ($p = .84$).

The main effect of task was significant, $F(1,52) = 5.56$, $p < .05$, $\eta^2 = .10$, with reaction time being longer in the dual task ($M = 0.83$, $SD = 0.27$) than in the simple task ($M = 0.74$, $SD = 0.18$).

The main effect of stimulus type was also significant, $F(1,52) = 42.69$, $p < .001$, $\eta^2 = .45$, with visual stimuli involving longer reaction times ($M = 0.82$, $SD = 0.24$) than sound stimuli ($M = 0.75$, $SD = 0.22$).

The interaction between group and task was not significant $F(2,52) = 0.91$, $p = .41$, but the interaction between group and stimulus was $F(2,52) = 4.21$, $p < .05$, $\eta^2 = .14$. More specifically, the difference between sound and visual stimuli was not significant in the young group of participants ($p = .61$), whereas both groups of old participants took significantly more time to respond to visual stimuli than to sound stimuli ($p < .01$).

The interaction between task and stimulus type was significant $F(152) = 31.87$, $p < .001$, $\eta^2 = .38$. While the difference between sound and visual stimuli was not significant in the simple reaction-time task ($p = .76$), participants took longer to respond to visual stimuli than to sound stimuli in the dual task ($p < .001$).

The interaction between group, task, and stimulus type indicated a marginal trend toward significance, $F(2,52) = 3.03$, $p = .0567$, $\eta^2 = .10$; see Fig. 4. Post-hoc analyses showed that the difference between sound and visual stimuli was nonsignificant on the simple reaction-time task for all three groups of participants. While the difference between sound and visual stimuli was still not significant for young participants in the dual task ($p = .72$), both groups of old participants took significantly more time to detect visual stimuli than sound stimuli in the dual task of walking while scanning the environment ($p < .001$).

The analysis of the errors made, i.e., when the participant pressed the response button when no stimulus was delivered (see Table 2), could be done only for the dual task because the simple reaction-time task did not involve trials where no stimulus was presented. The analysis revealed no significant effect of group $F(2,52) = 1.45$, $p = .24$. On average, participants pressed the response button once out of the 6 trials with no stimulus.

Omissions, i.e., when the participant did not press the response button even though a stimulus was presented, were rare (see Table 2). No significant effects of group or stimulus emerged from the Anova.

Table 2

Mean (and SD) of errors and omissions observed in the three groups of participants on the simple RT task and the dual walking-while-scanning task.

	Simple RT Task		Dual Task	
Errors				
Young			M = 0.6 (SD = 0.13)	
Younger-old			M = 1.28 (SD = 0.06)	
Older-old			M = 1 (SD = 0.05)	
Omissions	Sound	Visual	Sound	Visual
Young	M = 0 (SD = 0)	M = 0 (SD = 0)	M = 0 (SD = 0)	M = 0.13 (SD = 0.35)
Younger-old	M = 0 (SD = 0)	M = 0 (SD = 0)	M = 0 (SD = 0)	M = 0.06 (SD = 0.23)
Older-old	M = 0 (SD = 0)	M = 0 (SD = 0)	M = 0 (SD = 0)	M = 0.05 (SD = 0.22)

3.2. Street-crossing task: decisions that led to collisions

The 3 (age group: young, younger-old, and older-old participants) × 2 (lane: near and far lanes) × 2 (speed: 40 and 60 km/h) ANOVA revealed a significant main effect of age group on the mean percentage of decisions that led to collisions, $F(2,52) = 5.44$, $p < .01$, $\eta^2 = .17$. Post-hoc tests indicated that older-old participants made significantly more decisions that caused collisions with approaching cars ($M = 3.87\%$, $SD = 8.11$) than young participants did ($M = 0.36\%$, $SD = 1.58$) ($p < .01$). The difference between younger-old participants ($M = 2.21\%$, $SD = 5.34$) and older-old participants was not significant ($p = .23$), nor was the difference between younger-old and young participants ($p = .21$).

The main effect of lane was also significant, $F(1,52) = 15.72$, $p < .001$, $\eta^2 = .23$, with a higher percentage of collisions in the far lane ($M = 4.09\%$, $SD = 7.85$) than in the near lane ($M = 0.59\%$, $SD = 2.71$).

The main effect of speed was also significant, $F(1,52) = 15.52$, $p < .001$, $\eta^2 = .23$, with a higher percentage of collisions at 60 km/h ($M = 3.78\%$, $SD = 7.64$) than at 40 km/h ($M = 0.90\%$, $SD = 3.56$).

The interaction between age group and lane was marginally significant, $F(2,52) = 2.99$, $p = .0588$, $\eta^2 = .10$. Post-hoc tests revealed that both groups of older participants made significantly more collision-triggering decisions in the far lane than in the near lane ($p < .05$), whereas lane differences were not significant in the young group ($p = .99$; see Fig. 5a). Furthermore, while in the near lane, differences
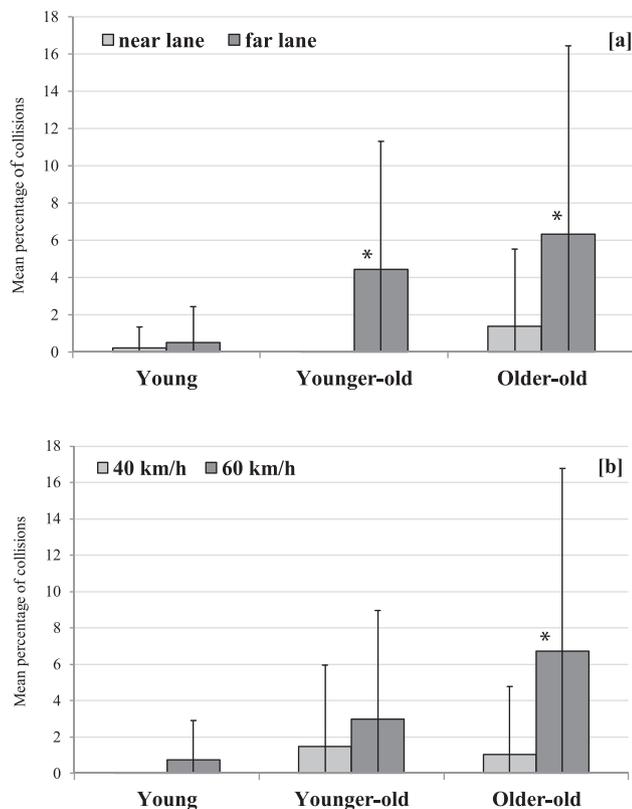
Fig. 5. Mean percentage of collisions in young, younger-old, and older-old participants, according to (a) the lane and (b) the speed of approaching cars. Vertical bars represent standard deviations. An asterisk indicates a significant value < .05 at Tukey HSD post-hoc tests.

between the three age groups were not significant, in the far lane, older-old participants made more decisions that led to collisions than young participants did (p < .01). This difference did not reach significance for the younger-old and young participants (p = .10).

The results also indicated a significant interaction between age group and speed, F(2,52) = 5.67, p < .01, η^2 = .18. While speed differences were not significant in the young group (p = .99), post-hoc tests indicated that older-old participants made significantly (p < .001) more decisions that led to collisions when vehicles were approaching at 60 km/h than at 40 km/h (see Fig. 5b). Speed differences were not significant in the younger-old group (p = .77). At 40 km/h, no group differences were significant. By contrast, at 60 km/h, older-old participants made more decisions resulting in collisions than did the younger-old group and the young group (ps < .05).

The interaction between lane and speed was significant, F(1,52) = 8.5, p < .01 η^2 = .14, with speed difference being significant in the far lane only (p < .01).

The interaction between age group, lane, and speed was not significant, F(2,52) = 1.96, p = .15.

A descriptive analysis of the decisions made by participants (2200 decisions: 40 trials x 55 participants) yielded a total of 74 decisions that led to collisions: 12 (16%) involved a collision in the near lane and 62 (84%) involved a collision in the far lane.

For collisions in the near lane (12 out of 74, 16%), we found that 100% of the decisions occurred on trials where vehicles were approaching at 60 km/h and when the available time gap was strictly equivalent to the individual participant's mean walking speed (WS).

Regarding collisions in the far lane (62 out of 74, 84%), we noted that most (47 out of 62, 76%) also involved vehicles that were approaching at 60 km/h and with insufficient time gaps. In these situations, time gaps were actually sufficient in the near lane (WS + 50%,

+100%, or +150%) but insufficient in the far lane (WS). Out of the 47 far-lane collisions with insufficient time gaps and vehicles approaching at a high speed, 2 concerned young participants (4.3%), 14 concerned younger-old participants (29.8%), and 31 concerned older-old participants (65.9%).

3.3. Walking-speed comparisons across tasks

Walking-speed comparisons were made between the simple walking task, the dual task of walking while scanning, and the street-crossing task for each trial where the participant attempted to cross the street. On all three tasks, the mean walking speed was calculated as the mean time taken to walk between the two sidewalks (in m/s), one on each side of the street.

The 3 (age group: young, younger-old, and older-old participants) × 3 (task: walking task, walking-while-scanning task, street-crossing task) ANOVA revealed a significant main effect of group on mean walking speed, F(2,52) = 14.9, p < .00001, η^2 = .36. Post-hoc tests indicated that older-old participants walked significantly (p < .001) more slowly (M = 1.22 m/s, SD = 0.21) than young participants did (M = 1.51 m/s, SD = 0.24). Younger-old participants (M = 1.30 m/s, SD = 0.23) also walked more slowly than young participants did (p < .01). The difference between the two groups of old participants was not significant (p = .21).

The main effect of the task performed was also significant, F(2,104) = 83.01, p < .0001, η^2 = .62, with participants walking more rapidly on the simple walking task (M = 1.49 m/s, SD = 0.26) than on both the dual task (M = 1.20 m/s, SD = 0.22) and the street-crossing task (M = 1.30 m/s, SD = 0.19). As a whole, participants also walked more rapidly in the street-crossing task than in the dual task (ps < .001).

The interaction between age group and task was significant, F(4,104) = 5.48, p < .001, η^2 = .17; see Fig. 6. Post-hoc analyses showed that young participants walked significantly faster in the simple walking task than in both the dual walking-while-scanning task and the street-crossing task (ps < .001). The difference between the dual task and the street-crossing task was not significant (p = 1.0). In contrast, such trends were not observed among the older participants. Both old groups walked significantly faster in the street-crossing task than in the dual task (ps < .05). And younger-old participants' mean walking speed when crossing the street did not even differ significantly from the speed observed during simple walking (p = .07). The difference between the street-crossing task and the simple walking task was significant, however, in the older-old group of participants (p < .05), but only slightly.
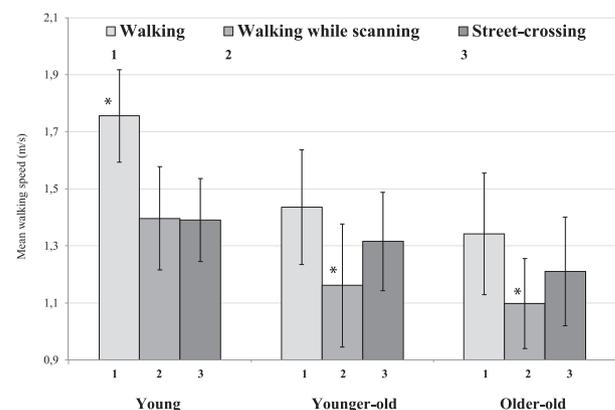

Fig. 6. Mean walking speed (m/s) among young, younger-old, and older-old participants on the three tasks: (1) simple walking, (2) walking while scanning the environment, and (3) crossing the street. Vertical bars represent standard deviations. An asterisk a significant value < .05 at Tukey HSD post-hoc tests.

3.4. Perceived-workload comparisons across tasks

A 3 (age group: young, younger-old, and older-old participants) x 3 (task: walking task, dual task, street-crossing task) $\times$ 6 (NASA-TLX subscale) ANOVA yielded no significant main effect of age group on the mean subscale score, $F(2,52) = 1.15$, $p = .32$.

The results, however, revealed significant differences between tasks, $F(2,104) = 49.77$, $p < .00001$, $\eta^2 = .49$, with the overall score being significantly ($p < .001$) higher on the street-crossing task (M = 37.98, SD = 28.24) than on both the simple walking task (M = 23.52, SD = 32) and the dual walking-while-scanning task (M = 30.75, SD = 29.39). The mean score was also significantly higher in the dual task than in the simple walking task ($p < .001$).

Main differences between the NASA-TLX subscales showed up in the analyses, $F(5,260) = 299.25$, $p < .00001$, $\eta^2 = .85$. Performance scores were significantly higher than all other scores ($p < .0001$), and frustration scores were among the lowest ($p < .0001$).

The interaction between age group, task, and subscale was marginally significant, $F(20,520) = 1.58$, $p = .0525$, $\eta^2 = .06$. Post-hoc tests indicated significantly higher scores for young participants than for either group of old participants on several dimensions of the street-crossing and walking-while-scanning tasks. On both of these tasks, young participants gave a significantly higher rating for mental and physical demands than younger-old and older-old participants did ($ps < .05$; see Fig. 7).

4. Discussion

The aim of the present study was to gain a better understanding of whether and how the street-crossing task is physically and cognitively demanding, especially with aging, in such a way that it could be regarded as a dual task involving walking while scanning the environment. In line with previous research (Dommes et al., 2014; Oxley et al., 2005; Lobjois and Cavallo, 2007, 2009; Holland and Hill, 2010), the results indicated an increased risk of collision with aging. Older-old participants made more decisions that led to collisions with approaching cars than did younger-old and young participants. But younger-old participants did not have significantly more collisions than young participants did. These results are in line with crash data in France indicating more pedestrian accidents at a very old age only (over 75 years). While people over 75 represented 40% of pedestrian fatalities in 2016 in France, pedestrians between 65 and 74, and between 15 and 24 represented only 12% and 10% of pedestrian fatalities, respectively (ONISR, 2017).

Gap-acceptance difficulties with aging appeared to be particularly marked in the two-way traffic situations, with older pedestrians having trouble taking the second lane, where traffic is also approaching, into account in their decisions to cross. Contrary to young participants, younger-old and older-old participants had more collisions in the far lane than in the near lane. This finding has already been observed in the accident analyses made by Oxley et al. (1997) and Fontaine and Gourlet (1997), as well as in the simulator studies by Dommes et al. (2014, 2015b). Older pedestrians seem to adopt inadequate visual-exploration

strategies, favoring the observation of the traffic approaching in the near lane while neglecting the far lane. Considering both lanes may be too demanding, overloading cognitive resources in older pedestrians.

The results also pointed out age-related difficulties in considering the speed of approaching vehicles when deciding to cross. Older-old participants were more often hit when vehicles were approaching at 60 km/h than at 40 km/h. Such a speed difference did not affect young participants' decisions to cross. This finding is in line with previous simulator studies (Dommes et al., 2014, 2015a,b; Lobjois and Cavallo, 2007, 2009; Oxley et al., 2005), which reported the use of distance-based heuristics by older pedestrians that were potentially linked to a decline in visual-motion sensitivity with aging (Snowden and Kavanagh, 2006).

While these aging effects on the decision-making process are now becoming well-known, those that affect the second part of the street-crossing task are less obvious. After making her/his decision and starting to cross, the pedestrian has to continue observing oncoming vehicles and adjust her/his walking speed. Although gait changes with aging are known, few studies have examined the ways in which this second part of the street-crossing task is physically and cognitively demanding for the older person, as any dual task can be. To investigate this issue, the present study compared street-crossing performance to performance on a dual task involving walking while scanning the environment. The results revealed that reaction times were much higher for both old groups when they had to detect visual stimuli while walking than while simply standing on the sidewalk. In contrast, reaction times did not vary significantly in young adults, whether they had to simply press the response button while standing on the sidewalk or while walking, or had to respond to a sound or visual stimulus. Such an increase in reaction times in old people when scanning for visual stimuli while walking may reflect a heavy workload. Walking and scanning for visual stimuli may require attentional resources that use the same visual channel, and are limited, thus increasing the workload. This result is in line with several studies showing that dual-task and multi-tasking costs are greater for older adults than for younger ones (Kramer et al., 1999; Neider et al., 2011), suggesting age-related declines in attentional control and working memory. Our findings are also consistent with other studies showing that dual-task costs in older adults become larger as demands on attentional-control processes increase (e.g., Lindenberger, Mariske, and Baltes, 2000; Salthouse et al., 1996). Dynamic sensorimotor tasks such as walking seem to become cognitively more demanding with aging (e.g., Lindenberger et al., 2000; Woollacott and Shumway-Cook, 2002). In recent years, several studies have reported greater co-variation and interdependence of sensory and cognitive functions in old age (Anstey et al., 2001; Baltes and Lindenberger, 1997; Lindenberger and Baltes, 1994, 1997; Salthouse et al., 1996).

Walking speed comparisons between tasks, however, brought out some new findings. Nonsignificant differences between the dual walking-while-scanning task and the street-crossing task were observed in young participants, suggesting an apparent correspondence and similarity of these two tasks in terms of physical and mental demands, as well as task priority. In contrast, older-old and younger-old participants
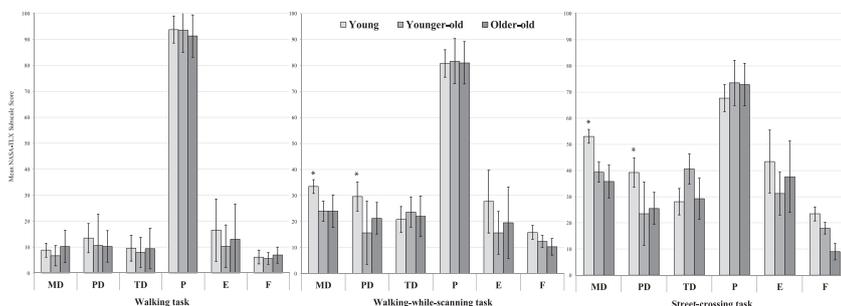

Fig. 7. Mean NASA task load index (NASA-TLX) subscale scores on the three walking tasks. Vertical bars represent standard deviations. MD = Mental Demand, PD = Physical Demand, TD = Temporal Demand, P = Performance, E = Effort, F = Frustration.

An asterisk indicates a significant value < .05 at Tukey HSD post-hoc tests.

walked significantly faster in the street-crossing task than in the dual walking-while-scanning task, suggesting that they placed more priority on walking rapidly than on scanning the environment. This finding suggests that, with aging, once the decision to cross is made, older individuals place priority on walking without falling, even if it involves not looking for approaching traffic, and going as fast as possible to avoid spending time on the road where there are vehicles. This finding is in line with the few recent studies suggesting that older pedestrians allocate their attention to watching their path as they walk and neglect active visual control during the street-crossing phase (Avineri et al., 2012; Tapiro et al., 2016; Zito et al., 2015). To confirm and expand this finding, future studies need to be conducted, using very fine motion analyses, to more precisely study walking-speed variations in young and older pedestrians during the street-crossing phase. After deciding to cross, young pedestrians may update their decision by adjusting their walking pace to the continuous perception of traffic. On the contrary, older pedestrians looking at their path as they walk may not adjust their walking speed to the perception of approaching traffic. Studying such walking-speed variations to assess task priority and resource allocation during the street-crossing task could also be done using eye-tracking measures to carefully examine the visual strategies of young and older pedestrians before and during crossing.

Finally, the results of the present study also provide new insight into perceived workload. Perceived workload during street crossing was correctly rated by participants to be higher than during simple walking or when performing the dual walking-while-scanning task. But the differences were surprisingly small, as if people were not aware how great street-crossing task requirements are. Moreover, the younger participants were the ones who gave higher ratings for the mental and physical demands, which may mean a lack of awareness of task demands among old participants in particular. This finding suggests poor metacognition in older adults, with a lack of awareness of age-related declines and thus, inadequate compensation strategies. However, Butler, Lord, and Fitzpatrick (2016) used an everyday risk-taking questionnaire and found different results. Their "exact group", i.e., the older pedestrians who performed the best in their simulated street-crossing task were those who reported taking the greatest risks in everyday life, while other groups of older pedestrians, who performed less well in the simulator, reported avoiding risk-taking behaviors in everyday life situations (compensation strategies?). Butler et al. (2016) concluded that crossing errors in older people were not the result of a type of "risk-taking". Our results also showed how subjective ratings like the ones we collected using the NASA-TLX did not match objective workload measurements during task performance in a simulator. People's perceptions may be biased, and simulator studies may reveal difficulties that may be sometimes compensated for in natural environments. Other studies should be conducted to further investigate the links between metacognition, risk-taking behaviors, and compensation strategies in older pedestrians, in a laboratory as well as in natural environments.

While the results of the present study offer new findings to add to previous results on the same topic, several limitations need to be listed and addressed in future research. First, the sample size was quite small, which may limit the scope of the statistical analyses we used. The present results therefore need to be interpreted with caution, and to confirm our conclusions, future studies need to be conducted with a larger sample. Although measuring subjective workload using the NASA-TLX was informative regarding the fact that people may be unaware of street-crossing constraints, the behavioral measures we collected such as collision rate, walking speed, and reaction time revealed a non-negligible workload in old pedestrians. Such behavioral measures can be considered as indirect measures of workload because they are not continuous. It would be interesting to collect physiological measures of workload (e.g., electroencephalography, pupillometry, heart rate variability, etc.; see Ranchet et al., 2017) while pedestrians are crossing a street. This would allow us to assess fluctuations in workload during task performance. Data about head positions and eye movements before and during street crossing are also needed to further assess task demands, workload, and task priority. Lastly, the study of walking speed adjustments during street crossing needs the use of finer motion data than used in the present experiment, not only in controlled laboratory experiments but also in real-life situations.

5. Conclusions and recommendations

The findings of the present study suggest that collisions during street crossing may be linked to inadequate decision-making processes, insufficient compensation by means of faster walking and proper traffic scanning, task overload, and poor metacognition with aging. Beyond gap-acceptance difficulties, older pedestrians, after deciding to cross, appear to place priority on walking rapidly to avoid spending time in the street, to the detriment of scanning approaching traffic. Compensating for gap-acceptance difficulties is therefore not possible because of looking-at-the-ground behaviors and physical limitations that constrain faster walking. Aging increases walking-task demands, in such a way that scanning the approaching traffic while walking may overload available attentional resources and increase the risk of falling. Even if some older pedestrians say they are cautious (Bernhoft and Carstensen, 2008; Holland and Rabbitt, 1992), they appear, as a whole, to be insufficiently aware of the street-crossing-task requirements, and of the extent to which walking while scanning the approaching traffic is physically and cognitively demanding. Unawareness of how age affects performance may impede compensation strategies (such as avoiding multiple-road crossing).

The present findings allow us to make several recommendations for finding ways of compensating for age-related declines and difficulties in crossing the street, at the three levels of the road system. Firstly, regarding the infrastructure, building pedestrian areas where the pedestrian has the priority and is not in contact with vehicles would certainly ensure greater safety. Another important question concerns the number of crosswalks equipped with traffic and pedestrian lights, as well as their locations (close to areas of interest, avoidance of visibility obstacles, preventing cars from parking there, etc.). While older pedestrians often say they prefer to cross on marked crosswalks (Bernhoft and Carstensen, 2008), it may be because obeying signals helps them compensate for their declining age-related abilities (Dommes et al., 2015a). To reduce the time spent in the street, infrastructures such as sidewalk extensions and narrower lanes should also be part of the solution. Reducing traffic speed is also a good way to help compensate for the difficulty older pedestrians have in taking speed into account in their crossing decisions. This would also decrease the risk of death following a collision (the lower the speed, the less violent or even fatal the impact will be).

Secondly, regarding the vehicles on the road, research and industry need to continue developing sensor-assisted cars that can help avoid pedestrian injuries. Such cars are already on the market and will become the standard in a few years. But collision-warning systems with auto-braking and pedestrian detection have to address several limitations before being able to prevent all crashes, for example, ones due to hidden obstacles (e.g., left/right turns) and technical constraints (these systems are optimized for relatively low vehicle speeds and short distances, and cannot infer the intentions of pedestrians standing on the sidewalk, etc.). Inventing and designing technological devices that also permit precise and complete communication between vehicles, infrastructures, and pedestrians is a challenge that should continue to encourage researchers to supplement on-board sensors and approach the system as a whole.

Finally, regarding the pedestrians themselves, education and training programs, along with safety campaigns devoted to pedestrian vulnerability would also be useful for reducing crashes. Older pedestrians are not always aware of their gap-acceptance difficulties or slower walking speeds (Naveteur et al., 2013), and young pedestrians

often wrongly feel that they are not concerned with this issue (e.g., smartphone use while walking; see Schwebel et al., 2012). The results of the present study show furthermore that we cannot "force" older pedestrians to look at approaching traffic while walking if they are unable to do so because the demands are too great. They need to visually control their walking to avoid falls. One way of compensating for this need could be to train them physically. Several initiatives have shown that physical exercise is not only able to improve strength, balance, mobility, and endurance in older people (e.g., Liu et al., 2014), but can also enhance cognitive functioning (e.g., Colcombe and Kramer, 2003). Healthy older adults appear to also benefit from training in motor–cognitive dual-task situations (Wollesen and Voelcker-Rehage, 2014).

Acknowledgments

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