The role of perceptual, cognitive, and motor abilities in street-crossing decisions of young and older pedestrians

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Abstract

Purpose: The present experiment investigated the role of perceptual, cognitive, and motor abilities in street-crossing behaviour with ageing. Previous research has shown that older pedestrians make many unsafe crossing decisions when cars are approaching at high speeds, and miss many crossing opportunities when car speeds are low. The older subjects seem to ignore information about the speed of the approaching cars and to preferentially use simplifying heuristics based on vehicle distance. The objective of the present study was to better understand the underlying age-related changes that lead to these behaviours, with a specific focus on perceptual factors.

Method: Twenty young (age 20–30), 21 younger-old (age 61–71), and 19 older-old (age 72–83) participants took part in the experiment. All participants individually carried out a simulated street-crossing task and took a battery of functional tests assessing perceptual, cognitive, and motor abilities.

Results: In line with earlier findings, the seniors made a greater number of incorrect crossing decisions, with many risky decisions when the vehicle was approaching at a high speed and many missed opportunities at a low speed. Correlation and regression analyses pointed out several functional performance measures as predictors of the way the pedestrians took or did not take information about vehicle speed into account in their decisions. Processing speed and visual attention abilities were shown to play the most important role in explaining the variance in incorrect decisions: these abilities allowed participants to focus their attention on the relevant speed information and to make timely, correct decisions. Time-to-arrival estimates, which informed the pedestrians about the time available for crossing, were found to be the second most predictive factor. Walking speed, by way of which the pedestrians adapted their crossing pace to the perceived available time, also came into play. Inhibition abilities ended up as the last functional predictor; they allowed the pedestrians to ignore irrelevant information and inhibit automatic but unsuitable responses.

Conclusions: The present study provided a multidimensional explanation of increased gap-selection difficulties with ageing, including a combination of perceptual, cognitive, as well as physical performance declines with increasing age. The findings have implications for improving older pedestrians’ safety in terms of speed limits, road design, and training.

Introduction

Crossing the street is a highly difficult task for older people, who 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 of age, whereas this age group represents <15% of the population. In spite of this obvious safety challenge, and
contrary to research on older drivers, only a few studies have been dedicated to senior pedestrians.

Previous research has pointed out greater difficulty in selecting safe gaps and adopting sufficient safety margins with ageing, especially on two-way roads. One of the striking characteristics of older people’s behaviour is that their decisions to cross are strongly affected by the approaching car’s speed, whereas younger pedestrians’ behaviour is largely independent of vehicle speed, older people have been found to accept shorter and shorter time gaps as speed increases. For a given available time gap, the distance of the approaching car is necessarily greater at high speeds than at low speeds. Considering the greater distance, older people more often decide that it is safe to cross, walk more slowly, and adopt shorter safety margins when the speed of the approaching vehicles is high than when it is low. As a corollary, the shorter car distances associated with lower approach speeds lead older pedestrians to decide not to cross and to miss crossing opportunities. With ageing, then, distance gap instead of time gap becomes the overriding parameter for deciding whether or not to cross. The use of this heuristic is dangerous, however, and leads to risky decisions when cars are approaching at high speeds.

Risky street crossing decisions in older pedestrians have often been explained by age-related declines in motor, cognitive, and/or perceptual abilities. But contrary to driving performance, experimental studies are still scarce. In a recent study, mobility and walking speed were shown to be significant predictors of safe crossing choices. Clearly, motor abilities are crucial components of safe crossing, especially for handling perilous situations by increasing walking pace or by running when a car is arriving faster than expected.

The reduced cognitive abilities associated with normal ageing have also been suspected to increase gap-selection difficulty. The use of simplifying distance-based heuristics by older adults may be a means of compensating for age-related cognitive declines such as longer processing time, impaired visual attention, or reduced executive functions (inhibition, flexibility and updating).

A decline in perceptual abilities has also often been mentioned to account for the greater number of unsafe road-crossing decisions in older pedestrians. Older adults have been shown to exhibit poorer performance in estimating the time-to-arrival of approaching cars and in detecting a collision with an obstacle. The decline in visual motion sensitivity, especially the ability to perceive slow angular movements, may cause seniors to ignore a vehicle’s visual movement and disregard speed information. Such a loss of sensitivity is particularly handicapping whenever the car is approaching at a fast speed, since the vehicle is far away and generates a very slow visual movement.

While age-related declines in functional abilities are frequently mentioned when interpreting gap-selection difficulties in older pedestrians, little empirical evidence has yet been provided. To date, no multidimensional approach has been used to jointly study the respective roles of motor, cognitive, and perceptual factors. The goal of the present study was to investigate the relationship between several functional abilities and their role in the street-crossing behaviour of young and older pedestrians. Walking speed was used to measure motor abilities. Standard tasks were used to evaluate cognitive abilities such as processing speed, visual attention, and executive functions. Because they have never been investigated in road crossing studies, perceptual tasks were specifically designed to assess visual motion perception abilities. Regression analyses were performed to study the link between these functional abilities and crossing behaviours collected on a simulator. In line with our previous research, we hypothesized that perceptual abilities play a major role in gap selection, especially in the way pedestrians take the speed of the approaching car into account in their street-crossing decisions.

**Method**

**Participants**

Twenty young participants (10 women, 10 men) between the ages of 20 and 30 (mean 25.2, S.D. 3.4 years), 21 younger-old participants (12 women, nine men) ranging in age from 61 to 71 (mean 68.1, S.D. 2.7 years) and 19 older-old participants (11 women, eight men) ranging in age from 72 to 83 (mean 76.7, S.D. = 3.5 years) took part in the experiment. All participants had normal or corrected-to-normal visual acuity (at least Snellen 6/10, Ergovision; Essilor, http://www.organising-vision.com/). The older participants underwent a medical examination to insure the absence of severe physical or mental pathologies and all of them were in good health and were living on their own. The institutional ethics committee approved the study.

**Street-crossing task**

Street-crossing behaviour was studied using an immersive, interactive street-crossing simulator based on the INRETS Sim² simulation tools. The used device comprised of a portion of a 4.2-m-wide experimental road on which participants actually walked. It also included an image-generation system, three-screen projection, a 3D sound-rendition system, and a recording system. The visual projection system provided participants with a horizontal visual field between 90° (when standing on the

Ophthalmic & Physiological Optics 31 (2011) 292–301 © 2011 The College of Optometrists 293
sidewalk) and 140° (in the middle of the experimental road), and a vertical visual field of 40°. The images (refreshed at 30 Hz) were calculated and projected at the height of the participant’s eyes. Scenes were updated interactively by a movement-tracking system that records the participant’s positions via a cable attached to his/her waist. The scenes depicted 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 left to right with respect to the participant.

All participants were tested individually on the street-crossing simulator. They started at the edge of the sidewalk facing the experimental road and had to look left at 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 (Figure 1). The participant’s decision to cross or not to cross and his/her motion until reaching the other sidewalk were recorded.

Vehicle speed (30, 40, 50, 60, and 70 km h\(^{-1}\)) and time gap between the two cars (1–7 s, in 1-s increments) were varied. The number of repetitions per time gap differed according to their probability of being accepted for crossing. In fact, the shortest gaps were ones that would be systematically refused and the longest gaps were ones that would be systematically accepted. Therefore, time gaps of 1 and 7 s were presented once, time gaps of 2 and 6 s were shown twice, and the ‘critical’ time gaps of 3, 4, and 5 s were presented three times, making 15 trials in all. The combination of these 15 trials and the 5 speeds resulted in a total of 75 trials. They were presented in random order in two blocks, with a break between the blocks. The street-crossing task lasted about 30 min.

Perceptual, cognitive, and motor measures

The participants also took a battery of functional tests. We designed two tasks to assess perceptual abilities reflecting motion and time-to-arrival perception, which are two visual skills likely to be involved in crossing decisions. Regarding cognitive abilities, we assessed processing speed and selective visual attention via the Useful Field of View test (UFOV\(^\circ\); Visual Awareness, Inc., http://www.visualawareness.com/), and inhibition via the spatial Stroop task. These cognitive abilities were suspected to be linked to age-related difficulties in processing information about the approaching car’s speed and integrating it into the decision-making process. Motor performance was also assessed since it has been shown to be a significant predictor of safe crossing choices. The tests lasted about 1 h.

Motion-discrimination task.

A black disk (with an angular size of 3°) on a white background was displayed on a computer screen. The disk moved horizontally at an angular velocity of 0.5 or 1° per s. Presentation time was varied between 200 and 1200 ms. For each of the 72 experimental trials proposed, the participants had to determine whether the motion velocity was slow or fast.

Time-to-arrival (TTA) estimation task.

The same virtual environment as in the street-crossing task was used. A vehicle was approaching at 30, 50, or 70 km h\(^{-1}\). The visual scene was interrupted 3–6 s before the vehicle reached the simulated location of the participant. For each of the 36 experimental trials, the participant had to estimate the moment when the vehicle would pass in front of him/her by pressing a response button.

UFOV\(^\circ\) test.

The UFOV\(^\circ\) is a computer-based test of rapid visual-scene perception, without eye or head movements. Three subtests measure the individual’s speed of processing across increasingly complex visual displays; divided and selective attention are also involved. In this paper, we analyzed the threshold scores on Subtest 3 only, which measures processing speed under the highest demand conditions of a selective attention task: participants had to simultaneously identify a central target and locate a peripheral target. The central target (silhouette of a 2-cm by 1.5-cm truck or car) was presented against a black background in a 3-cm by 3-cm fixation box. The peripheral target (2-cm by 1.5-cm silhouette of a car) was presented at one of eight radial locations. Visual distractors (triangles of the same size and luminance as the target) were arranged in concentric circles around the peripheral target. Each trial consisted of four screens displayed in succession: a fixation box, a test stimulus, a full-field white-noise visual mask, and a response screen.

Figure 1. Illustration of a participant crossing the experimental street.
Spatial Stroop task.
A left-pointing or right-pointing arrow target was displayed randomly on the left, centre, or right of the computer screen. Participants were required to determine the direction of the arrow while ignoring its location. Ten neutral stimuli (right- or left-pointing arrows displayed in the centre of the screen), 20 congruent stimuli (e.g. a right-pointing arrow on the right) and 20 incongruent stimuli (e.g. a left-pointing arrow on the right) were proposed, making a total of 50 experimental trials.

Walking speed.
Walking speed (m s\(^{-1}\)) was measured while crossing the experimental road as an indicator of motor ability. The average walking speed during the crossing trials was calculated. The number of trials used to calculate the mean of each participant depended on the number of accepted crossings among the 75 proposed.

Results
Data analysis
Dependent measures from the street-crossing and functional tasks were input into analyses of variance (ANOVAs). The significance level was set at 0.05. Effect size was also computed (\(\eta^2\)). Significant effects were further analyzed using Tukey post-hoc tests. Correlation and regression analyses were computed to find out whether perceptual, cognitive, and/or motor abilities predicted crossing decisions.

Street-crossing decisions
The behavioural indicators used for the present analysis were the percentages of incorrect decisions, i.e. unsafe crossings and missed opportunities. These decision categories were defined with respect to crossing time (CT) and safety margin (SM, or the time between the moment when the participant reached the finishing sidewalk and the moment when the front end of the approaching car reached the participant’s crossing line). An unsafe decision was counted for accepted crossings when the SM was negative, i.e. the participant was not hit, but was still on the road when the car passed the crossing line.\(^a\) A missed opportunity was counted when the participant refused to cross although s/he would have had enough time to cross safely considering her/his mean CT and an SM of 1.5 s (the criterion of 1.5 s was based on previous work on this subject).\(^5\) The percentages of unsafe decisions and missed opportunities were converted to arcsin values. The statistics were done on transformed data, but percentages are presented in the descriptive text and figures.

Unsafe decisions.
The analyses revealed a significant main effect of age (\(F_{2,57} = 17.8, p < 0.0001; \eta^2 = 0.38\)). This effect was due to fewer unsafe decisions among young participants (M = 1.1%, S.D. = 3.3) than among younger-old (M = 9.3%, S.D. = 12.1) and older-old (M = 11.9%, S.D. = 15) participants, whereas the two older groups did not differ significantly from each other.

The main effect of speed was also significant (\(F_{4,228} = 56.2, p < 0.0001; \eta^2 = 0.50\)), with the percentage of unsafe decisions increasing as the speed of the approaching car increased (except between 30 and 40 km h\(^{-1}\)).

Lastly, the interaction between age and speed was significant (\(F_{8,228} = 13.6, p < 0.0001; \eta^2 = 0.32\)): unsafe decisions did not vary significantly for young participants, but rose significantly as speed increased in both groups of older participants (see Figure 2). More specifically, the two groups of older participants made more unsafe decisions than the young participants did when vehicles were approaching at high speeds (60 and 70 km h\(^{-1}\)).

As walking speed was an important factor in calculating unsafe decisions, a separate ANCOVA was computed. When walking speed was entered as a covariate, the age effect remained significant (\(F_{2,56} = 12.2, p < 0.0001, \eta^2 = 0.30\)), as did the main effect of speed (\(F_{4,224} = 4.41, p < 0.01; \eta^2 = 0.07\) and the interaction between age and speed (\(F_{8,224} = 9.8, p < 0.0001, \eta^2 = 0.26\)). The covariate was not significant.

\(^a\)Very few collisions occurred (seven of the 4500 trials). These data were excluded from the statistical analyses.

Figure 2. Unsafe decisions (%) as a function of age and speed of approaching vehicles. Vertical bars represent standard deviations.
Missed opportunities.
The analyses yielded a significant main effect of speed ($F_{4,228} = 30.3$, $p < 0.0001$; $\eta^2 = 0.35$), with more missed opportunities at the lower speeds (30 and 40 km h$^{-1}$) than at the higher ones (50, 60, and 70 km h$^{-1}$). No significant effect of age, or an age by speed interaction was observed. However, the younger-old participants tended to miss more crossing opportunities when the car was approaching at 30 km h$^{-1}$ than the young participants did (see Figure 3).

To control for the influence of walking speed in the calculation of missed opportunities, a separate ancova was computed. The effect of age was not significant whether or not walking speed was entered as a covariate. But the effect of speed became non-significant. The covariate was not significant.

Functional performance

Motion discrimination.
A threshold was computed to determine the duration (in ms) at which the participant could correctly perform the motion perception task 75% of the time. The analysis yielded a significant main effect of age ($F_{2,57} = 7.68$, $p < 0.01$; $\eta^2 = 0.21$) indicating that young participants needed less time to correctly discriminate the angular velocities than younger-old and older-old participants did (see Table 1). No significant differences were found between the two groups of older participants.

Time-to-arrival (TTA) estimation.
Estimated TTA was expressed as a percentage of actual TTA (see Table 1). Whereas the analysis revealed no main effect of age on estimated TTA, there was a main effect of speed ($F_{1,57} = 136.4$, $p < 0.0001$; $\eta^2 = 0.71$): the participants underestimated TTA when the vehicle was approaching slowly (mean 83.3%) and overestimated TTA when it was approaching rapidly (mean 105.2%). A significant age by speed interaction ($F_{2,57} = 8.7$, $p < 0.001$; $\eta^2 = 0.23$) indicated that the speed differences were greater for the older groups of participants (see Table 1), and in particular, that the older-old participants overestimated the available time when the vehicle was approaching at a high speed more often than did the young participants. Expressing this speed difference as a score in percentage points (TTA estimate at a high speed minus TTA estimate at a low speed, see Table 1), and entering it into the analysis, we found that the speed difference score increased significantly with advancing age ($F_{2,57} = 8.7$, $p < 0.001$; $\eta^2 = 0.23$): the older-old participants exhibited a significant higher speed difference in their TTA estimates than the other two groups did, whereas no significant difference was found between the young and younger-old participants. The speed-difference measure reflects interindividual TTA estimates differences in the perceptual distortions caused by the approaching car’s speed. Speed difference was therefore a better measure for conducting correlation and regression analyses.

Processing speed and selective visual attention.
A threshold score on UFOV® Subtest 3 was considered here. It was equal to the display duration (in ms) at which the participant could correctly perform the test 75% of the time. The analysis indicated a significant main effect of age ($F_{2,57} = 19.8$, $p < 0.0001$; $\eta^2 = 0.41$): young participants got smaller threshold scores than did the other two groups of participants (see Table 1). The

Table 1. Means (and standard deviations) of the perceptual, cognitive, and motor measures

<table>
<thead>
<tr>
<th></th>
<th>Young</th>
<th>Younger-old</th>
<th>Older-old</th>
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<tbody>
<tr>
<td>Motion perception: threshold (ms)</td>
<td>314.4 (143.8)</td>
<td>473.9 (166.8)</td>
<td>486.4 (151.0)</td>
</tr>
<tr>
<td>Time-to-arrival: estimated time/actual time × 100 (%) and speed difference (% points)</td>
<td>Low speed 86.4 (14.5)</td>
<td>78.3 (15.9)</td>
<td>85.3 (20.0)</td>
</tr>
<tr>
<td>High speed 99.0 (20.5)</td>
<td>99.3 (24.0)</td>
<td>117.2 (33.8)</td>
<td></td>
</tr>
<tr>
<td>Speed difference 12.6 (10.4)</td>
<td>21.1 (11.5)</td>
<td>32.0 (20.1)</td>
<td></td>
</tr>
<tr>
<td>Processing speed and selective visual attention: threshold (s) on the UFOV® Subtest 3</td>
<td>Mean threshold 60.6 (44.1)</td>
<td>179.2 (105.7)</td>
<td>247.8 (117.1)</td>
</tr>
<tr>
<td>Inhibition: interference score (s)</td>
<td>Mean score 31.6 (52.8)</td>
<td>97.2 (63.1)</td>
<td>86.6 (55.9)</td>
</tr>
<tr>
<td>Motor abilities: mean walking speed (m s$^{-1}$)</td>
<td>Mean speed 1.00 (0.11)</td>
<td>0.90 (0.07)</td>
<td>0.92 (0.09)</td>
</tr>
</tbody>
</table>
difference between younger-old and older-old participants fell short of the statistical significance level ($p = 0.06$).

**Inhibition.**

An interference score was calculated from performance on the spatial Stroop task by subtracting the mean reaction time on correct answers to congruent stimuli, from the mean reaction time on correct answers to incongruent stimuli. The results revealed a significant main effect of age ($F_{2,57} = 7.6, p < 0.01; \eta^2 = 0.21$): young participants had lower interference scores than the two older groups (see Table 1). No significant difference appeared between younger-old and older-old participants.

**Walking speed.**

Walking speed (m s$^{-1}$) was measured while participants crossed the experimental road. The analysis yielded a significant main effect of age ($F_{2,57} = 5.9, p < 0.01; \eta^2 = 0.17$): young participants walked faster than both groups of older participants (see Table 1). No significant difference was found between younger-old and older-old participants.

**Role of perceptual, cognitive, and motor abilities in street-crossing decisions**

Correlation and regression analyses were performed to investigate the role of functional abilities in street-crossing decisions, with a particular focus on how these decisions were affected by speed. Given that the speed effect showed up in both categories of street-crossing decisions, a new indicator called ‘incorrect decisions’ was created by averaging (1) the percentage of unsafe decisions when vehicles were approaching at a high speed (70 km h$^{-1}$), and (2) the percentage of missed opportunities when vehicles were approaching slowly (30 km h$^{-1}$). A high percentage of incorrect decisions reflected a participant’s difficulties taking the oncoming vehicle’s speed into account when making a crossing decision, leading to both unsafe decisions at a high speed and missed opportunities at a low speed.

The measures of perceptual, cognitive, and motor abilities made here were used as predictors. The perceptual predictors were the motion-discrimination threshold and the speed difference in TTA estimates. The cognitive predictors were the threshold collected in the processing-speed and visual-attention task and the inhibition score. Motor abilities were measured by walking speed.

Pearson correlations were used to examine the relationships between incorrect street-crossing decisions, age, and functional abilities. The correlation matrix is presented in Table 2.

As already suggested by the previous anovas, incorrect street-crossing decisions correlated significantly with age: older age was associated with a higher percentage of incorrect decisions. Incorrect decisions were also significantly correlated with the five functional abilities assessed. A high percentage of incorrect decisions was significantly correlated with a high motion-discrimination threshold, a large TTA-estimate distortion caused by the approaching car’s speed, a high processing-speed and visual-attention threshold, inhibition difficulties, and a slow walking speed.

A hierarchical multiple regression analysis was then performed to determine the best predictor, or subgroup of predictors, of incorrect crossing decisions. The five functional ability measures were entered one at a time, the order of entry being determined by the variable that caused the greatest $R^2$ increase, given the variables already entered into the model. Each one that turned out to be significant ($p < 0.05$) was included, and the non-significant ones were discarded. Age was added on the last step to find out how much residual age-related variance in incorrect decisions remained unexplained after taking the significant functional factors into account. The results are summarized in Table 3.

The processing-speed and visual-attention threshold emerged as the first and most significant functional predictor, accounting for 33% of the variance in incorrect street-crossing decisions. After controlling for processing speed and visual attention, perceptual distortions in the

### Table 2. Correlations between incorrect street-crossing decisions, age, and functional measures

<table>
<thead>
<tr>
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<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
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<th>6</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Incorrect decisions</td>
<td>0.65**</td>
<td>0.43**</td>
<td>0.45**</td>
<td>0.57**</td>
<td>0.43**</td>
<td>-0.40**</td>
</tr>
<tr>
<td>2. Age (years)</td>
<td>0.32*</td>
<td>0.63**</td>
<td>0.63**</td>
<td>0.63**</td>
<td>0.37**</td>
<td>-0.32*</td>
</tr>
<tr>
<td>3. Motion discrimination</td>
<td>0.41**</td>
<td>0.45**</td>
<td>0.50**</td>
<td>0.45**</td>
<td>0.54**</td>
<td>-0.36**</td>
</tr>
<tr>
<td>4. Time-to-arrival estimation</td>
<td>0.01</td>
<td>-0.12</td>
<td>-0.36**</td>
<td>-0.01</td>
<td>-0.28*</td>
<td>-0.21</td>
</tr>
<tr>
<td>5. Processing speed and visual attention (threshold)</td>
<td>-0.01</td>
<td>-0.12</td>
<td>-0.36**</td>
<td>-0.01</td>
<td>-0.28*</td>
<td>-0.21</td>
</tr>
<tr>
<td>6. Inhibition (interference score)</td>
<td>-0.21</td>
<td>-0.28*</td>
<td>-0.36**</td>
<td>-0.01</td>
<td>-0.28*</td>
<td>-0.21</td>
</tr>
<tr>
<td>7. Walking speed (m s$^{-1}$)</td>
<td>-0.21</td>
<td>-0.28*</td>
<td>-0.36**</td>
<td>-0.01</td>
<td>-0.28*</td>
<td>-0.21</td>
</tr>
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</table>

** $p < 0.01$; * $p < 0.05$.**
TTA estimates caused by the approaching car’s speed added 10% to the variance explained by the model, suggesting that this was the second most important functional variable predicting incorrect crossing decisions. The third significant factor was walking speed. Inclusion of this factor added 5% to the variance explained by the model. Inhibition abilities ended up being included as the last significant functional predictor, adding 4% to the variance explained. These four significant functional predictors accounted for a total of 52% of the variance in incorrect street-crossing decisions. The motion discrimination threshold was not included in the model as it did not account for a significant increment in the variance explained. Finally, the inclusion of age on the last step accounted for a small but statistically significant amount of additional variance in incorrect decisions (4%).

Discussion

In line with previous research,\textsuperscript{3,6,8} crossing behaviour was found to be affected by the speed of the approaching car, and this speed effect was more pronounced with age: unlike young pedestrians, older people were found to make more and more unsafe decisions as the speed of the approaching car increased, and to place themselves in greater danger at the highest vehicle speed. They also missed many safe-crossing opportunities at the lowest speed. At the same time, we noted that older participants exhibited significantly diminished functional performance compared to young participants: they had higher velocity-discrimination thresholds, and their time-to-arrival estimates were more biased by the speed of the approaching car. Seniors also exhibited slower processing speeds and lower selective visual attention performance, lower inhibition scores, and slower walking speeds. Analyses pointed out several of these functional-ability scores as predictors of the way the pedestrians took the speed of the approaching car into account in their decisions, i.e. in the number of unsafe crossing decisions made at the highest vehicle speed and missed opportunities at the lowest vehicle speed.

Processing-speed and visual-attention abilities measured on the UFOV\textsuperscript{©} test were shown to play the most important role in explaining the variance in incorrect street-crossing decisions. Selective visual-attention abilities and processing speed may contribute to focusing attention on relevant information (i.e. the speed of the approaching car), and to making timely and correct decisions. Older participants with declines in these specific perceptual and cognitive abilities may therefore exhibit gap-selection problems: they miss opportunities at low speeds and may be at a higher risk when vehicles are approaching rapidly because vehicle speed is not properly perceived, identified, and/or integrated into the decision-making process. The UFOV\textsuperscript{©} test actually relies on both visual-sensory and cognitive skills, thus providing an overall measure of visual-functional status.\textsuperscript{24} This test has already proven to be highly sensitive for predicting the risk of crash involvement among older drivers,\textsuperscript{24,25} and the results of the present study suggest that this measure is also highly relevant to predicting street-crossing difficulty.

Time-to-arrival (TTA) estimation appeared as the second most important functional predictor of incorrect decisions.
crossing decisions. TTA perception is fundamental because it indicates the time available for crossing. Assessing TTA correctly means estimating it in such a way that it is not affected by the approaching vehicle’s speed. In fact, a vehicle-speed effect translates into incorrect TTA estimates. Our findings confirmed that there were perceptual distortions in the TTA estimates caused by the speed of the approaching car, and they demonstrated dangerous misperceptions with ageing. Both young and older participants tended to underestimate TTA at a low speed, thus causing missed opportunities in both age groups. But older-old participants considerably overestimated TTA at a high vehicle speed, leading to risky decisions because they thought they had more time to cross than they actually did.

Locomotor abilities were also shown to play an important role in the probability that a pedestrian would make an incorrect decision. As recently suggested, the physical frailty and reduced mobility associated with ageing are some of the factors that may impair older pedestrians when it comes to crossing the road safely. The older pedestrians may have experienced difficulty in adapting their crossing pace to the perceived available time. The oldest and slowest pedestrians may no longer have been able to compensate for their choice of insufficient gaps by speeding up their walking pace when vehicles were approaching rapidly.

Finally, inhibition ability appeared as the last functional factor explaining incorrect street-crossing decisions. This ability allows pedestrians to ignore irrelevant stimuli in the environment and inhibit a prepared but unsuitable response. Inhibition ability may have been involved to a greater extent when vehicles were approaching at a low speed. For a given time gap, low speeds were associated with shorter car distances than higher speeds. When vehicles were closer, their angular size was bigger and their visual expansion as they approached was greater. This ‘looming’ effect may have generated a feeling of danger that caused these pedestrians to refuse gaps that were in fact acceptable. To avoid missing a safe opportunity to cross, the pedestrian must therefore inhibit this spontaneous fear response and consider the low speed of the approaching car. Because of impaired inhibition processes, the older participants may have refused many safe-crossing opportunities and disregarded motion information at low speeds, even though angular velocities were higher and thus easier to perceive at low speeds than at high ones.

Surprisingly, motion perception did not emerge as a significant predictor although incorrect crossing decisions were significantly correlated with motion-discrimination thresholds. It can be assumed that the task used for the present study did not sufficiently reflect the specific visual functions underlying vehicle-speed discrimination (the task was quite abstract since it involved a constant object size and constant angular velocities, whereas a car approaching at a constant speed shows accelerated angular-size and angular-velocity increases). However, the generally acknowledged decline in visual motion sensitivity with ageing is likely to considerably lengthen the time needed by older pedestrians to perceive the movement of an oncoming car, and may even make it impossible to use movement information in the allotted time. Further studies are needed to answer this question.

Overall, the present study provided a multidimensional explanation of increased gap-selection difficulties with ageing. It included a combination of perceptual, cognitive, and physical performance declines with advancing age. The findings suggest that age per se contributed very little to the prediction of incorrect street-crossing decisions, once the pedestrian’s perceptual, cognitive, and motor abilities were taken into account. Age accounted for a small amount of additional variance in incorrect decisions.

The present model explained 56% of the variance in incorrect crossing decisions, suggesting that other factors than those evaluated here came into play. The extent to which older people are aware of the functional declines from which they suffer is a factor that was not assessed in this study, but is nevertheless crucial in the way individuals with such deficits self-monitor and adapt their behaviour. Research on ageing has shown that older people are not always aware of their reduced abilities, and that insufficient compensation of age-related declines can explain their gap-selection difficulties. It seems important, in further multi-dimensional studies, to integrate self-awareness of age-related changes when investigating functional abilities associated with street-crossing behaviour.

Conclusion

The results of this study confirm that speed is a critical risk factor for older pedestrians crossing the street whenever vehicles are approaching at high speeds. Due to an age-related visual and cognitive decline, older people may not perceive TTA correctly. It is also very likely that seniors do not perceive speed in a timely way, and therefore do not integrate it into the decision-making process. Given that visual sensory declines prove difficult to remedy via training, an effective approach for enhancing the safety of older pedestrians seems to be speed limit management, which involves both road infrastructures and speed laws. Increasing the number of speed ramps and narrower streets, as well as pedestrian zones and 30-km h⁻¹ zones would considerably improve senior safety. Given the slow walking speed of seniors, car-free islands should be set up in the middle of two-way roads so that
people can cross in two stages. This not only lowers their proneness to accidents by decreasing the time spent in the street, but also lightens the cognitive load of the street-crossing task.

Training programs can be used as a supplement to the above safety regulations and ergonomic measures. Many studies have addressed the problem of safety training for older drivers\textsuperscript{29} and child pedestrians,\textsuperscript{30} but research on older pedestrians has barely begun. A recent behavioural training experiment on a street-crossing simulator demonstrated that while the overall safety of senior pedestrians could be increased, their ability to take the approaching speed of vehicles into account did not improve.\textsuperscript{31} Another potentially effective method to consider is cognitive training similar to that offered to older drivers.\textsuperscript{32} Developing effective training programs, however, requires furthering our knowledge of the source of risky behaviours among ageing individuals. It would be worthwhile not only to investigate the role of perceptual, cognitive and motor factors, but also to examine older people’s awareness of their declining abilities. Future studies should address these questions, especially in complex street-crossing situations, such as two-way roads and unfamiliar environments, where accidents are the most likely to occur.

References

24. Ball K, Owsley C, Sloane ME, Roenker DL & Bruni JR. Visual attention problems as a predictor of vehicle crashes


