Modality effects of secondary tasks on hazard detection performance of younger and older pedestrians in a simulated road crossing task

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Abstract

Older pedestrians are at higher risk of being involved in car crashes than younger pedestrians. As it is known from other domains such as driving, dual-task demands represent challenges, especially for older adults. Thus, one possible reason for high accident rates of older pedestrians might be the multitasking character of the road crossing situation. With regard to safety, hazard detection represents the primary task. However, additional secondary tasks such as scanning for obstacles, navigation, and walking are mostly conducted simultaneously. According to the Multiple-Resource Model, demands of tasks regarding the main processing stage can be characterized in visual perceptual, cognitive, and motoric. The aim of the current study was to compare the effects of secondary tasks with different main process stages on the primary task of hazard detection. For this purpose, a laboratory experiment was conducted with 20 older and 20 younger participants, using a pedestrian traffic simulation. Secondary tasks differed with regard to modalities (visual search, n-back and simulated walking). Reaction time, number of errors and perceived workload served as dependent variables. Older adults performed slower, but equally accurate across all dual-task conditions compared to younger adults. Dual-task costs were found for the visual-search and the n-back task concerning number of errors, but not for response speed. No dual-task costs arouse for the walking task, which in contrast even increased hazard detection speed. The hierarchy of different dual-task costs did not differ between the two age-groups.

Introduction

Older adults (65+) accounted for 20% of injured pedestrians in Germany in 2012 (Statistisches Bundesamt, 2013). Comparing total numbers, they are not involved in accidents more often than other age groups. However, in relation to the walking distance, older pedestrians are injured more often than younger people (Rytz, 2006). Furthermore, they die more often as a consequence of the accident, as nearly half of all persons deceased after a crash were 65 years or older (Statistisches Bundesamt, 2013). That makes it important to reduce older pedestrians’ crashes in traffic.

Therefore it is necessary to understand the differences of younger and older pedestrians’ behaviour in road crossings and to analyse the underlying reasons.

Several studies have found diverse behavioural deficits of older pedestrians, such as they walk slower and leave smaller safety margins, they focus more on the pathway and less on the traffic, and they do not take into account velocity but only distance information when accepting gaps in traffic (e.g. Dommes, Cavallo, Dubuisson, Tournier, & Vienne, 2014; Oxley et al., 1997; Avineri et al., 2012; Wiczorek et al., 2016). Age-related declines of cognitive and motoric functions have been identified as reasons for those differences.

However, age-related differences in specific tasks are not the only cause for older pedestrians’ problems in traffic. In addition to that, one has to consider the multitasking character of the situation. Pedestrians perform several different activities during road crossing. That can be navigating, checking the pathway for bumps, and the walking itself. These activities can distract pedestrians from the main task of hazard detection and therefore be considered as secondary tasks.

While so-called dual-task costs, (performance decrements in the primary task when being engaged in a secondary task) can be observed across all age groups (Pashler, 1994), they are often higher for older than for younger adults (Verhaeghen et al., 2003). Though, a meta-analysis indicates that the extent of age-specific dual task costs depends on the characteristics of the task (Ribi et al., 2004). For example, costs are higher when one of the tasks is cognitively demanding and they are more pronounced for speed than for accuracy. Furthermore it was found that older people tend to give the priority in a dual-task situation to tasks related to motion, such as walking. This effect has been referred to as ‘posture first’ (cf. Schaefer, 2014). The reasons may be reduced capacity to keep the balance and increased fear of falling (cf. Davidse, 2007; Dietz, 2002; Schott, 2008). Thus, the multitasking character of the road crossing situation may contribute to the occurrence of car crashes with older pedestrians.

Current studies of multitasking in road crossing usually use external tasks such as talking at the phone or texting as secondary tasks. These tasks always delay the initiation of behaviour and under some conditions reduce attentive behaviour and increase collision frequency (Neider et al., 2010; Banducci et al., 2016; Byington & Schwebel, 2013). Similar results were found when participants performed a cognitively demanding 2-back task (Gaspar et al., 2014). The only two studies that included older pedestrians found the usual age-related dual-task costs but it was mentioned that those were related to older participants’ scores in motoric and cognitive screening tests (Neider et al., 2011; Nagamatsu et al., 2011). Considering the already multitasking character of the road crossing it is not surprising that older people were outperformed by younger, considering that they actually had to perform more than two tasks simultaneously. Apart from that, cell phone use in traffic is rather a problem of younger than older adults. Thus, it is necessary to investigate whether and how road crossing imbedded secondary tasks negatively affect hazard detection in younger and older adults.

With the help of the Multiple Resource Model (MRM; Wickens, 1984; 2002) it is possible to predict the amount of dual task costs dependent on the nature of the task. According to the MRM a task can be characterised along five dimensions:
dual-task effects in road crossing of older pedestrians

- processing stage (perception vs. cognition vs. responding),
- perceptual modalities (visual vs. auditory),
- visual channels (focal vs. ambient),
- processing codes (spatial vs. verbal) and
- response execution (manual spatial vs. vocal verbal).

The more similar two tasks are on these dimensions, the higher are the predicted dual-task costs.

Research in the driving context shows the applicability of the model for the investigation of multitasking effects of older adults in traffic. For example age-specific dual-task costs were observed when participants had to respond to a secondary task manually while driving, but not when the response was given verbally (Brouwer et al., 1991; Fofanova & Vollrath, 2011). Higher costs for older adults are also found during driving when the secondary task requires visual perception, but not when it requires auditory perception (Chaparro et al., 2004; Horberry et al., 2006). Thus, it was decided to use the MRM as theoretical framework for the current investigation.

**Current Study**

The aim of this study is to investigate the effects of different modality specific secondary tasks on hazard detection in younger and older adults in a simulated road-crossing environment. The hazard detection task used in the current experiment consists of the perception of crossing cars in different road situations and the indication of intention to stop (i.e. not to cross the street) via joystick. Three different secondary tasks are used, which pose specifically high demands on one of the processing stages described in the MRM. The tasks require either visual-perceptual resources, cognitive resources or motoric resources.

It is expected that performance of older adults in the primary task is worse than performance of younger adults due to age-related declines in cognitive and attentional capacities (e.g. Salthouse & Somberg, 1982; Kramer & Madden, 2011; Ball, 1990). Dual-task costs should result for both age groups but should be higher for older than for younger participants, reflecting age-specific dual task cost (cf. Riby et al., 2004).

Furthermore, it is hypothesized that dual-task costs differ between the three secondary task conditions. The primary task places the highest demands in the perceptual processing stage, because potential hazards have to be detected visually. Medium demands of resources are required for the cognitive processing stage, when deciding whether the detected object represents a hazard or not. Finally only a few resources are needed for the responding stage that consists of the movement of a joystick. Thus, it is expected that dual-task costs are highest in the visual-perceptual condition followed by the cognitive condition and lowest in the motoric condition. However, as it was shown that older people give priority to motoric tasks (cf. Riby et al., 2004), the described order of dual-tasks costs is predicted only for the younger participants. For the older adults over proportionally high dual-task cost are
expected in the motoric condition and thus, the order of dual-task costs should be different for them.

Method

Participants

Forty participants of two age groups attended the study. The younger group (age ≤ 30 years) consisted of 20 students (6 male, 14 female). Their age ranged from 18 to 30 years (M=25.5; SD=3.5). The older group (age ≥ 65 years) also consisted of 20 participants (6 male and 14 female), with an age range from 67 to 82 years (M=71.6; SD=4.0). Further characteristics of younger versus older participants were respectively: possession of a driver licence (14 vs. 17), regular drivers (4 vs. 12), regular cyclists (10 vs. 9), walked regularly (20 vs. 20). Mean Montreal Cognitive Assessment (MoCA; Nasreddine et al. 2005), a screening test for mild cognitive impairment (27.65 vs. 25.75). All participants eyesight (M=.99 vs M=.63) was higher than the required minimum of 40%, (necessary to fulfil the task).

Simulation Environment and Apparatus

Animated videos are played with PsychoPy (Peirce, 2007) and projected on a wall with a width of 5.50m, a height of 1.50m, and a resolution of 3840x1080 pixels, using two Acer S1283 HNE projectors. Participants stand central at a height-adjustable standing desk 1.50m away from the projection with a visual angle of 133° to the edges of the video so that the edges of the road can only be seen through peripheral vision or head movements. Participants react to the hazard detection task using a joystick, which is attached at the top of the desk. During the cognitive and the visual-perceptual secondary task participants wore a headset. During the motoric secondary task participants used a foot switch with two pedals, which was attached at the ground under the desk. Figure 1 shows a schematic representation of the laboratory setup.

![Schematic representation of the laboratory setup](image)

**Figure 1. Schematic representation of the laboratory setup.**

Hazard Detection Task

Two different types of road crossing tasks were examined in this study. One consisted of hazard detection. The other one was a ‘gap acceptance’ task and will
not be reported here. Each trial in the hazard detection task consists of a video sequence with duration of 20 seconds. In these video sequences a road is displayed and a car enters from the left or from the right edge of the scene at a pseudo random time and passes the whole screen in eight seconds. A screenshot of one of the videos can be seen in Figure 2. The road, the colour and brand of the car vary between the sequences. In total there were three different roads. Sequences of the same road were displayed in a row. Thus it was not possible for the participant to know when a trial started and thus appearance of cars was not predictable. The order of the sequences was counterbalanced between the different experimental blocks. The participants’ task is to react as quickly as possible when seeing a car, by pulling the joystick towards themselves. E-bikes which are driving on the opposite pathway serve as distractors. Participants were instructed not to react to the e-bikes, which appear on average in four sequences per block in a pseudo random order.

![Figure 2: Screenshot of a video used in the hazard detection task.](image)

**Secondary Tasks**

Secondary tasks were created with the aim to interfere mainly with one of the three processing stages of the primary task, while not (much) interfering with the others. Therefore, the motoric and the cognitive task used the auditory perceptual modality to not interfere with the visual modality of the primary task. Cognitive demands of the motoric and the visual task were kept as low as possible to not interfere with the cognitive requirements of the primary task. The visual task and the cognitive task required vocal response execution to not interfere with the manual response of the primary task.

**Visual-Perceptual Task:** Participants performed a visual scanning task, which was adapted from the “Testbatterie zur Aufmerksamkeitsprüfung” (Testing Battery for Attentional Performance; Zimmermann & Fimm, 2012). A 5x6 matrix with a width of 63.5cm and a height of 52.5cm is shown centrally at the top of the projection. Every element of the matrix is a square, which is opened to one of the four sides. The target stimulus is a square opened towards the top. The task of the participants is to decide whether the matrix includes a target stimulus or not. Participants indicate their decision by saying “yes” or “no” into the microphone of the headset. Responses are recorded and a new matrix is displayed automatically after every response. Matrices alternate between white squares on black background and vice versa to make the appearance of a new matrix clear for participants. Matrices were presented in random order.
Cognitive Task: Participants performed an auditory 1-back task (Mehler et al., 2011). Every 3.33 seconds a number between zero and nine is played over a headset. After a number is read out, participants are supposed to name the number which was played one step before as quickly as possible. Responses are recorded via microphone.

Motoric Task: Participants task is to press the two pedals of a double foot switch alternating the left and the right foot in the rhythm of a regular metronome beat. Beats are played via loudspeaker every 1.33 seconds so that participants have to press the switch 45 times per minute. This frequency corresponds to a cadence of 90 steps per minute (pressing the foot switch requires two steps: moving the foot forward to the pedal and backward again). The cadence of most healthy elderly adults lies between 80 and 130 steps per minute (Whittle, 2014).

Design and Dependent Measures

Design: The study consisted of a 2x4 mixed design. The between factor was age-group and the within factor was secondary task with four conditions (baseline/single task, cognitive dual-task, visual-perceptual dual-task, and motoric dual-task. The dependent measures were:

- Number of errors: sum of false negatives and false positives
- Reaction time: between time of appearance of a car and pull of the joystick. (Reaction time was assessed via frame numbers of the video)
- Subjectively perceived workload: assesses with the NASA- Task Load Index (NASA-TLX; Hart & Staveland, 1988)

Procedure

On arrival, participants were briefly instructed about the course of the experiment and filled in a declaration of consent. Afterwards they performed an eyesight test with Landolt rings. Following up participants were acquainted with the laboratory equipment. Participants trained each of the secondary tasks and performed it for five minutes in order to get familiar with the task. The order of the tasks was counterbalanced. After a 5-minute break participants trained the two primary tasks (hazard detection and gap acceptance). The experiment started with the first baseline measure block which consisted of five minutes single task hazard detection and five minutes single task gap acceptance. The order of the tasks was counterbalanced between participants. Subsequently participants completed three dual-task blocks with a duration of 2x5 minutes each. The order of the secondary tasks and the road crossing tasks corresponded to the order of the training. Participants had been instructed that both tasks were important. The secondary tasks started 20 seconds before the 5-minute road crossing tasks. The first and the last dual-task block were followed by a 5-minute break. Afterwards participants performed a second baseline block. The average of the measures of both baseline blocks was used for the analysis in order to prevent biases due to learning effects or fatigue. After each of the baseline and experimental blocks participants filled in the NASA-TLX. In the end of the experiment participants filled in the MoCA and a demographic questionnaire. Finally they received a financial compensation.
Results

To test for effects of learning and fatigue the data of the two baseline measures was compared using a 2x2 ANOVA for repeated measures. Afterwards the average of the two baseline measures was used for further calculations. The number of errors, reaction time and subjective workload were compared between dual-task conditions using 2x4 ANOVAs for repeated measures. A priori defined contrasts were used to analyse the order of dual-task costs between the three secondary tasks.

Comparison of Baseline blocks: Analysis revealed a main effect of order, $F(1,38)=5.109$, $p<.05$, and a main effect of age, $F(1,38)=5.630$, $p<.05$, which were further qualified by a significant age x order interaction effect, $F(1,38)=7.983$, $p<.001$. Older participants made more errors than younger people in the first baseline block but reduced there number of errors to the lower level of the younger group in the second baseline. This indicates a learning effect. No significant differences were found for reaction time and subjective workload between the two age groups and the two measures.

Error rate: Analysis revealed a main effect of secondary task, $F(3,114)=9.737$, $p<.001$, but no other significant effects. A priori defined contrast showed significant differences between the visual-perceptual condition and the baseline, $F(1,38)=12.507$, $p<.001$, as well as the motoric condition, $F(1,38)=13.760$, $p<.001$. The same pattern revealed for the cognitive condition when compared to the baseline, $F(1,38)=16.130$, $p<.001$ and the motoric condition, $F(1,38)=16.369$, $p<.001$. As can be seen in Figure 3, more errors were made in the visual-perceptual condition and in the cognitive condition, compared to the baseline and the motoric condition.

![Figure 1: Means of number of errors of the averaged baseline and the three dual-task conditions for younger and older adults. Error bars reflect Standard Error.](image)
Reaction time: The concurrent presentation of matrices and videos in the visual-perceptual dual-task condition led to a reduction of M=10.8 frames per matrix, which had to be corrected manually afterwards. Comparison of the averaged baseline measure and the three dual-task conditions showed a main effect of age, $F(1,38)=6.431$, $p<.05$ with older adults being slower than younger adults. Furthermore a main effect of secondary task was observed, $F(1,38)=31.093$, $p<.001$. Planned contrasts showed that the reaction time in the motoric condition was shorter than in the baseline $F(1,38)=69.299$, $p<.001$. The reaction time in the motoric condition was also shorter than in the cognitive, $F(1,38)=36.878$, $p<.001$, and the visual-perceptual condition, $F(1,38)=55.646$, $p<.001$. Reaction times between the baseline and the cognitive and the visual-perceptual condition did not differ. Figure 4 shows results of reaction time.

Subjective workload: Comparison of the data from the NASA-TLX revealed a main effect of secondary task, $F(3,114)=60.499$, $p<.001$. Planned contrasts showed the difference of perceived workload between all four conditions with the least workload in the baseline condition, followed by the motoric condition, $F(1,38)=65.548$, $p<.001$, the visual-perceptual condition, $F(1,38)=13.508$, $p<.001$, and the highest workload in the cognitive condition, $F(1,38)=5.275$, $p=.027$. F-values refer to contrasts with the condition with the next lower workload. No main effect of age and no interaction effect were found. Results can be seen in Figure 5.
Discussion

The current study was conducted to investigate the effects of road crossing imbedded secondary tasks on hazard detection performance in simulated pedestrian crossing situations. The aim of this study was to identify differences and similarities of younger and older pedestrians when performing secondary tasks, which differed with regard to their main processing stage. Number of errors, reaction time and subjective workload were assessed. Dual-task related performance decreases in the primary task of hazard detection were expected for all the participants. The older adults however, should additionally produce age-specific (i.e. higher) dual-task costs than the younger group. It was also hypothesized that the three secondary tasks produce different amounts of dual-task costs. The highest costs were expected for the visual-perceptual secondary task, followed by the cognitive task, with the fewest for the motoric task. This order is based on the different demands of the primary task on the three processing stages. Hazard detection should require the most resources for the visual-perceptual processing stage, followed by the cognitive stage and only a minimum of motoric resources as the motoric component consisted of moving a joystick. However, it was further hypothesized that this order would be different for older adults. As they were found to not fulfil the task of walking as automatically as younger people and to need additional attention resources, it is possible that the motoric task also interferes with one of the other processing stages.

The comparison of two baseline measures conducted at the beginning and at the end of the experiment indicated a learning effect of older adults. For the following analysis, the two baseline blocks were averaged.
No difference between younger and older adults could be observed with respect to the number of errors. However, older adults reacted slower than younger adults. This is in line with previous research, which found higher age-specific performance decrements when considering response speed than when considering response accuracy (Verhaeghen et al., 2003).

Dual-task costs were observed regarding number of errors, but not for reaction time. Older and younger adults made more errors in the primary task of hazard detection when they performed a cognitive or visual-perceptual task concurrently. It seems that participants accepted making more errors in order to maintain their reaction speed. In real-life road crossing this behaviour can have fatal consequences, when pedestrians overlook potential hazards. However, it has to be noted that the number of false positives (reactions in the absence of cars, for example to the e-bikes used as distractors) was higher than the number of misses. Nevertheless also false positives can lead to dangerous traffic situations, for example when pedestrian behaviour diverts from the expectations of other road users.

In contrast to the other two secondary tasks, the motoric task not only did not cause any dual-task costs, but even improved performance in terms of reaction speed. There are some possible explanations for this unexpected result. First, the motoric task might have been too easy, compared to normal walking. Participants could hold on the standing desk and had always one food on the ground. Thus, there was no risk of losing balance, which can explain why no dual-task costs were found. Furthermore, neuropsychological research shows that motion can influence visual perception, either directly or via attentional mechanisms (Ishimura & Shimojo, 1994). That could explain the observed benefits for the hazard detection when conducting the motoric task in parallel. In an experiment with mice, Ayaz et al. (2013) found neurons in the visual cortex to have a higher firing frequency when subjects were running on a treadmill. If this effect holds true also for humans, it could explain the faster reaction times in the motoric condition.

The unexpected results in the motoric condition could also explain why the order of dual-task costs did not differ between younger and older adults. It was expected that the motoric task would only produce small dual-task costs in younger adults, because the primary task did only induce minor motoric demands. However, older adults were expected to suffer from higher dual-task costs, because for them walking is less automatic and requires more attentional resources (Lindenberg et al., 2000). Thus, walking could possibly interfere also with the visual-perceptual and the cognitive task. In order to examine this hypothesis a more realistic motoric task should be used in further research.

However, it has to be noted that also the subjectively perceived workload did not differ between younger and older adults but showed significant differences among all four conditions. The baseline single task condition was considered the least demanding followed by the motoric dual-task, the visual-perceptual and the cognitive dual-task. Differences in the NASA-TLX score for the visual-perceptual and the cognitive dual-task condition were not accompanied by differences in performance. Performance in the single task condition was similar to the visual-
perceptual and the cognitive dual-task conditions with regard to number of errors but resembled most the motoric dual-task in terms of reaction time.

The three secondary tasks were created in a way they would interfere with only one of the three processing stages according to the MRM. As expected the least impairment was observed in the motoric process, which only consisted of pulling the joystick in the primary task and therefore did not require a lot of resources. No significant differences were found between the visual-perceptual and the cognitive task with regard to number of errors and reaction time. However, it is possible that differences would emerge on a behavioural level rather than on the performance level. As it was shown that scanning behaviour in road crossing differs between older and younger adults (Tapiro et al., 2016), investigation of eye movements could possibly also show differences between secondary tasks.

Findings of this study can be used to make road crossing safer for younger as well as for older adults. They underline the need for awareness campaigns, which point out the risks of multitasking during road crossing. Results also show that crossing points should be designed in a way that they induce as few additional workload as possible. This can be achieved by using smooth sidewalks and minimising billboards, especially on places which are used frequently for road crossing. Findings of this study will also help to clarify demands of a pedestrian assistance system for older adults, which is currently developed by the junior research group FANS at the TU Berlin (cf. Breitinger et al., 2015). According to current findings, the system should support users to investigate all resources in hazard detection. That means, execution of other road crossing imbedded tasks such as scanning the ground for obstacles and navigation should be done before or after but not in parallel to the primary task. Whether the same holds true for concurrent walking will be further analyses using a more realistic walking task.

References


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