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Special Issue – Research Article

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On the Influence of Walking on Hazard Detection for Prospective User-Centered Design of an Assistance System for Older Pedestrians

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Abstract: As older pedestrians are at high risk of being involved in car crashes, an assistance system is currently under development. One of it's aims is to encourage them to stop walking before looking for traffic. The approach was evaluated in two studies. Age group *-young vs. old-* and motoric condition *-walking vs. standing-* served as independent variables in both experiments. Experiment one was conducted in a pedestrian traffic simulation with a traffic related visual hazard detection task with simulated walking. Analysis revealed no age-specific dual-task costs for accuracy and response time. This unexpected result was ascribed to the insufficient operationalization of the walking task, which lacked important aspects of real walking such as requirements of keeping the balance. Therefore, experiment two, comprised real walking but a simple visual task. In the second experiment older participants missed more targets than younger. More important, number of errors increased as a function of motor load only for older participants. Response times were enhanced for older participants and faster for both groups while standing compared to walking. Results are discussed with regard to the development of an assistance systems for older pedestrians and theoretical implications for prospective user-centered experimental design.

Keywords: Older pedestrians, assistance systems, user-centered design, road crossing, hazard detection

1 Theory

According to a report by the World Health Organization (WHO, [54]) special attention must be drawn on the safety of pedestrians since 22% of worldwide road traffic deaths in 2015 are among these road users. In Germany, 6967 pedestrians aged 65 or older were involved in an accident [45]. In addition, 27% (281) of deaths in this age group caused by a traffic accident were pedestrians. Thus, improving the safety of older pedestrians is of high importance. When comparing older and medium aged adults (30–65 years) being part of car crashes as pedestrians, the involvement of older adults is slightly fewer but the likelihood for them to die as a result of such an accident is more than four times higher [46]. Finally, it must be mentioned that when relating the number of crashes of pedestrians to their medium walking distance, the picture changes. Relative to their walking distance older pedestrians are involved more often in car crashes compared to younger [35].

Research in road crossing abilities of older adults focus on several different aspects, as potential reasons for them being involved in car crashes. Based on Older and Grayson [30] the task of road crossing can be subdivided into five different stages: selection of crossing location, traffic perception, analyzation of current traffic situation, crossing-decision and the actual crossing. Several studies identified age specific behavior within these stages. A questionnaire survey by Bernhoft and Carstensen [8] revealed an increased importance of pedestrian crossings and signalized intersections for the subjective safety of older pedestrians. Neider et al. [29] investigated crossing behavior in dual-task settings in younger and older adults within an immersive virtual reality environment. They found older adults to spent more time before initiating the crossing than younger when simultaneously talking on a cell phone. Oxley et al. [31] observed pedestrians at two-way streets and identified a greater percentage of older pedestrians with unsafe crossing strategies. Compared to younger, they tend to cross the street more often at close moving traffic especially on the far side of the street. Similar results were obtained by Dommes et al. [14]. They observed in a simulated street crossing scenario with a natural walking task, that especially participants older than 71 years showed more crossing-decisions leading to collision than younger. This was also found by Geraghty, Hol-

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land and Rochelle [16] for older pedestrians performance in a video based pedestrian simulation.

Studies investigated abilities related to the second stage of perception could also show age-related differences. In a study conducted by Avineri, Shiner and Susilo et al. [3] pedestrians reporting a higher fear of falling were found to dedicate less attention to the traffic because they were focusing on the ground. Tapiro et al. [48] could find different scanning patterns of older compared to younger adults prior to their road crossing decisions. Older adults focus more on the center while younger adults also scan the periphery. Even though there are very few studies focusing on the perceptional stage of hazard perception in pedestrian road crossing yet, results are in line with findings obtained for older drivers. An eye-tracking investigation with drivers of different ages showed a similar tendency of the older drivers to over proportionally focus on the middle of the scene [33]. Horswill [19] found that hazard detection ability in driving decrease with age. Further analysis showed that this effect was caused by reductions in the useful field of view, the contrast sensitivity and general response time. In the context of driving it was found that a hazard perception ability of older adults defined as increased response time is negatively correlated with their accident frequencies [18].

The current research emphasis on the second stage: traffic perception, because German police reports state that most accidents caused by older pedestrians are due to stepping on the road without having sufficiently checked the current traffic situation [44]. Basic research has shown an age-related decline in divided attention, which is needed to deal with dual-task demands (cf. [6]). Thus, we suppose that older adults' problems with traffic perception might be the result of insufficient availability of visual attention caused by dual-task requirements of the hazard perception situation. Scanning for upcoming traffic while walking towards the road might not be intuitively understood as two tasks from the perspective of a younger person. However, routine walking can be considered as a not exclusive automated motor task that needs attentional resources (for a review see [55]). In addition, basic motor dual-task research with older adults shows a "posture first" effect (e.g. [41, 37]). That is, older adults' tendency to prioritize motor tasks such as walking over cognitive or visual tasks when stability is potentially threatened. This effect may be a result of their reduced capability of keeping balance and a related fear of falling (e.g. [49, 12, 39]). While older participants are usually found to be slower and to conduct more errors in dual-task situations compared to younger (cf. [47]), the posture first effect can reduce performance in secondary tasks even further. Another functional prioritization that highlights age-related problems in motor dual-tasks is known from studies depending on the *Walking while talking* (WWT) paradigm. Lundin-Olsson, Nyberg and Gustafson [23] have shown, that especially older adults with a high risk of falling tend to stop walking when starting a conversation or performing a cognitive task. This was assumed to be an indicator of an inability to divide attention between a cognitive and a motor task successfully.

Within the research project FANS (Fußgänger-Assistenzsystem für ältere Nutzerinnen und Nutzer im Straßenverkehr – Pedestrian Assistance System for Older Road Users), we are currently working on an assistance system aiming at supporting older pedestrians in hazard perception for safer road crossing.

The system consists of a sensor part using multi-sensor fusion and integration to detect the street environment. Information from a distance sensor is combined with pictures taken from a webcam to identify the curbstone and thus, locate the road in front of the pedestrian. The sensors of the system will be mounted on a walking frame occasionally used by older pedestrians. That allows for multiple sensor positions and the walker has the advantage to additionally improve the stability of the user. The actuator part is wearable. It communicates with the user by indicating the approaching of a road using tactile feedback. However, the final product needs to be independent of such a walking frame in order to also assist pedestrians that do not (yet) suffer from sever walking impairments. The development follows a user-centered approach [1]. That means the future system is prospectively designed with the early and iterative involvement of the future user [17].

Based on the described reasoning, we suppose that hazard detection while walking bears the potential of performance decrements in either one or both parallel executed tasks. Therefore, changing the dual-task situation (scanning for traffic while walking) to a single task situation (scanning for traffic) might improve hazard detection by freeing attentional resources. Consequently, we hypothesize that the first step for improving older pedestrians' hazard detection ability is to make them stop walking. In order to achieve this goal, the planned assistance system should encourage users to stop at the edge of the road and to scan the traffic environment without additional demands of a motor task. Despite extensive results on motor dual-task interferences in different age groups and cognitive tasks (for reviews see [53, 2, 37]) little is known about specific test scenarios with a focus on visual hazard detection performance of older adults in different parallel executed motor tasks. Maillot et al. [24] compared two virtual street crossing scenarios, one large scale simulation that required actual walking and with a stationary small scale device that was based on estimations for task completion. Older adults were more often engaged in virtual collisions in the stationary devices, when no actual motor task had to be accomplished. The results highlight the need of ecological task design for assumptions about actual behavior. However, most results concentrated on the decision part of the road crossing task and not on the preceding perceptual stage. Therefore, we want to test the underlying hypothesis, prior to implementing such a function.

Two experimental studies evaluating the benefit of standing over walking with regard to hazard detection in traffic were conducted. Subsequently, the two studies are described and results are discussed with regard to the development of the assistance system. Furthermore, the comparison of both studies should bring more insights into laboratory evaluation of real world requirements. Finally, we give an outlook regarding to the next steps in the user-centered design process of our pedestrian assistance system.

1.1 Current Studies

Due to safety reasons it is not possible to test older pedestrians' traffic behavior with regard to the overlooking of potential threats in real life situations. Therefore, we conducted two laboratory studies covering different aspects of ecological task validity, focusing on either the visual task or the motor task. The first experiment took place in a pedestrian traffic simulation. The visual task consisted of hazard detection in a road crossing situation, while the motor task was realised by a simulation of walking using foot pedals. The second experiment, on the other hand, aimed to isolate the effect of realistic walking compared to standing on response times and conducted errors within a more artificial visual perception task. The experimental setup allowed for real walking but was limited to a simple response task (with flashing lights from the periphery) that was thought to represent the detection of lateral approaching cars.

Several basic research reports gave evidence for commonly age-related declines in response time [36] and vision impairments, especially when targets are presented in the peripheral visual field [5]. Based on these findings, we expected older participants to react slower to visual stimuli compared to younger and to make more errors. With regard to multiple motor dual-task results (for a review see [55]) we expected a decline in the visual task performance for both groups when they had to walk simultaneously as well as when they were conducting the simulated walking in parallel. While taken intensified "posture first" strategies in healthy older participants into account (e.g. [21]), it was hypothesized furthermore, that the negative impact of the motor task on the visual task performance would be more pronounced in the older group than in the younger group and increases with motor task complexity (e.g. [22]).

2 Method Study 1

2.1 Participants

Twenty younger (18–30 years) and twenty older (≥ 65 years) persons participated in this study. Both groups had an equal gender proportion of 6 males and 14 females. The age of the younger group ranged from 18 to 30 years with M = 25.5 and SD = 3.5. The age of the older group ranged from 67 to 87 years with M = 71.6 and 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 of Montreal Cognitive Assessment (MOCA; [28]), a screening test for mild cognitive impairment (27.65 vs. 25.75).

2.2 Task and Simulation Environment

The pedestrian simulation environment consisted of animated videos projected onto the wall with a width of 5.50m and a height of 1.50m. Figure 1. displays a schematic representation of the laboratory. The videos showed scenes of three different roads from a pedestrian perspective at the edge of the road. In each trial a car passed by entering from the left or the right side of the scene. Five sequences were presented for every street.

The duration of each sequence was 20 seconds. Every sequence contained one passing car. The onset time the car entered the scene varied across sequences between

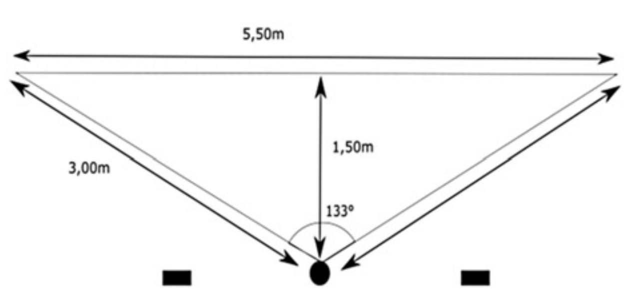

Figure 1: Schematic representation of the laboratory.

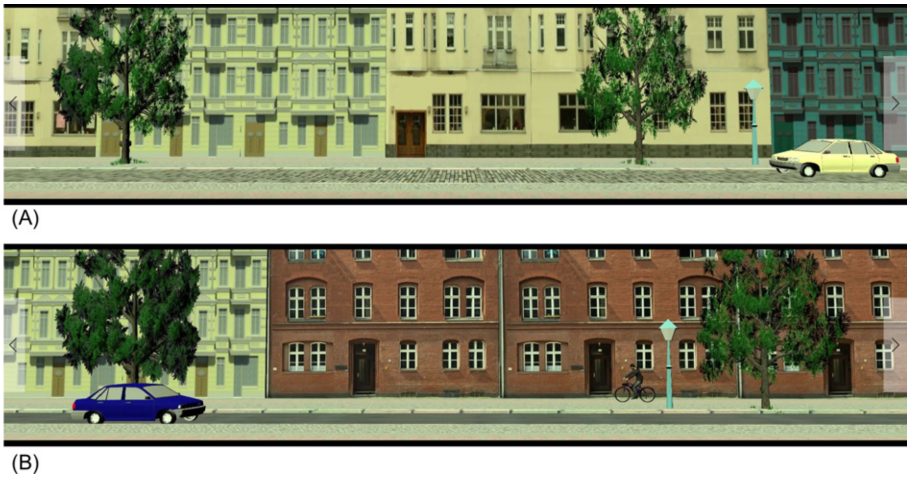

Figure 2: Screen shots of two video sequences of different roads with a car coming from the right side (A) and a car coming from the left side with an e-bike coming from the right side (B).

2–10 seconds after start. The order of the sequences of each street was counterbalanced. Participants conducted a *hazard detection* task where they had to react as correct and as fast as possible when a car entered the screen. Participants reacted by pulling a joystick that was located in front of them on a standing desk. The car needed eight seconds in total to pass through the whole scene. Participants were asked to stand in the middle of the 5.5 m wide screen. They had to react within four seconds before the car crossed their position. Later responses and no responses were treated as misses. In some of the sequences an e-bike passed at the opposite side pathway. The e-bikes served as distractors and participants were instructed not to react to them. Responses to e-bikes and all other responses in the absence of a car were treated as false alarms. The scenes did not contain any other distracting elements. Two screen shots of video sequences can be seen in Figure 2. In the *motor condition*, they performed a *simulated walking task* concurrently to the hazard detection task. The simulated walking task required pressing a double foot pedal with both feet alternating in a predefined rhythm. The rhythm was indicated by a metronome beat of 1.33 seconds. That corresponds to 90 foot presses per minute and was chosen in accordance to the step frequency for healthy old adults, which is about 80 to 130 per minute [50]. Figure 3 shows a photograph of the standing desk with the joystick and the double foot pedal.

Figure 3: Photograph of the standing desk with the joystick and the double foot pedal.

2.3 Procedure

The current experiment was part of a bigger study, dealing with effects of different secondary tasks on hazard detection, which will not be described in detail here. When participants arrived, they first filled in a consent form and an eye side test was performed to assure they had a minimum vision of at least 40%. Afterwards, they read the instruction and were given at least two minutes of training for each task or even longer in case it seemed necessary. The experiment consisted of three blocks. Each block contained 15 sequences with a duration of 20 seconds each (5 minutes block duration).

Fifteen cars appeared in every block as well as four e-bikes that were randomly inserted in the car-sequences. In total participants had to respond to 45 cars, 15 per block and to avoid responding to twelve e-bikes, four per block. Participants had to react as fast as possible and within four seconds before the car crossed their position. Every car needed eight seconds of the 20 second sequence to cross the whole screen. The onsets of the cars were not predictable for participants because of variations across sequences. The first and the last block served as baseline measures, as participants conducted only the hazard detection task. In the second block, they fulfilled the hazard detection and the simulated walking task simultaneously. We decided to use two baseline blocks in order to control for potential effects of learning or fatigue. At the end, participants received a financial compensation and were thanked for their participation.

2.4 Design and Dependent Measures

The design consisted of a 2(age group) × 3(block) between-within-subject design. The first and last blocks served as baselines where participants were only standing. In the second block they performed a simulated walking task in parallel. The number of errors and the response time (between the car entering the scene and the participants pulling the joystick) served as dependent measures. Errors were defined as the sum of misses (when participants did not react to the car before it arrived at the middle of the screen or reacted after the car had already passed their position), false alarms (when participants reacted to the distractor e-bikes). Response time was defined as the time between the appearance of a car and the pulling of the joystick.

3 Results Study 1

Dependent measures were analyzed with 2 × 3 ANOVAs for repeated measures. Greenhouse-Geisser corrections were used to alter degrees of freedom in case of violation of sphericity. Analysis of number of errors revealed a significant main effect of age group, $F(1, 38) = 6.86$, $p = 0.013$, $\eta_p^2 = 0.15$, and a significant interaction effect of age group x condition, $F(1.56, 76) = 3.68$, $p = 0.030$, $\eta_p^2 = 0.08$. The main effect of condition was not significant. As can be seen in Figure 4, both groups had a high level of accuracy in the hazard detection task as they conducted less than one error per block. However, number of errors in the first block was higher for the older age group compared to the younger. Performance of the younger group remained relatively stable during the three blocks. The older group reduced their number of errors from the first baseline to the motor block and almost approached the level of the younger group in the second baseline. These results indicate a learning effect of older participants. No reduction of accuracy in the hazard detection task occurred when the simulated walking had to be performed simultaneously.

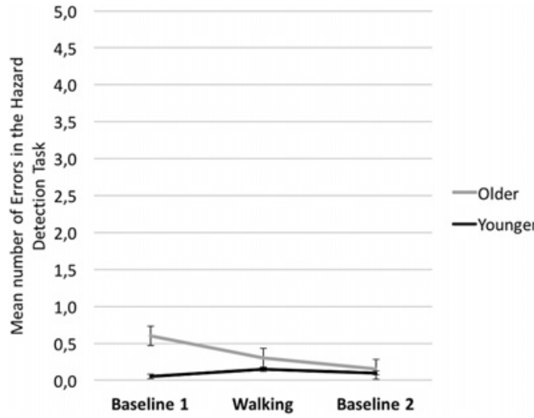

Figure 4: Mean number of errors for the two age groups during the different conditions (first baseline, walking, second baseline).

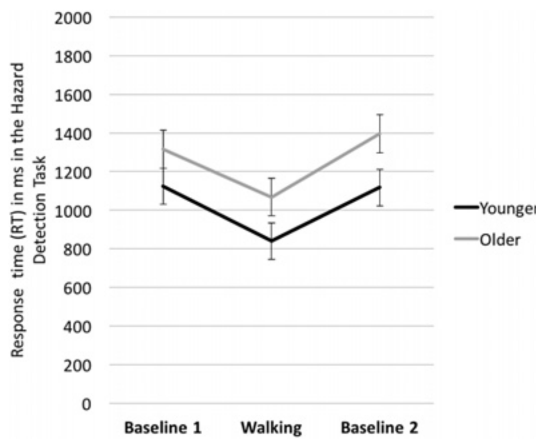

Figure 5: Mean RT in seconds for the two age groups during the three conditions (first baseline, walking, second baseline).

Analyses of response time revealed a significant main effect of age group, $F(1, 38) = 5.01$, $p = 0.031$, $\eta_p^2 = 0.12$, and a significant main effect of condition, $F(1.60, 76) = 52.27$, $p < 0.001$, $\eta_p^2 = 0.58$. The interaction effect was not significant. Figure 5 displays the mean response times for both age groups under the three conditions. The older participants had a longer response time as compared to the younger group in all three conditions. While performing the simulated walking task in parallel, participants reacted faster to the passing cars in the condition. This effect was not in line with expectations but was found for both age groups.

4 Discussion Study 1

In line with expectations, older adults made more errors in the hazard detection task compared to the younger group.

However, that was only true in the first baseline block, indicating that older participants needed longer to familiarize themselves with the new situation. In the second and third block, age-differences with regard to number of errors disappeared.

The simultaneous conduction of a simulated walking task, unlike our hypothesis, did not lead to more errors. That was true for both age groups. It has to be emphasized that the average number of errors was below one per block, which is very low. As an explanation for the absence of an increase in error frequency we suppose that the alternating foot presses did not induce sufficient requirements of keeping the balance as it is required in real walking. Because participants had always one foot on the ground and could hold onto the standing desk, the posture first effect did not take place. Response time to cars was longer for the older group compared to younger participants. This result is in line with prior findings. The conditions with and without parallel motor task differed with regard to response times. The differences were fairly small for both age groups, even though significant. However, the direction of the effect did not correspond with our hypothesis. Both age groups reacted faster to cars, when they had to perform simulated walking in parallel than when doing the hazard detection while just standing. It appears that the motor activity did not only lack the expected increase in error frequency but even improved performance in terms of response time. This might be explained evolutionary. An increased visual performance while running could have been of advantage in the past. Correspondingly, experiments with mice showed higher firing rates in the visual cortex while running on a treadmill [4]. Whether this effect holds true also for humans is not clear so far. Yet, the first experiment shows the importance of using realistic tasks such as real walking when it comes to the examination of effects of motion on cognitive or visual performance. The realization of one "close to reality" visual task involving videos of crossing cars is not sufficient to understand the problems older pedestrians face in real dual-task situations. Thus, study two was conducted with a focus on the ecological validity of the motor task. Instead of simulated walking as in Study one, a naturalistic walking task was combined with a simple visual perception task.

5 Method Study 2

5.1 Participants

Data of 16 older (9 female, age range: 69–80 years, $M = 73.25$, $SD = 3.04$, education level: $8 \leq 12$ years, $4 = 12$ years, $4 \geq 12$ years) and 16 younger (7 female, age range: 19–31 years, $M = 26.06$, $SD = 3.92$, education level: $1 = 12$ years, $15 \geq 12$ years) participants were considered for the analysis. All were right handed as assessed by the Edinburgh handedness inventory (German adaption) and reported to be in a good physiological condition and to be free of any neurological impairments.

All participants completed a short cognitive screening test (Montreal Cognitive Assessment score ≥ 26 points, younger $M = 28,6$ points, older $M = 27,4$ points). One older participant was included with a score of 25 points after age and educational cut-off score adjustments, as recommended by e.g. Rosetti et al. [34] and Malek-Ahmadi et al. [25]. All reported normal or corrected to normal vision and held a horizontal visual field of more than 120°, measured by Vienna Test System subtest for peripheral perception (Schuhfried GmbH, Mödling, Austria).

5.2 Experimental Set-Up

Visual stimuli were presented as short yellow light bursts with 50*ms* duration. Therefore, 300 light-emitting diods (LEDs, Adafruit Industries, New York, USA) were integrated in each side of a corridor of ten-meter length (Fig. 6). The head orientation was measured online by an optical motion capture system (PhaseSpace, San Leandro, USA). Reactions to visual targets were recorded via Bluetooth gaming controller (Nintendo, Kyöto, Japan). LEDs were controlled by a microcontroller in relation to the received online input about the relative position of the person.

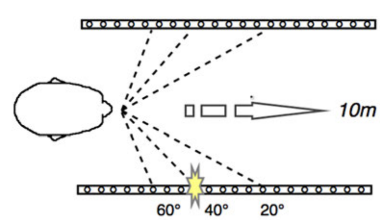

Figure 6: Outline of the 10*m* LED-corridor that was built up for the visual detection task.

5.3 Tasks and Procedure

Data collection took place on two consecutive test days. A first one-hour screening including all pretests was carried out to familiarize participants with the experimental set-up. The second test session started with the preparation of an electroencephalography measurement system that was part of the recordings but will be reported elsewhere. Brief instruction followed by a training session for the visual detection task. The task consisted of the detection of different visual targets in the periphery of the participants' visual field, as required in hazard detection at the edge of a road. Visual targets were presented in three different horizontal angles (20°, 40° and 60° from the central field of view). Participants were asked to respond to each light by pressing a button on a handhold gaming controller device with the left or right index finger, congruent to the perceived stimulus direction. All participants performed the visual task combined with one of three different motor task conditions. They were either asked (1) to sit at a desk without any head and body movements, (2) to stand still between the LED-arrays or (3) to walk up and down the hallway of ten-meter length. For reasonable comparisons with Study 1, only the results from the standing and walking condition will be reported here. Each session was divided into twelve task blocks with four subblocks consisting of 284 visual trials within each motor task. Each participant performed 1200 visual task trials in total while standing and walking with 100 trials from each angle and side within each motor task. In addition, 288 trials were presented from random angle positions. The motor task order was counterbalanced between participants. For the walking condition, participants were instructed to walk at a normal pace while performing the visual task as fast and as accurate as possible. Prior to the first walking block a baseline measurement consisting of gait assessment from a 50*m* walking distance (5 times up and down the corridor) took place without any additional task. All participants received a financial compensation.

5.4 Dependent Measures

As in study one, *response times* and number of errors were analyzed as dependent measures. Errors were differentiated by *false responses* (the sum of button presses with the wrong hand) and the number of *missed targets*. Response time was defined as the time between the onset of the visual target and the subsequent button press.

6 Results Study 2

The analysis comprises a $2 \times 2 \times 2$ repeated measures of variance (ANOVA) with the between factor age and the within factors motor task (standing or walking) and visual presentation or response side in the secondary task (left or right).

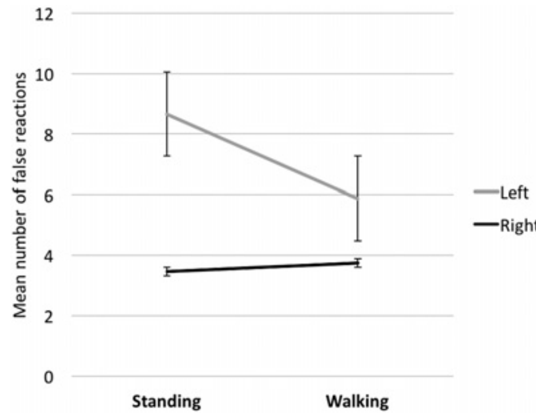

Figure 7: Mean number of false responses with the left and right hand during the different motor task conditions (standing, walking).

6.1 False Responses

Analysis revealed a main effect of motor task, $F(1,30) = 11.81$, $p = 0.002$, $\eta_p^2 = 0.28$ and presentation side, $F(1,30) = 22.63$, $p < 0.001$, $\eta_p^2 = 0.43$. More mistakes were made while standing than while walking and for targets presented from the left compared to the right side. An additional interaction effect of motor task x presentation side, $F(1,30) = 14.89$, $p = 0.001$, $\eta_p^2 = 0.33$, indicates that besides a general enhancement for left side errors, even more left hand errors were committed while standing compared to walking (see figure 7). No main or interaction effects depending on the age group were found.

6.2 Misses

Analysis revealed main effects of age group, $F(1,30) = 7.30$, $p = 0.011$, $\eta_p^2 = 0.22$, and motor task, $F(1,30) = 9.17$, $p = 0.005$, $\eta_p^2 = 0.23$. Older missed more targets than younger and, overall, more targets were missed while walking compared to standing. This differences were specified by a significant motor task x age group interaction, $F(1,30) = 10.97$, $p = 0.002$, $\eta_p^2 = 0.27$. As depicted in Figure 8, younger participants missed a comparable number of targets while standing and walking whereas older missed more targets in the walking condition. The main effect of presentation side and associated interaction effects were not significant.

6.3 Response Time

Analysis revealed significant main effects of age group, $F(1,30) = 15.76$, $p < 0.001$, $\eta_p^2 = 0.98$, motor task, $F(1,30) =$

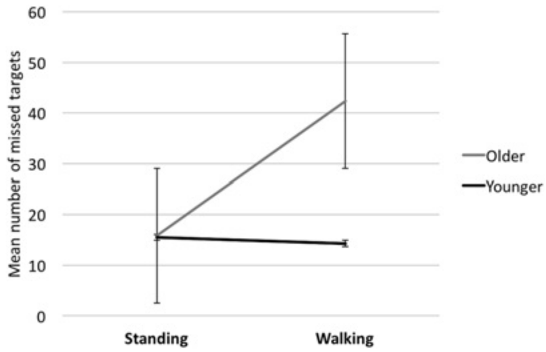

Figure 8: Mean number of missed targets by younger and older participants during the different motor task conditions (standing, walking).

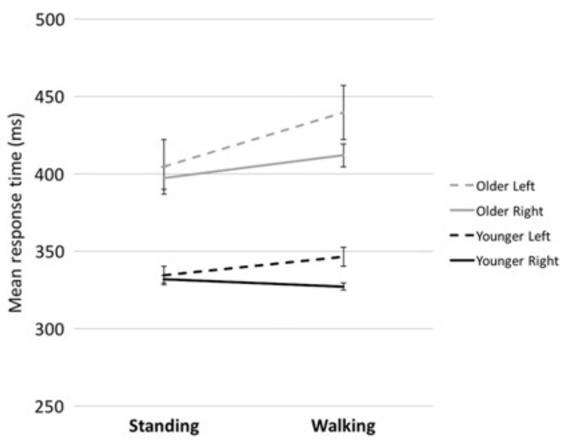

Figure 9: Mean response times for left and right side responses for older and younger participants in the two different motor task condition (standing, walking).

4.89, $p = 0.035$, $\eta_p^2 = 0.14$, and response side, $F(1,30) = 20.28$, $p < 0.001$, $\eta_p^2 = 0.40$. Older participants reacted slower than younger. Both groups were faster while standing compared to walking and slower with the left hand compared to the right hand. A motor task x response side interaction, $F(1,30) = 8.59$, $p = 0.006$, $\eta_p^2 = 0.22$, revealed faster response times for the right hand compared to left hand while walking, but no such difference between response sides was found for the standing condition (see figure 9). Moreover, the group difference did not vary with the two different motor task conditions.

7 Discussion Study 2

Experiment 2 revealed the expected age-related and motor condition main effects. Older participants generally reacted slower and both groups were faster while standing compared to walking. However, this group difference did not vary with the amount of motor task load or presentation and response side. Furthermore, both groups performed equally well in terms of false responses in the walking condition and did not differ in both accuracy measures in the standing condition. This result demonstrates that older adults were able to maintain a certain performance level under low motor task demands. However, an increase in motor load produces age-related dual-task costs in visual perception as indicated by an increased number of misses by older participants compared to younger.

Accordingly, presentation and response side analysis strengthened the assumptions of a general influence of increased motor task load on performance in a visual secondary task. For the standing condition, no response time differences were found for left and right button presses but more false responses were made with the left hand than with the right hand. This result can most likely be explained by the fact that all participants reported to be dominant right handed. Whereas results from the walking condition present a slightly different picture. While mean response times were enhanced compared to right hand responses, fewer errors were made with the left hand while walking compared to left hand errors within the standing condition. When faced with the speed-accuracy trade off (for a review see [51]) younger participants accepted an increase in response time in favor to maintain their accuracy level. The older participants however, showed an increase in both, response time and number of misses. The number of false responses decreased in the walking condition.

According to the multiple resource theory [52], the increased response times might be due to an interference between common shared motor resources that are needed for the manual executed button presses as well as for the walking task. Similar resource conflicts were shown in driving tasks, where e.g. steering appears to be more influenced by a parallel executed manual task like dialing a phone number than by using a voice operated device (cf. [40], for a review see [7]). As a result, prolonged response times appear as functional error avoiding and thus a strategy working out for the response execution part for both groups.

Furthermore, no influence of the presentation side on the number of missed targets was found for both groups in both motor tasks. As no motor task was involved, the dominant hand had consequently no influence on perception in both groups.

Study 2 confirmed the expected effects of age and motor condition on response time. Older participants reacted slower than younger participants and both groups were faster while standing compared to walking. Also as hypothesized, the accuracy of older participants was more affected by an enhanced motor task complexity.

8 General Discussion

Two studies were conducted to investigate older pedestrians' visual task performance within different parallel executed motor tasks. Based on the results regarding older adults' dual-task performance, differences were especially expected in task conditions that included concurrent motor load. Each experiment was set-up to mimic different challenges of hazard perception scenarios for road crossing and therefore thought to cover different aspects of ecological task validity. Whereas study one emphasized on the visual demands of a realistic road crossing scenario, study two required real walking and therefore met the motor task more accurate. Due to difficulties in simulating the task of walking, only results of the second study were in line with our main hypotheses. Results of the second study will be discussed with regard to prior findings and implications for the design of an assistance system for older pedestrians. Additionally we discuss the implications of results and problems related to the first experiment for future study designs.

Findings of the second experiment using real walk show a negative effect of the simultaneous walking on both, response time and misses in the concurrent visual detection task for the older participants. These results are in line with prior basic research studies (for reviews see [53] or [38]). Even the younger group responded slower while waling but managed to maintain their accuracy level. These results indicate an age-specific dual-task effect of walking on perception. Apparently, locomotion of older adults seems to be less automated and in need of additional attentional resources compared to younger participants. This represents an example of the frequently reported ability of older adults to compensate for age-related declines until a certain task complexity is reached (e.g. [20]).

Earlier studies have already found age related differences in several other stages of the road crossing as selection of crossing location, analyzation of current traffic situation, crossing-decision and the actual crossing (cf. [8, 14, 16, 29, 31]). The few studies so far that focused on the stage of traffic perception already indicate two different age-specific behaviors being detrimental for the hazard perception. Older participants with fear of falling do not pay sufficient attention to the traffic because they are busy scanning the surfaces [3]. Furthermore, when focusing on the traffic, their range of scanning is much narrower compared to younger participants [48]. The current results point to a third behavior leading to potential problems at the perceptional stage. A lot of people are used to scan the road for potential hazards while approaching the road (i.e., while simultaneously walking). This behavior is feasible for younger adults as our analysis show, but increases the risk of older pedestrians to overlook upcoming cars.

8.1 Practical Implications for the Development of an Assistance System for Older Pedestrians

Results from study two provide valuable information regarding the design of a pedestrian assistance system. The observed competition for attentional resources between both tasks emphasizes the importance to encourage older pedestrians to interrupt their locomotion when approaching the road. That allows them to invest most of their attentional capacities in the hazard detection task.

Indicating people to stop can be accomplished in different ways. The most ridged way would be the integration of automatic breaks to the walking frame. This imposes ethical questions of older pedestrians' safety and autonomy. As described by Sorell and Draper [43] in their ethical discussion regarding design for older adults, the individual autonomy should be given the priority over safety. Thus, we decided not to stop the users automatically but to inform them when they are approaching the road.

We do not presume older pedestrians to be unaware of the existence of the road in front of them but rather want to remind them to shift their priority from the motor task to the visual requirement. The communication with users might be done with different modalities. The most discreet and at the same time most direct way would be the use of tactile information. This could be given for example via vibration. While the visual and the auditory channels are much occupied in traffic situation, the vibration could be used to make older pedestrian aware of the requirement to focus their attention to the traffic. However, the effectiveness and efficacy of this type of user interfaces in real traffic situations has to be investigated further.

8.2 Theoretical Implications for Prospective User-Centered Experimental Design

The obtained differences between both study results highlight the importance of realistic test designs. As shown by the comparison between simulated and real walking, simulations of certain tasks might fail to cover actual task demands. We believe, in this special walking case, mainly safety-related aspects with regard to requirements of keeping the balance were essential for the given differences. Thus, when investigating effects of walking it has to be assured that not only the type of motion corresponds but also the balance requirements. Real walking as used by Dommes et al. [13] should therefore be used when investigating effects of walking. Even though the foot pedal task might be perceived as physically exhausting as real walking, it did not contain an actual potential for balance disturbance. As participants were allowed to steady their stand by holding onto a handrail, the task could be performed without serious risk. The potential for hidden task aspects should always be kept in mind when conducting evaluation studies. The use of simulators is very widespread and researchers have to face diverse restrictions with regard to ethical, economic, and safety issues. Nevertheless, it should be attempted to use as many realistic tasks as possible in order to not neglect important underlying aspects. Locomotion appears as a conclusive example, as even routine walking is considered as a not exclusive automated motor task that needs attentional resources (for a review see [55]). Especially these non-motor aspects are hard to cover by simulated tasks as they are not really assessable for external examinations. In the current use case, we faced the trade-off between "close to reality" traffic simulation that is presented in a rather static way and the nature of realistic walking being the opposite of static.

One possible solution for the future may be the use of new portable and head-mounted displays (HMD) for virtual reality such as the oculus rift (oculus VR, Inc., CA, USA). Participants can wear the device while moving naturally. In the meantime, these techniques offer the possibility to simulate traffic situations that are close to reality. Although recent reports have shown the successful usage of adequate HMD pedestrian simulator scenarios with younger participants (e.g. [42], [26]) and reasonable indicators for high levels of immersion [15] it has to be investigated, whether the use of a HMD is possible when working with older adults. When using virtual scenarios, simulator sickness has to be taken into account as a potential risk factor (e.g. for HMD: [27]). Even though, many studies do not provide sufficient statistics, several results indicate higher drop out rates for older participants due to simulator sickness (e.g. [10], [9], [32]). However, a general statement can hardly be made. Further investigations, especially for older participants in pedestrian simulations are needed. In addition, this type of virtual reality imposes new challenges with regard to safe walking as older adults tend to rely more on visual input while walking than younger (e.g. [11]). Therefore imperfect visual feedback -as it is still delivered by VR applications- might have a greater influence on older adults' locomotion. Further studies are needed to investigate the advantages and disadvantages of HMD for research with older adults. Another important finding of the first study concerns the observed learning effect of older participants. The prolonged time for familiarization with new tasks and new applications should be taken into account when evaluating technical devices by offering longer periods of training.

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