Age-Related Differences in Critical Driving Situations: The Influence of Dual-Task Situations, S-R Compatibility and Driving Expertise

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Lessons Learned

In the near future, there will be a significant increase in the number of older people who hold driving licenses. Maintaining mobility by driving a car is a key factor for elderly people as mobility is a prerequisite for social contacts, social integration and an autonomous lifestyle. Contrary to the stereotype that older drivers are risky and constitute a threat to general traffic safety accident statistics show that fatality rates are the highest in young drivers and that rate declines to a minimum for drivers of the age of 40–60 years. This can partly be explained by compensatory driving strategies: older drivers prefer to drive shorter distances, avoid critical situations like rush hours and drive preferably during daytime. Nevertheless, there is an increased accident-risk of older drivers in complex driving situations resulting from decreasing driving practice and, more importantly, age-related changes in information processing capacities (see chapter Age-Differentiated Systems: Introduction and Overview to a Six Year Research Program in Germany, Schlick et al.). The aim of the project was to analyze age-related differences in the applied context of critical driving situations. Findings reported in the literature suggest a decreased performance of elderly people in laboratory situations as well

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as in a natural driving context. However, it is still an open question, whether this is also true for dual-task requirements in a driving context and whether expertise might compensate for age-related effects. In two experiments, we first studied the influence of age on spatial compatibility effects in natural scenes and, then, the effects of a secondary task as well as the effects of driving expertise were examined.

The results of the experiments indicate that in the driving context, reaction time in an avoiding situation (e.g. avoiding to drive into a person appearing unexpectedly on the scene by turning a steering wheel away from the person) was shorter than a turn of the steering wheel towards the stimulus. These results speak against an automatic response tendency elicited by the position of the stimulus, as assumed often by compatibility theories (Kornblum et al. 1990). Although older drivers (mean age 62; young drivers mean age 23) showed an inferior driving performance with slower reactions, the compatibility effect was not increased in older drivers, which contradicts the general pattern of results obtained in the literature. As one possible explanation for this observation, the influence of expertise was examined. In addition, the influence of a secondary task was tested by presenting an acoustical message by the navigation system. Participants reacted faster when the direction announced in the navigation message was contralateral to the pedestrians' side of appearance. Again, older drivers showed slower reactions, but there was no increased interference effect. Moreover, two groups of professional drivers (young, mean age 28, and old drivers, mean age 56) were tested: Older professional drivers reached a comparable performance in reaction times as younger professional drivers and driving experience resulted in a reduced vulnerability to interfering stimuli—probably because professional drivers are more experienced in the primary task (driving a car, or, more specifically, reacting in dangerous situations while driving a car) and because they are more used to dual-task situations while driving a car (using a mobile phone or listening to a message of the navigation system while driving a car).

Based on these findings the following recommendations can be derived:

- When designing electronic driver assistant systems (e.g., collision avoidance system, lane assistant) that support the driver to increase safety, it should be taken into account that every additional information given to the driver not only demands the driver's attention in general but that there are also specific cross task effects (e.g., a lateral signal from the collision avoidance system can have an interfering effect on a left/right reaction with the steering wheel).
- Age-related changes in information processing capacities can be compensated for by training. As it is not always possible for elderly people to avoid complex driving situations, older drivers should undergo driving courses regularly, especially if their driving practice decreases, and specifically train driving in complex situations (lane-changing manoeuvres, turning of at intersections, right of way decisions and driving situations with multiple task demands).

The Older Driver

Over the next thirty years there will be a significant increase in the number of older people who hold driving licenses. According to the US Institute of Highway Safety, by 2029 one out of four licensed drivers is anticipated to be an older driver (age 50+). This trend will not only be caused by demographic change but also by a more mobility-prone lifestyle in western societies. Many older drivers will have access to a car for all their lives, moreover the proportion of older women holding driving licenses will increase. Maintaining mobility by driving a car is a key factor for elderly people as mobility is a prerequisite for social contacts, social integration and an autonomous lifestyle (OECD 2001).

Common stereotypes perceive older drivers as risky and as a threat to general traffic safety. However, accident statistics contradict this stereotype: fatality rates are the highest in young drivers and that rate declines to a minimum for drivers of the age of 40–60 years to slightly increase again to a maximum for those aged 75 and older (Statistisches Bundesamt 2005). Research in traffic and accident analyses shows that older drivers are particularly prone to have accidents resulting from inadequate handling of complex traffic situations such as lane-changing manoeuvres, turning of at intersections, right of way decisions and in driving situations with multiple task demands (e.g. driving a car and using a mobile phone; cf. Mcgwin and Brown 1999; Cox and Cox 1998; Hancock et al. 2003). Contrary to that, older drivers are "under-represented" in crashes involving loss of control or collisions due to speeding, risky overtaking or driving under the influence of alcohol. The higher accident-risk of older drivers in complex driving situations can be explained by two factors: (1) decreasing driving practice and (2) age-related changes in information processing capacities. Regarding decreasing driving practice, older drivers tend to use compensatory driving strategies. They prefer to drive shorter distances, avoid critical situations like rush hours and drive preferably during daytime which leads in sum to a lower annual mileage and to a reduction of driving practice (Hartenstein 1995; Stutts 1998). Referring to age-related changes in information processing capacities, a number of physiological and psychological functions decline with increasing age, which negatively affects driving abilities and performance. A more detailed description of those changes will be given in the following section.

Dual-Task Demands and Cross-Task Compatibility in Driving

Age-related changes in the information processing system comprise changes in perceptual, motor and cognitive abilities, which are gradual and vary widely from individual to individual (Park and Schwarz 1999). Age-related changes in the *perceptual system*, which are relevant in driving, refer to a decline in auditory and visual abilities of older adults (Kline and Scialfa 1997). Changes in the auditory system comprise an increase in the auditory threshold (especially for high-frequency tones), difficulties in the perception of speech and in the discrimination and the spatial location of tones. Apart from an ongoing decrease in visual acuity, the eyes' ability to accommodate and adapt to light changes declines and the sensitivity to glare and reflections increases. Older adults therefore have higher difficulties seeing and determining the speed and distance of the traffic they need to merge with. *Motor abilities*, that is the ability to execute fast and accurate movements, are also declining over the life span (Vercryssen 1997). Moreover, there is a decline in muscle power, nerve sensitivity, skeletal strength and flexibility, which may limit driving operations and makes it difficult to move the head to see traffic at junctions. The most relevant changes in the context of the present study refer to age-related declines in *cognitive functions*—for instance, the decline in working-memory capacities, the slowing of processing speed and the reduced ability to distinguish relevant from irrelevant information (Park and Schwarz 1999). The most prominent change is the slowing of information processing, i.e. a slowing in stimulus detection, decision making, response selection, and response execution (Salthouse 1996). Processing capacity is also reduced over the lifespan, with increased problems while simultaneously processing information such as talking and carrying out some driving manoeuvre. The ability to discriminate relevant from irrelevant information is most impaired in elderly people if they have to perform the task under time pressure (Plude and Hoyer 1986). Many studies provided evidence for age-related declines in information processing abilities, especially with increasing task complexity (Kliegl et al. 2003; Li et al. 2004).

Dual task demands are typically studied in a dual-task paradigm, where participants are required to react as fast as possible to two stimuli being presented in close succession. For example, participants are instructed to press a left/right key (R1) in response to a high/low tone (S1) and to say "blue" or "yellow" (R2) in response to a blue or yellow stimulus (S2). Under conditions with a short time interval (stimulus-onset asynchrony, SOA) between the presentation of S1 and S2 (i.e. S2 is presented when response preparation and production of R1 has not yet been completed), dramatic increases in reaction time and errors in the secondary task (S2–R2) are observed. These performance impairments were explained by capacity limitations at the response selection stage (for an overview see Pashler 1998). It was assumed that two reactions could not be selected simultaneously because the central stage of response selection was limited to process one event at a time. As a consequence, response selection of the secondary task had to wait until response selection of the primary task was completed. More recent dual-task studies found evidence that processing S1 not only impairs the selection of R2, but also impairs perceptual encoding of S2. Using a go/no-go manipulation in the primary task, Müsseler and Wühr (2002) demonstrated that performance in the secondary task is impaired even under conditions under which only identification of the stimulus but no response selection is required in the primary task (see also Jolicoeur 1999). Moreover, by introducing compatibility relationships between tasks (Lien and Proctor 2002), it was shown that compatibility information could successfully bypass the response-selection bottleneck (Hommel 1998; Müsseler et al. 2005, 2006). Therefore, cross-task compatibility is a further important factor, which has to be considered in dual task situations.

Cross-task compatibility describes whether the information presented in the second task provides information, which is compatible or incompatible to the primary task. While driving a car a driver often has to immediately react to visual information that is spatially localized (e.g. avoiding obstacles that suddenly appear at the right side of the road). From compatibility research it is well known that speed as well as accuracy of a spatial reaction is influenced by the spatial location of the imperative stimulus. A stimulus that is presented ipsilaterally (at the same side at which the reaction is required) results in faster responses and less errors than a stimulus that is spatially non-corresponding with the required reaction. In classical compatibility theories, this pattern of results is explained by an automatic activation of the corresponding reaction that in the case of an incompatible situation has to be inhibited first before the correct response can be performed (Kornblum et al. 1990).

Up to now, the question about the effects of compatibility and dual task demands in driving situations has been mostly ignored in research. Moreover, it is important to note that the increase of age-related competencies such as driving expertise and more defensive and anticipatory driving style cannot fully compensate for the age-related decrease in the information processing system. Older drivers do not necessarily drive worse; however, as it is not always possible to avoid problematic and demanding traffic situations elderly people drive with higher cognitive load. Thus, it is important to study the influence of this fact on reactions in critical situations in which a coordination of different tasks is required. Therefore the present study aimed for an investigation of the effects of age, compatibility and dual task demands in an applied context of critical driving situations. We were interested to address the following questions:

- Do older drivers show an inferior driving performance in critical driving situations?
- Does age increase interference effects of dual task demands and cross-task compatibility in critical driving situations?
- Does driving expertise compensate for the effects of age?

Experiment 1: Spatial Compatibility in Natural Scenes: The Effect of Age

The purpose of Experiment 1 was twofold: First, we examined whether driving responses in a taxi-driver scenario would follow the assumptions of spatial compatibility or if we are able to replicate the findings presented in Müsseler et al. (2009). There we found that the typically observed advantage of spatially compatible responses was reversed for dangerous situations in natural scenes, that is, for critical driving situations the spatially incompatible response was faster than the compatible response. Classical compatibility theories would imply that first an automatic activation of the corresponding reaction (i.e. in the direction of the dangerous stimulus) takes place, which then has to be inhibited before the correct response can be selected. The question was whether this automatic activation of the ipsilateral response was the same in driving situations. Second, we analyzed compatibility effects in critical driving situations in an older sample. As interference effects in compatibility tasks increase in elderly people (Pick and Proctor 1999), we assumed that compatibility effects in an applied driving situation would be more pronounced in an older sample.

A taxi-driver scenario was realized in the experiment, where younger and older participants watched short movies from the driver's perspective. The movies showed a street scene, in which participants approached an intersection and a pedestrian suddenly entered the street from the left or the right side, either calling a taxi by waving with the arm or causing a critical situation by carelessly entering the street. Participants were instructed to react as fast as possible by turning a steering wheel clockwise or counterclockwise either towards the location of the person (in order to pick this person up) or away from the person (in order to avoid hitting the person).

Based on the findings presented in Müsseler et al. (2009), we expected faster reactions when participants had to turn the steering wheel away from the stimulus (avoiding reaction; spatially incompatible condition) in comparison to a turn of the steering wheel towards the stimulus (spatially compatible condition). Moreover, as interference effects in compatibility tasks increase in elderly people, we expected the group of older adults to show not only slower reactions but also an increased compatibility effect.

Method

Participants

A total of 30 participants, 15 older adults with a mean age of 61.7 years (range 56–65 years) and 15 younger adults with a mean age of 24.2 years (range 21–30 years) took part in the experiment. A valid driver license was required to participate in the experiment. Younger adults held their driver license, on average, for 6 years (range 3–10 years) whereas older adults held their driver license for more than 41 years (range 37–45 years). Average amount of driving amounted to 9,600 km per year in the younger adults and 12,100 km per year in the older adults. All participants of the present and the subsequent experiments were right-handed and reported normal or corrected-to-normal vision. Older participants were recruited by advertisements in a local newspaper, younger participants were students, which fulfilled a course requirement or were recruited through the social network of the experimenter.

Fig. 1 Experimental setup: participant in the seat box in front of the screen

Apparatus and Stimuli

The experiment was carried out in a dimly lit and soundproof room and was controlled by a Macintosh computer with Matlab using the Psychophysics Toolbox (Brainard 1997; Pelli 1997). Stimuli were projected with a beamer (Epson EMP-82 with a resolution of 1024 × 768 pixel) on a screen (146 × 208 cm). Participants sat on a car seat in a seat box 240 cm in front of the screen (see Fig. 1). They used a steering wheel (Logitech Formula GP Racing Wheel, 25 cm in diameter) to react to the stimuli. A 45°-deviation of the steering wheel from the home position (straight ahead) determined reaction times. Response directions were also collected to analyze accuracy. Participants started a trial by stepping on an accelerator pedal, which was placed in front of the car seat positioned according to participants' length of legs.

As visual stimuli movies showing traffic scenes were presented. They were projected with a size of 110 × 150 cm on the screen and showed a straight-ahead driving scene in a one-way street from the participants' perspective. The movies were based on digitized photos of a street scene and the zooming-in function of a video software (iMovie, Apple Computer Inc.) was used in order to evoke a driving impression. After 2 s the movie ended and a picture of a pedestrian (39 × 14 cm) was superimposed into the street scene 6° to the left or the right of the screen center. The pedestrians' pictures were mirrored in order to equally enter the street scene from the left or right hand side. The pedestrian either waved and turned towards the participant holding eye contact; or was carelessly entering the street without keeping eye contact.

Procedure

First, the car seat was adjusted to participants' seating preferences and participants were instructed to grab the steering wheel with their dominant hand on the top. In this position, the hand movement or direction of the steering-wheel rotation corresponded to the driving direction (for different results with regard to the hand position (see Guiard 1983; Stins and Michael 1997). Participants were told to act like taxi-drivers, which were exclusively driving on one-way streets (in order to allow turning to the left side of the street without considering the oncoming traffic). Each trial started with a static street scene and the taxi drive was started by stepping on the accelerator pedal. After 2 s a pedestrian (either waving or carelessly entering the street) appeared to the left or right hand side of the street and participants had to react with a steering-wheel movement. As taxi-drivers they were instructed to turn towards waving pedestrians to pick them up (compatible S–R relationship) or to turn away from pedestrians stepping on the street to avoid hitting them by moving the steering wheel in the opposite direction (incompatible S–R relationship). Participants were instructed to react as fast and correct as possible.

After participants' steering-wheel response the screen cleared and participants had to realign the steering wheel into a straight-ahead position. If participants gave a wrong steering wheel response or if reaction times exceeded 1,500 ms, an auditory error feedback was given. The next trial started with a step on the accelerator pedal. Each participant accomplished 16 practice trials in order to ensure an understanding of the experimental procedure. The experiment lasted about 60 min.

Design

The experiment had a two-factorial design with age (younger vs. older adults) as between-subject factor and spatial compatibility (compatible vs. incompatible) as within-subject factor. Participants performed 256 trials, with a short break after half of trials. As dependent variables reaction times of steering-wheel responses and percentage errors (proportion of incorrect response directions) were recorded.

Results and Discussion

Median reaction times and percentage of errors of each participant were entered into 2 (age) × 2 (spatial compatibility) analyses of variance (ANOVA). The analysis of reaction times revealed highly significant main effects of age ($F(1, 28) = 19.8$, $MSE = 16607.14$, $p < 0.001$) and spatial compatibility ($F(1, 28) = 19.6$, $MSE = 1652.03$, $p < 0.001$). The interaction between age and spatial compatibility missed statistical significance ($p > 0.10$). The main effect of age indicated longer reaction times in older participants ($M = 743$ ms, $SD = 116$) in comparison to younger participants ($M = 595$ ms, $SD = 57$). The spatial compatibility effect referred to

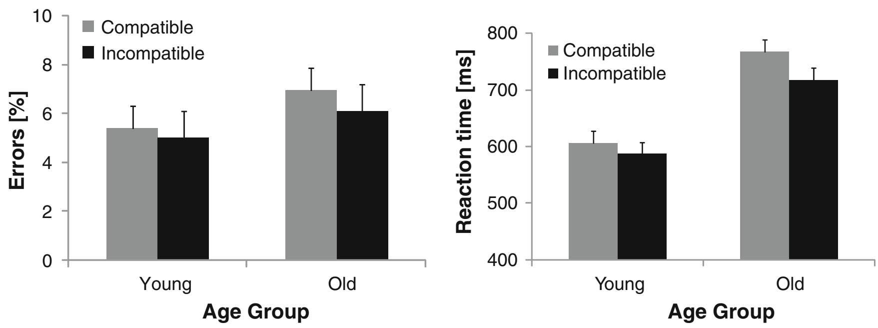

Fig. 2 Mean reaction times (*left*) and percentage errors (*right*) of younger and older drivers in compatible and incompatible situations in Experiment 1

faster reaction times in spatially incompatible conditions (M = 646 ms, SD = 120) than in spatially compatible conditions (M = 692 ms, SD = 121), i.e. participants reacted 47 ms faster when they had to avoid a collision with a pedestrian by turning the steering wheel in the opposite direction than picking up the pedestrian by turning the steering wheel towards them (Fig. 2).

The missing interaction between age and spatial compatibility indicates that the spatial compatibility effect was not increased in the group of older drivers. Reaction times of younger participants were 30 ms faster in the incompatible condition; older participants reacted 63 ms faster in the incompatible condition. The analysis of percentage errors did not reveal any significant effects or interactions. For older and younger participants as well as for spatially compatible and incompatible conditions no appreciable differences were observed in error rates.

Contrary to assumptions of classical compatibility theories, reaction time was faster when drivers had to turn the steering wheel away from the stimulus (avoiding reaction; spatially incompatible condition) in comparison to a turn of the steering wheel towards the stimulus (spatially compatible condition). Apparently, driving performance (as measured in reaction time and errors) in a natural setting of younger and older drivers was affected by the affective meaning of stimuli leading to reversed compatibility effects for dangerous situations— which replicates our findings in a younger sample (Müsseler et al. 2009, Exp. 1). Older drivers showed an inferior driving performance with slower reactions. No interaction between age and compatibility was found—contrary to previous findings in laboratory situations with neutral stimuli—which indicates, that the compatibility effect was not increased in older drivers. One possible explanation is, that older drivers' higher driving expertise moderated compatibility effects. This explanation will be tested in Experiment 2b.

Experiment 2a: Spatial Compatibility in Natural Scenes: The Effect of a Secondary Task

Experiment 2 further examined the effects of spatial compatibility and age in driving in a dual task situation. The same driving scenario was used as in the previous experiment. Younger and older participants watched short movies showing a street scene where pedestrians suddenly entered the street. They were instructed to avoid a collision with the careless pedestrian by turning the steering wheel as fast and correct as possible in the opposite direction (primary task). Additionally, an auditory driving direction message of a navigational system was presented to which participants had to react in an unspeeded manner (secondary task). Research using dual-task paradigms has not only shown unspecific impairments in reaction times and errors but also so-called cross-task compatibility effects. Reaction times in the primary task were impaired when an incompatible stimulus was presented in the secondary task (Müsseler et al. 2005, 2006). Thus, we expected an effect of cross-task compatibility between the primary task of driving and the secondary task of responding to the message of the navigation system. Moreover, as the influence of a secondary task has been shown to increase with age (see chapter Age-related Changes of Neural Control Processes and their Significance for Driving Performance, Hahn et al.), we examined the effects of cross-task compatibility in older drivers, expecting enlarged interference effects across tasks in older drivers.

Method

Participants

A total of 34 new participants, 17 older adults with a mean age of 60.7 years (range 56–65 years) and 17 younger adults with a mean age of 23.2 years (range 21–30 years) took part in the experiment.

Apparatus and Stimuli

The same experimental setup was used as in Experiment 1 with two exceptions. The experimental procedure was controlled by a Syntron AMD PC running on Windows XP. The auditory driving direction message (“turn left”/“turn right”) was recorded and added as sound track to the movies and presented via speaker boxes (Logitech R-10), which were placed 50 cm to the left and to the right of the participant. Moreover, only the careless pedestrian entering the street without keeping eye contact was presented.

Procedure

As primary task, participants were required to react with an avoiding response to a pedestrian, who suddenly entered the street from the left or right side. Just before the presentation of the visual stimulus, participants heard a spoken driving direction message of a navigation system ("turn left/turn right"). The secondary task required participants to remember this message and to give an unspeeded response by turning the steering wheel according to the driving direction message to the left or the right after the primary task was accomplished.

As in Experiment 1 each trial started with the presentation of a static street scene and the movie was started by stepping on the accelerator pedal. Before the pedestrian appeared the spoken message of the navigation system was presented. In order to assess the baseline driving performance in the primary task, in 1/3 of the trials no navigation message was presented. Moreover, in order to reduce the frequency of dangerous driving situations, in 1/3 of the trials no pedestrian appeared and participants only had to respond to the secondary task. The experiment lasted about 90 min.

Design

The experiment had a two-factorial design with age (younger vs. older adults) as a between-subject factor and spatial correspondence (corresponding vs. non-corresponding) as within-subject factor. Spatial correspondence refers to the spatial location of the visual stimulus in the primary task (pedestrian appearing at the left or at the right side of the scene) and the spatial information given in the acoustical message of the navigation system ("turn left", "turn right"). Note, that under spatial correspondence between the stimuli in the primary and secondary task, the required steering wheel reaction is incompatible to the spatial location of the person and the spatial information given in the acoustical message of the navigation system and vice versa.

Participants performed 252 trials (84 trials per condition) in randomized order. As dependent variables reaction times of steering-wheel responses and percentage errors (proportion of incorrect response directions) were recorded.

Results and Discussion

Median reaction times and percentage of errors of each participant were entered into 2 (age) $\times$ 2 (spatial correspondence) ANOVA. The ANOVA on reaction times revealed a highly significant main effect of age, with older drivers showing slower reactions than younger drivers [$F(1,32) = 42.5$, $MSE = 17391.49$, $p < 0.001$)] and a highly significant main effect of correspondence ($F(1,32) = 12.6$, $MSE = 192.38$, $p = 0.001$), with faster reactions in non-corresponding situations (Fig. 3).

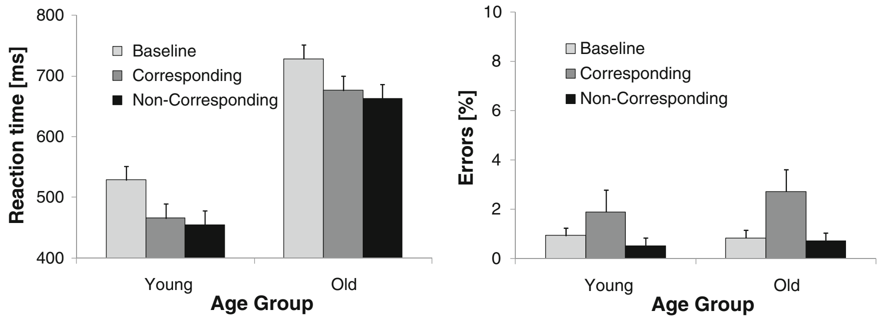

Fig. 3 Mean reaction times (*left*) and percentage errors (*right*) of younger and older drivers in the baseline condition and in corresponding and non-corresponding situations in Experiment 2a

The interaction between age and correspondence again missed statistical significance ($p > 0.20$). Contrary to expectations, older drivers did not show higher correspondence-related interference effects. The main effect of age implies, that older participants showed slower reactions (M = 669 ms, SD = 99) in comparison to younger adults (M = 461 ms, SD = 88). Regarding the main effect of correspondence, reactions were faster in non-corresponding conditions (M = 559 ms, SD = 140) in comparison to corresponding conditions (M = 571 ms, SD = 141). The analyses of percentage errors closely mirrored the pattern of results obtained in reaction times.

Unexpectedly, in the single task condition (baseline) reaction times were significantly slower than in the dual task condition, both in the group of young participants (single task: M = 513 ms, SD = 82, dual task: M = 448 ms, SD = 71; $p < 0.001$) as well as in the group of old participants (M = 652 ms, SD = 126, dual task: M = 583 ms, SD = 137; $p < 0.001$). This might be explained by the fact that the auditory signal from the navigation system (stimulus in the secondary task) always directly preceded the visual stimulus in the primary task (pedestrian suddenly appearing on the scene). Therefore, the stimulus in the secondary task probably served as a cue for the stimulus in the primary task thus resulting in reduced reaction times under dual task conditions.

Findings show that participants' driving performance was superior in non-corresponding situations, i.e. when the driving direction message of the navigation system was contralateral to the pedestrians' side of appearance. In other words, participants reacted faster and with lower error rates when the direction of the navigation message corresponded to the escape direction when avoiding the collision with the pedestrian. As expected, we found slower reactions in older drivers. Contrary to expectations, there was no increased interference effect in older drivers. One possible explanation for that finding is, that older drivers' expertise again compensated for age-related interference effects. Therefore the factor driving expertise was included in Experiment 2b.

Experiment 2b: Spatial Compatibility in Natural Scenes: The Effect of Driving Expertise

In Experiment 2b, the effect of driving expertise on age and compatibility in a dual-task driving situation was examined. For this purpose, a group of professional drivers was tested using the identical setup that was applied to non-professional drivers in Experiment 2a and the performance of both groups was compared directly. We assumed that the age-related decrease in driving performance in the dual-task situation is compensated by the greater amount of driving expertise in the elderly people.

Method

Participants

A total of 34 new participants, 17 older adults with a mean age of 55.7 years (range 50–65 years) and 17 younger adults with a mean age of 27.9 years (range 21–35 years) took part in the experiment. Driving expertise was operationalized by professional driving of at least 1,000 km per month regular driving experience in the last two years, at minimum. On average, professional drivers spent 32 h per week driving as compared to 5 h in the non-professional drivers.

Stimuli, Procedure and Design

Stimuli, procedure and design were identical to those in Experiment 2a.

Results and Discussion

For the sake of concision, we directly compared the results of professional with non-professional drivers. Median reaction times and percentage of errors of each participant were entered into 2 (age) $\times$ 2 (expertise) $\times$ 2 (spatial correspondence) ANOVA.

The analysis of reaction times revealed highly significant main effects of age ($F(1,64) = 38.0$, $MSE = 16389.72$, $p < 0.001$), expertise ($F(1,64) = 20.3$, $MSE = 16389.72$; $p < 0.001$) and interactions between age and expertise ($F(1,64) = 11.1$, $MSE = 16389.72$; $p < 0.005$) as well as between correspondence and expertise ($F(1,64) = 15.7$, $MSE = 2764.13$; $p < 0.001$). The main effect of correspondence, the interaction between correspondence and age and the triple interaction of age, expertise and correspondence did not reach statistical significance.

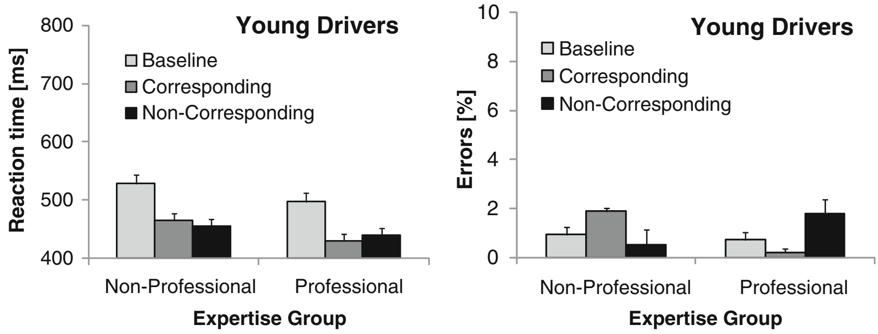

Fig. 4 Mean reaction times (*left*) and percentage errors (*right*) of young professional and nonprofessional drivers in the baseline condition and in corresponding and non-corresponding situations in Experiment 2b

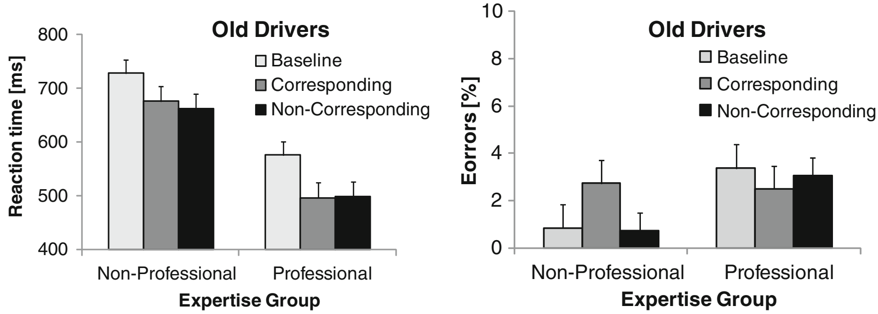

Fig. 5 Mean reaction times (*left*) and percentage errors (*right*) of old professional and nonprofessional drivers in the baseline condition and in corresponding and non-corresponding situations in Experiment 2b

The main effect of age indicates, that older participants showed 128 ms slower reactions (M = 583 ms, SD = 136) in comparison to younger adults (M = 455 ms, SD = 75). Regarding the main effect of expertise, non-professional drivers (M = 565 ms, SD = 140) were 93 ms slower than professional drivers (M = 472 ms, SD = 93). The interaction between age and expertise indicates that age-related differences in driving performance were larger in non-professional drivers than in professional drivers (Figs. 4 and 5). Older non-professional drivers showed 209 ms slower reactions (M = 669 ms, SD = 98) in comparison to younger non-professional drivers (M = 461 ms, SD = 88; $p < 0.001$). In professional drivers this difference between younger (M = 435 ms, SD = 48) and older drivers (M = 497 ms, SD = 115) was only 62 ms but still significant ($p < 0.05$).

Regarding the interaction between expertise and correspondence, correspondence effects were only found in non-professional drivers, whereas professional drivers reacted comparably fast in corresponding and non-corresponding situations. As reported in Experiment 2a, non-professional drivers' reactions were

12 ms faster in non-corresponding conditions (M = 559 ms, SD = 140) in comparison to corresponding conditions (M = 571 ms, SD = 141; $p < 0.05$). However, for professional drivers no significant differences in reaction times between corresponding (M = 463 ms, SD = 94) and non-corresponding conditions (M = 469 ms, SD = 91; $p > 0.05$) were found.

Again, when comparing reaction times in the dual-task condition with the baseline condition (where no navigation message was presented), faster reaction times were obtained in the dual-task condition ($F(1,67) = 199.5$, MSE = 761.59; $p < 0.001$). Participants reacted 67 ms faster with the navigation message (M = 516 ms, SD = 128) than in the baseline condition without navigation message (M = 583 ms, SD = 126).

The analysis of percentage errors revealed a significant main effect of age ($F(1, 64) = 5.0$, MSE = 9.03; $p < 0.05$) and an interaction between expertise and correspondence ($F(1,67) = 200.9$, MSE = 761.59; $p < 0.001$). No other reliable effects were found. The main effect of age indicates that older drivers had higher error rates (M = 2.26 %, SD = 2.79) than younger drivers (M = 1.09 %, SD = 1.09). Regarding the interaction between expertise and correspondence, non-professional drivers had a 1.68 % higher error rate in corresponding (M = 2.31 %, SD = 2.76) than in non-corresponding situations (M = 0.63 %, SD = 1.07; $p < 0.001$). Contrary to that, professional drivers' error rates were lower in corresponding (M = 1.37 %, SD = 3.05) than in non-corresponding conditions (M = 2.42 %, SD = 2.91; $p < 0.05$; Figs. 4 and 5). The presence or absence of the navigation message did not affect participants' error rates.

Older drivers showed a considerably reduced driving performance, but contrary to typical findings in the literature no increased age-related interference effects were found, which hint at compensating resources in older drivers. As a potential compensating factor investigated in this study driving expertise moderated the effects of age in driving performance, with older professional drivers reaching a comparable performance in reaction times as younger professional drivers. Moreover, driving expertise co-acted with correspondence-mappings in the driving task: for non-professional drivers a reversed correspondence-effect was found with superior performance in the spatially non-corresponding condition, which is probably a result of valence correspondence overruling spatial correspondence (Müsseler et al. 2009). However, in professional drivers no effect of cross-task-compatibility was obtained, suggesting that expertise not only reduces age-related performance differences but also affects compatibility-related interference effects. Finally, the inferior performance in the baseline condition, where no navigation message was given, suggests that the navigation message had a cue-function, which facilitated driving reactions in the primary task.

General Discussion and Conclusion

The aim of the present study was to analyze age-related differences in the applied context of critical driving situations. Findings reported in the literature suggest a decreased performance of elderly people in laboratory situations as well as in a natural driving context. However, it is still an open question, whether this is also true for dual-task requirements in a driving context and whether expertise might compensate for age-related effects. In two experiments, we first studied the influence of age on spatial compatibility effects in natural scenes and, then the effects of a secondary task as well as the effects of driving expertise were examined.

In Experiment 1, we replicated and extended the findings obtained by Müsseler et al. (2009). They demonstrated that the typically observed advantage of spatially compatible responses is reversed for dangerous situations in natural scenes. In the driving context, reaction time in an avoiding situation (e.g. stimulus: an unexpected person appearing on the right side of the scene, reaction: turning a steering wheel to the left) was shorter than a turn of the steering wheel towards the stimulus. These results speak against an automatic response tendency elicited by the position of the stimulus, as assumed often by compatibility theories (Kornblum et al. 1990). The advantage of an incompatible stimulus–response coupling was not only observed in young subjects but also in a group of elderly participants. Although older drivers showed an inferior driving performance with slower reactions, no interaction between age und compatibility was found. Thus, different to the general pattern of results obtained in the literature, the compatibility effect was not increased in older drivers. As one possible explanation for this observation, the influence of expertise was examined in Experiment 2.

In Experiment 2, the effects of a secondary task as well as the effects of driving expertise were examined. Recent studies using the dual-task paradigm demonstrated so-called cross-task-compatibility effects, that is, performance in the primary task was not only impaired by the presence of a secondary task in general, but there were also specific impairments based on the compatibility relation between the stimulus in the secondary task and the reaction in the primary task (Müsseler et al. 2005, 2006). Results obtained in Experiment 2 showed that participants' driving performance was superior in non-corresponding situations, however, in this case a cross-task compatibility effect was obtained. Participants reacted faster when the direction announced in the navigation message was contralateral to the pedestrians' side of appearance. Again, older drivers showed slower reactions but there was no increased interference effect.

One possible explanation for the absence of increased interference effects in the group of elderly participants might be the fact, that age of participants is confounded with driving experience. The group of young participants had on average 5 years of driving experience, whereas the group of older drivers had 40 years of driving experience on average. Therefore, two factors might be at work producing these results. On the one hand, with increasing age, susceptibility to interference effects increases with increasing age, as research on spatial compatibility as well as dual-task situations has demonstrated (e.g. Pick and Proctor 1999). On the other hand, with increasing driving experience the influence of interfering stimulation (e.g. the acoustical message of a navigation system) should be reduced.

To test this explanation, two groups of professional drivers (young and old drivers) were tested with the identical experimental setup in Experiment 2b. In accordance with our hypotheses, expertise moderated the effects of age in driving performance. First, older professional drivers reached a comparable performance in reaction times as younger professional drivers. Second and more importantly, driving expertise co-acted with compatibility mappings in that in professional drivers no effect of cross-task-compatibility was obtained. Thus, driving experiences result in a reduced vulnerability to interfering stimuli probably because professional drivers are more experienced in the primary task (driving a car, or, more specifically, reacting in dangerous situations while driving a car) and because they are more used to dual-task situations while driving a car (using a mobile phone or listening to a message of the navigation system while driving a car).

One unexpected result was obtained in the comparison of single-task vs. dual-task situations. In all four groups of participants (young and old, professional and non-professional drivers) increased reaction times were observed in the single-task situation (baseline) as compared to the dual-task situation. A typical result, however, would have been that the secondary task requires processing capacity and due to limited processing capacity reaction time increases in dual-task conditions. In the present study, the stimulus in the secondary task (acoustical signal of the navigation system) was always presented immediately before the stimulus of the primary task (person suddenly appearing on the scene). As the reaction in the primary task required participants to react as fast as possible with a turn of the steering wheel, the acoustical signal probably served as a cue for the appearance of the visual stimulus and thus, facilitated the reactions in the primary task, even though it was only predictable in 66 % of the trials (in 1/3 of the trials no visual stimulus followed).

The results obtained in the present project do not only have to be considered in research but also have practical consequences for the design of electronic driver assistant systems. Although further research is needed to validate the findings in different applied situations (e.g., with information given from a collision warning system), the present results already indicate that it should be taken into account that every additional information given to the driver not only demands the driver's attention in general (see chapter Age-related Changes of Neural Control Processes and their Significance for Driving Performance, Hahn et al.) but that there are also specific cross task effects. Moreover, the results indicate that age-related changes in information processing capacities can be compensated for by training. As it is not always possible for elderly people to avoid *complex* driving situations, older drivers should undergo driving course regularly, especially if their driving practice decreases.

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