Effects of age and contextualized material on working memory span performance

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Abstract The present research explores the effects of contextualized material on age-related working memory performance. Two experiments examining younger and older adults are reported. ANOVA results of the first experiment showed age effects in both a standard operation span and a contextual task of parallel structure (air travel task). The second experiment also revealed a significant age effect in a standard operation span task. However, there was no age difference in a contextual task providing additional visual context (rail travel task), mainly due to older adults being unaffected by task type manipulation and younger adults performing worse in the contextual than in the standard task. The present research suggests that contextual task material may not necessarily lead to improved working memory performance in older adults. Several methodological and conceptual conclusions for future research are discussed.

Keywords Working memory · Age effects · Context effects · Operation span

Introduction

Working memory has been defined as a central cognitive resource for simultaneously storing and processing information (Baddeley 1986). It represents a key cognitive function for all aspects of everyday cognitive functioning, because the concurrent storing and processing of information is necessary for most complex cognitive activities

in everyday life (Craik 2000; Harris and Qualls 2000; Salthouse and Babcock 1991; Zeintl et al. 2007). In numerous studies, complex span tasks (e.g., operation span, reading span, counting span) have been used to measure working memory performance (e.g., Dougherty and Hunter 2003; Jarrold and Towse 2006; Turley-Ames and Whitfield 2003; Zacks et al. 2000). Usually, such tasks are dual tasks with alternating presentations of a recall and a processing component (e.g., Conway et al. 2005). For instance, the operation span task (Turner and Engle 1989) requires solving simple math problems and, at the same time, memorizing additionally presented words. Working memory span tasks are characterized by high reliability and construct validity (Conway et al. 2005), and have been referred to as “gold standard” measures of working memory capacity (Cowan et al. 2005).

In the context of cognitive aging, working memory is primarily conceptualized as a general limited-capacity system that declines with advancing age (e.g., Park 2000). Older adults are considered to have specific difficulties with the simultaneous storing, manipulation, and integration of information (Craik 2000; Zacks and Hasher 1997). Correspondingly, comparisons of older and younger adults' performance in working memory span tasks usually show significant age-related differences, with older adults performing worse than younger adults. So far, age effects have been repeatedly confirmed in various complex span tests (e.g., Bopp and Verhaeghen 2005; Brébion 2003; Campbell and Charness 1990; Craik 2000; Zeintl and Kliegel 2007a, b).

While age-related differences in typical complex span tasks are well-established in the cognitive aging literature, previous research in other cognitive domains suggests that older adults can achieve comparable performance levels as their younger counterparts by means of compensation for

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declining cognitive ability through experience (e.g., Henry et al. 2004; Phillips et al. 2006; Willis 1996). For instance, in studies on speed of processing, Salthouse (1984) and Bosman (1993) demonstrated that, in spite of reduced psychomotor speed, old typists performed comparably to young adults because they used their experience to look further ahead in the text to be typed. Correspondingly, a recent experiment on planning ability showed that, while younger adults outperformed older adults in a planning task using artificial material, they performed comparably in a similarly structured planning task using real-world material (Kliegel et al. 2007). Such research suggests that the type of material used in cognitive tasks may substantially contribute to the observed age effects. To our knowledge, so far, the role of contextualized material has not been investigated with regard to age-related differences in working memory span tasks. Therefore, the aim of the present research was to explore possible differences between the age effects in a standard working memory span task and a task using contextualized material that was of parallel structure.

Experiment 1

In the first experiment, we used the operation span task (Turner and Engle 1989) as standard working memory span task. In order to approximate comparability with the standard task, a task of parallel structure using contextualized material was constructed. Thus, both working memory tasks were dual-tasks with words to be remembered and math problems to be solved. Therefore, both tasks yield analogous performance scores from the storage component and from the processing component, respectively. Based on previous research, we expected age-related differences in the standard operation span task. Moreover, we aimed to investigate if older adults may specifically benefit from the use of familiar material in a working memory span task.

Method

Sample and design

Thirty-two younger ($M = 26$ years; $SD = 5.32$; range: 20–42 years; 17 women) and 31 older ($M = 67$ years; $SD = 5.93$; range: 60–80 years; 14 women) adults took part in the first experiment. Older and younger adults were comparable in years of education, younger adults: $M = 14.16$, $SD = 3.31$; older adults: $M = 13.82$, $SD = 3.87$; $t(61) = 0.37$, $P > 0.05$. Moreover, older adults had even higher scores in verbal intelligence as measured by the MWT-B (Lehrl 1977), younger adults: $M = 108.05$, $SD = 15.36$; older adults: $M = 118.19$, $SD = 14.80$;

$t(61) = -2.55$, $p < 0.05$. A 2 (between-subjects factor age: younger vs. older adults) $\times$ 2 (within-subjects factor task material: standard vs. contextualized working memory task) mixed factorial design with randomized order of the within-subjects factor was applied. The study was conducted in Zurich, Switzerland.

Instruments and procedure

Younger and older adults performed two working memory span tasks: a standard version modeled after Turner and Engle's (1989) operation span task and a task of parallel structure using contextualized material. In the standard operation span task, each participant was presented with simple math problems (e.g., $[2 \times 16] - 2 = 30?$) one after the other on a computer screen. With each problem, a result was presented on the screen. Participants had to specify, if they considered the presented result correct or not by pressing a designated key for right or wrong on the computer keyboard. Immediately after pressing a key, the next problem appeared on the computer screen. Additionally, a noun (target word) was written next to each presented arithmetic problem and participants were supposed to read out and memorize the target word. If participants did not respond to a math problem within 20 s, the next problem was presented. After each item (i.e., sequence of successive problem-word elements), three question marks were shown on the computer screen. This indicated that the participants were supposed to recall the memorized target words in the same order as they had been presented.

The working memory task using *contextualized material* was embedded in an air travel setting. Participants were told to imagine that they were on a trip around the world visiting different cities (e.g., Miami, Hongkong, Sydney) and crossing various time zones on the way. To stay in contact with their relatives and friends at home (i.e., Zurich), for each city on their trip, they were supposed to calculate the current time in Zurich. Successively, participants were presented with displays, each containing the following information: the city of departure and the destination with corresponding take-off and landing times, the time difference between the destination and Zurich, and a suggested current time for Zurich. In the example given in Fig. 1, the traveller would leave Hongkong at 7 p.m. and arrive in Tokyo at 11 p.m. The time shift information indicating that Tokyo time is 7 h ahead Zurich time ("time shift [+7 h]") could be used to judge if it is 4 p.m. in Zurich when it is 11 p.m. in Tokyo. Parallel to the structure of the operation span task, participants had to decide if the announced current time for Zurich was correct or not by pressing a designated key on the keyboard and, concurrently, read out the city of destination and remember it for later recall. In the example, the answer would be yes,

Time shift [+ 7 hours]	
Hongkong	Tokio
7 pm	11 pm
Is it 4 pm in Zurich?	

Fig. 1 Example item of the air travel task used in Experiment 1

because $11 - 7 = 4$. If participants did not respond to a display within 20 s, the next display was presented. After each item (i.e., a sequence of successive displays), three question marks were shown on the computer screen indicating that participants had to name the destinations in the presented order.

In both working memory span tests, memory set size (i.e., number of elements in a sequence) varied from two to six and each set was presented twice within the standard and the contextualized material versions, respectively. The ten memory sets per version were displayed in random order which was identical for all participants. Each task version started with a practice part and it was ensured that participants had understood the task before starting the main part. Between the two working memory task versions, participants performed the verbal intelligence test (MWT-B; Lehl 1977).

Results and discussion

Following the scoring procedure of earlier studies (e.g., Zeintl et al. 2007), working memory performance in both working memory span tasks was assessed via all-or-nothing unit scoring (e.g., Conway et al. 2005). Thus, the working memory span scores indicate the mean number of items that were recalled completely and in correct order regardless of memory set size.

The correlation between individual differences in the operation span task and the air travel task was high ($r = 0.80$, $p < 0.001$). We performed a 2 (age) $\times$ 2 (task material) analysis of variance (ANOVA) to analyze mean level effects of age-related working memory performance in the standard tasks versus the air travel task. The results showed a significant overall age effect for working memory span performance, $F(1,61) = 18.30$, $p < 0.001$, partial $\eta^2 = 0.23$, indicating that, generally, younger adults performed better than older adults in the working memory span tests (see Fig. 2 for descriptive data). Additionally, there was a general effect for task material, $F(1,61) = 31.78$, $p < 0.001$, partial $\eta^2 = 0.34$, which showed that, overall, participants performed significantly better in the standard version than in the version with contextualized

Fig. 2 Mean performance scores of younger and older adults in the working memory span task versions in Experiment 1. Working memory span performance scores are the mean number of items that were recalled completely and in correct order. Error bars indicate standard errors

material. There was no significant interaction. Moreover, we re-analyzed the present data using additional scoring procedures: partial-credit scoring, i.e., the mean proportion of correctly recalled words within a set size (Conway et al. 2005), and the sum of correctly recalled words without considering order information, yielded comparable results as already reported for all-or-nothing scoring, which further strengthens the present findings.

In terms of conclusions, the present results clearly revealed better performance of younger adults compared to older adults in both the standard and the meaningful material working memory span versions. Thus, data support previous evidence of age effects in working memory span task performance (e.g., Bopp and Verhaeghen 2005; Craik 2000; Zeintl and Kliegel 2007a, b). In contrast, however, findings are not in line with previous studies demonstrating beneficial effects of contextualized material on other complex cognitive tasks such as planning (e.g., Kliegel et al. 2007).

In order to further qualify the present results, we performed a 2 (age) $\times$ 2 (task type) analysis of variance (ANOVA) on the processing component data. Results showed a significant effect of age on processing component accuracy scores, $F(1,61) = 8.10$, $p < 0.01$, partial $\eta^2 = 0.12$, indicating that, overall, younger adults performed more accurately than older adults. Moreover, there was a significant interaction of both factors, $F(1,61) = 10.45$, $p < 0.01$, partial $\eta^2 = 0.15$, suggesting differential age effects for both task types. Indeed, post hoc analyses revealed that, while there was no significant age difference in accuracy scores in the standard operation span task, younger adults: $M = 92.50$, $SD = 4.75$; older adults: $M = 92.10$, $SD = 7.33$; $t(61) = 0.26$, older adults had significantly lower accuracy scores than younger adults in

the processing component of the air travel task, younger adults: $M = 84.14$, $SD = 10.01$; older adults: $M = 74.60$, $SD = 11.96$; $t(61) = 3.44$, $p < 0.01$. Thus, in the standard operation span task, the age effect in working memory performance cannot be explained in terms of the processing component being more difficult for older than for younger adults. However, the post hoc analyses indicate that at least in the contextualized task version, the age effect on working memory performance may be partly due to older adults having more problems in calculating time-shift problems.

Interestingly, besides the overall age effect in working memory span performance there was also a main effect of task type: inconsistent with our initial expectations, both younger and older participants performed worse in the contextualized task than in the standard task. The ANOVA results of the processing component data suggest that the standard and the contextualized working memory span tasks may have been different in task difficulty, since results showed a significant effect of task type, $F(1,61) = 83.60$, $p < 0.001$, partial $\eta^2 = 0.58$, indicating that, overall, participants were significantly less accurate on the processing task of the air travel task than of the operation span task (operation span task: $M = 92.30$, $SD = 6.11$; air travel task: $M = 79.44$, $SD = 11.93$). This suggests that at least the processing component of the air travel task, i.e., time-shift calculations, may have been more demanding than solving simple math problems although it contained only one addition or subtraction operation (e.g., $11 - 7 = 4$) in contrast to two operations (one division or multiplication operation and one addition or subtraction operation; e.g., $[2 \times 16] - 2 = 30$) in the standard operation span task; which appears to argue against a straightforward operation difficulty effect. In addition to the operation requirements, the names of the to-be-remembered cities from all over the world may have not been known to all participants, which may have complicated the performance on the storing component. In contrast, the operation span task only used common nouns that should be familiar to all participants. These task differences may have played a critical part in the general worse performance of participants in the contextualized task as compared to the standard working memory span task. Experiment 2 was conducted to address these issues.

Experiment 2

In a second experiment, we aimed at constructing a contextualized material task that would achieve processing and storing components of more comparable difficulty. Again, we used a standard operation span task and a travel task of parallel structure. However, this time, the real-world

context of the travel task was a rail travel around Switzerland. Thus, the to-be-memorized names were those of Swiss cities which should be rather familiar to the Swiss participants. Moreover, the memory task was visually supported providing a map of Switzerland with the rail trip being successively plotted on the map. The processing task consisted of calculating how long it would take to travel by train from one city to the next; a general operation that should be more familiar to participants than solving time-shift problems. By reducing the difficulty levels of the processing and storing components of the contextual working memory task, we aimed to further explore the specific effect of contextualized task material on age-related working memory performance.

Methods

Sample and design

Twenty-six younger ($M = 29$ years, $SD = 3.98$, range: 23–35 years, 17 women) and 25 older ($M = 64$ years, $SD = 4.86$, range: 59–79 years, 11 women) adults took part in the second experiment. Older and younger adults were comparable in years of school education, younger adults: $M = 14.29$, $SD = 2.62$; older adults: $M = 14.90$, $SD = 3.91$; $t(48) = -0.65$, $P > 0.05$, and in verbal intelligence as measured by the MWT-B (Lehrl 1977), younger adults: $M = 112.35$, $SD = 14.04$; older adults: $M = 118.40$, $SD = 13.69$; $t(49) = -1.56$, $P > 0.05$. A 2 (between-subjects factor age: younger vs. older adults) $\times$ 2 (within-subjects factor task material: standard vs. contextualized working memory task) mixed factorial design with randomized order of the within-subjects factor was used. Again, the study was conducted in Zurich, Switzerland.

Instruments and procedure

In the second experiment, younger and older adults also performed two working memory span task versions: the standard version was identical to the operation span task used in the first experiment. The contextualized material task version was embedded in a rail travel setting—a common way of travelling in Switzerland. Participants were told to imagine being on a rail trip around Switzerland visiting common Swiss cities (e.g., Basel, Geneva, Lucerne). Successively, participants were presented with displays each containing the following information: the city of departure and the destination, the corresponding departure and arrival times, and a suggestion for the time it would take to get from the departure city to the destination. Additionally, each display also contained a map of Switzerland, indicating the course of the rail travel. Analogous to the structure of the operation span task, participants had

to decide if the given durations for each trip were correct or not by pressing a designated key on the keyboard and, concurrently, read out the city of departure and remember it for later recall. In the example given in Fig. 3, the traveller would depart at 9.45 a.m. in Basel and arrive at 10.35 a.m. in Solothurn. The given departure and arrival times could be used to judge if the trip would actually take 45 min. In the example, the answer would be no, because from 9.45 to 10.35 = 50 min. Again, time for recall was indicated by three question marks displayed on the computer screen.

As in the first experiment, for both working memory tasks, memory set size varied from two to six and each set was presented twice within the standard and the rail travel versions, respectively. The ten memory sets per version were displayed in random order which was identical for all participants. At the beginning of each task, participants performed a practice part and it was made sure that participants understood the task before starting the test. Between the two working memory task versions, participants were given the verbal intelligence test (MWT-B; Lehrl 1977).

Results and discussion

The correlation between individual differences in the standard operation span task and the rail travel task was of medium size ($r = 0.37$, $p < 0.01$). We performed a 2 (age) $\times$ 2 (task material) analysis of variance (ANOVA) to analyze mean level effects of age-related working memory performance in the standard tasks versus the rail travel task. The results showed a significant overall age effect for working memory span performance, $F(1,49) = 5.44$, $p < 0.05$, partial $\eta^2 = 0.10$, indicating that, generally,

younger adults performed better than older adults in the working memory span tests (see Fig. 4 for descriptive data). Additionally, there was a general effect for task material of the working memory span task versions, $F(1,49) = 12.50$, $p < 0.01$, partial $\eta^2 = 0.20$, showing that, overall, participants performed significantly better in the standard version than in the rail travel version.

Furthermore, the results revealed a significant interaction of both factors (age $\times$ task material), $F(1,49) = 6.77$, $p < 0.05$, partial $\eta^2 = 0.12$, suggesting a differential pattern of age effects in the two working memory task versions. Post-hoc analyses revealed a significant age effect for the standard operation span task, $t(49) = 3.33$, $p < 0.01$, partial $\eta^2 = 0.18$. However, older adults performed as well as younger adults in the rail travel task, $t(49) = 0.49$, $p > 0.05$. Additionally, younger adults had significantly higher scores in the standard than in the rail travel task, $t(25) = -4.10$, $p < 0.001$, partial $\eta^2 = 0.40$, while older adults performed comparably in both task versions, $t(24) = -0.71$, $p > 0.05$. Again, we re-analyzed the data using additional scoring procedures: partial-credit scoring (Conway et al. 2005) and the sum of correctly recalled words without order information showed similar results as presented for all-or-nothing scoring.

Next, the age and task type effects on accuracy levels for the processing component were analysed. Results of the 2 (age) $\times$ 2 (task type) ANOVA on the processing component data revealed a significant effect of task type on processing component accuracy scores, $F(1,48) = 23.55$, $p < 0.001$, partial $\eta^2 = 0.33$, indicating that, overall, participants performed more accurately in the processing task of the operation span task than of the rail travel task. There was no significant effect of age and no significant interaction.

Fig. 3 Example item of the rail travel task used in Experiment 2

Fig. 4 Mean performance scores of younger and older adults in the working memory span task versions in Experiment 2. Working memory span performance scores are the mean number of items that were recalled completely and in correct order. Error bars indicate standard errors

Thus, as in Experiment 1, analyses indicate that younger adults showed significantly higher working memory performance in both task types than older adults. Importantly, this time, the ANOVA results on the processing component data revealed no significant age effects indicating that the accuracy levels of both tasks were comparable for older and younger adults (*operation span task* younger adults: $M = 92.79$, $SD = 5.84$; older adults: $M = 91.56$, $SD = 7.62$; *rail travel task* younger adults: $M = 87.60$, $SD = 8.35$; older adults: $M = 85.52$, $SD = 8.60$). This suggests that potential age effects in working memory performance could not be explained by processing components being differently difficult for younger and older adults.

Moreover, with regard to the task material manipulation, there was a similar pattern as in the first experiment. In general, span performance was better in the standard working memory task than in the contextualized material task. As the ANOVA results on the processing component data indicate, this may be due to differential difficulty levels of the processing components, since overall participants were less accurate on the trip duration calculations than on the math problems (*operation span task*: $M = 92.20$, $SD = 6.71$; *rail travel task*: $M = 86.60$, $SD = 8.45$); although, again, they had to perform less mathematical operations in the contextual task version.

However, the significant interaction on working memory span performance suggests an important differential effect; while older adults were unaffected by our task manipulations, younger adults showed significantly worse performance in the rail travel compared to the standard task. Thus, even though the processing component in the contextual task may have been more difficult than in the standard task for both younger and older adults, only older adults maintained comparable levels of span performance in both the rail travel and the operation span task. In contrast, the younger adults may have been affected by the real-world context in the rail travel task, resulting in worse span performance compared to the standard operation span task. The following general discussion will consider possible explanations for this pattern.

General discussion

The present research is the first study to investigate if age effects in working memory span tasks may be reduced by the use of contextualized task material. The results of both studies confirm previously found age effects in standard operation span tasks (Turner and Engle 1989), with older adults performing worse than younger adults. Importantly, these age effects in operation span cannot be explained by older adults' selective difficulty with the processing component of the tasks, since performance levels in the

processing components were equal for both age groups in the traditional operation span versions.

With respect to the contextualized working memory tasks, results are less straightforward. While we expected a reduced age effect in the air travel task of the first experiment, older adults still showed significantly worse performance than younger adults. However, the air travel task may have been more difficult for older adults in general, since in contrast to the standard operation span task, older adults performed significantly worse in the processing component of the task.

Therefore, in the second experiment, we aimed at achieving comparable difficulty levels for younger and older adults in the processing component of the rail travel task and, indeed, accuracy levels of the processing component were similar for both age groups. Importantly, there was no age difference in the contextualized working memory task of the second experiment. Note, however, that in comparison to performance levels in the standard task, the “removed” age effect in the rail travel task resulted mainly from older adults showing equal performance independently from task material manipulations while younger adults performed significantly worse in the rail travel task than in the standard task. This result is surprising since the general expectation for studies examining the role of contextualized materials in age-related cognitive performance has been an improved performance of older adults in the contextualized condition based on the assumption that older adults may be able to compensate for declining cognitive ability via task-related experience (e.g., Kliegel et al. 2007, 2008; Salthouse 1984).

Being the first experiment to explore the role of contextualized material in a working memory span task, the present research has several important conceptual and methodological implications: first, the use of contextualized material in cognitive tasks per se may not always lead to improved performance in older adults. Hence, the results from previous research on different cognitive domains (e.g., planning ability; Phillips et al. 2006) may not directly transfer to working memory span tasks. This dovetails with evidence of age-related differences in other tasks using real-world material indicating that older adults may not always profit from contextualized material (Czaja et al. 2001; Morrow et al. 2001; Thornton and Dumke 2005). Moreover, in a study comparing younger and older adults in ecologically valid tasks of daily living performed in the participants' homes showed that older adults performed worse than younger adults in both unfamiliar, meaningless and familiar, practiced tasks (Dickerson and Fisher 1997). Thus, further research is needed to clarify the role of contextualized material in age-related working memory performance.

Second, while reduced age effects in cognitive tasks with contextualized material are generally explained by older adults using experience-related compensation strategies (e.g., Kliegel et al. 2007), results from the second experiment show that a reduced age effect may not always result from improved performance of older adults in the contextualized condition but also from diminished performance in the young adult group. Thus, from the present research, an important twofold question emerges, which has to be addressed in future work following up on the present results: why do younger adults perform worse in the contextualized than in the standard working memory task and why do older adults perform equally well in both task versions?

Several explanations may apply to the posed question. One explanation for the present results may be related to proactive interference effects.¹ Since all of the to-be-remembered words in the contextualized tasks were from one category (i.e., city names), proactive interference effects may have been more pronounced in the contextual task compared to the standard operation span task, in which unrelated words had to be memorized. Previous research has shown that the proactive interference plays an important role in (age-related) working memory span performance (e.g., Bowles and Salthouse 2003; Bunting 2006; Lustig et al. 2001; May et al. 1999; Zeintl and Kliegel 2007). This may well explain, why overall performance of younger and older adults was worse in the contextual compared to the standard working memory span task. Additionally, as suggested by the results of Experiment 2, older adults may have already suffered more from proactive interference in the standard operation span task than younger adults, so that the increase of proactive interference in the contextualized version did not lead to any further drop in the performance. In fact, the older adults showed equal levels of performance in both the standard and contextual conditions. In contrast, the younger adults seemed to manage the impact of proactive interference from unrelated words in the standard operation span task; however, they were affected by the increased proactive interference in the contextualized version leading to a marked decrease in performance. Indeed, younger adults showed better performance than older adults in the standard condition, while younger adults' performance dropped to the level of older adults in the contextual condition. Thus, instead of improving performance via context information, the present contextualized versions may have actually diminished performance due to larger proactive interference effects. This indicates that, if potential proactive interference problems are considered, future

research may still reveal beneficial effects of context information on older adults' working memory performance.

Another explanation may be that the contextual and operation span tasks also differed, in that, two words were presented in each display of the contextual tasks and only one word in the operation span task. However, there are other working memory span tasks like the reading span task (reading a sentence and remembering the last word of the sentence) in which even more (potentially distracting) words are presented that have to be processed (Conway et al. 2005). Importantly, those tasks have yielded similar results in terms of age effects as tasks such as the operation span task in which the items to be remembered are distinct single words (e.g., Schelstraete and Hupet 2002; Waters and Caplan 2001). Therefore, we assume that the additionally presented non-relevant words in the contextual tasks should not have contributed considerably to worse performance in the task. Rather we argue that proactive interference may have played a more pronounced role in performance in the contextual tasks.

Again, another explanation may relate to motivational aspects. While older adults may have been rather motivated by the real-world character of the contextualized task, younger adults may have been highly motivated to perform well in the seemingly more difficult "maths and memory" task and may have concentrated less on the rather "easy" everyday task. Similarly, in research on prospective memory showing that older adults often outperform younger adults in naturalistic tasks (e.g., Henry et al. 2004), some authors suggest that older adults may be highly motivated in naturalistic tasks and may take them more seriously than younger adults (e.g., Maylor 2008).

Moreover, older adults may have differentially profited from the contextualized information and/or the visual support of the storage component (i.e., map of Switzerland). This explanation is supported by the fact that compared to the standard task the processing component of the contextualized task was apparently more difficult for both younger and older adults. However, only older adults may have been able to use the contextual information in order to maintain performance levels. Still, as a limitation to the present research, the role of the visual aid in the rail travel task is difficult to interpret and it remains unclear if and how older and younger adults may have made use of it. Future research will have to further explore the role of visual aids for younger and older adults in memory performance.

A further possible limitation to the present research refers to the comparability of the standard and contextual working memory tasks. While in the standard operation span task, the to-be-remembered words of the storage component were not related to the math problems of the

¹ We thank an anonymous reviewer for suggesting the potential contribution of proactive interference effects to the present results.

processing component, in the contextual tasks, the storage (geographical locations) and processing components, (time zone or travel time calculations) are not entirely independent from each other. However, the formation of a meaningful relation between processing and storage components is one critical aspect of creating a naturalistic context in a working memory span task. Importantly, as shown by previous research, even in common working memory span tasks like the reading span task, in which the processing and storage components are clearly and even more strongly related (i.e., reading a sentence and remembering the last word of the sentence), older adults perform significantly worse than younger adults (e.g., Schelstraete and Hupet 2002; Waters and Caplan 2001). Thus, the introduction of context in separate working memory span elements does not seem to be sufficient to improve older adults' performance. Therefore, we aimed at generating a coherent and thus common context that applied to all presented operation-word displays (i.e., a travel around the world, a travel through Switzerland). Still, as noted above, this approach arguably bears the risk of increasing proactive interference within the contextual task. Further research is clearly needed to investigate how older adults could be supported via context information and avoid generating pronounced proactive interference effects.

Moreover, in the present contextual tasks, it was not possible to construct a cover story that would have explained the integration of a second mathematical operation in the processing tasks. Even if our results suggest that the difference in processing tasks (two mathematical operations in the standard tasks versus one mathematical operation in the contextual tasks) may not have affected the results, due to task comparability, future research should attempt to construct a contextual version of the operation span task that contains an equally structured processing component.

A fundamental assumption in the cognitive aging literature is that basic storage processes are relatively unaffected by aging, whereas tasks requiring online processing show larger age-sensitivity (e.g., Babcock and Salthouse 1990; Bopp and Verhaeghen 2005). Typical working memory span tasks are characterized by a combination of both a storage and a processing component. Therefore, it can be suggested that the age effects in working memory span tasks may primarily be caused by age-related differences in the processing component of the task. While age differences in the processing component of the air travel task in Experiment 1 may have been responsible for the age effect in span performance, analyses of the processing components of the operation span task in both experiments as well as the processing component of the rail travel task in Experiment 2 revealed that older and younger adults showed equal performance. This suggests that the age

effects in span performance in these tasks cannot be explained by age-related differences in processing task performance. Thus, we argue that the combination of processing and storage components, i.e., the dual-task-component of working memory span tasks may crucially contribute to age differences in working memory span performance.

Moreover, future studies may specifically consider the challenge of creating comparable difficulty levels for both the processing and storage components of both standard and contextual tasks. This will allow deepening of our initial understanding of contextualized material effects on task performance. Specifically, in future research, older and younger adults should be asked about their strategies and motivation when being confronted with different task versions. The reasoning behind the prediction of possible strategic differences comes from additional analyses on reaction time data of the processing components of both tasks as suggested by an anonymous reviewer. Results of the 2 (age) $\times$ 2 (task type) ANOVAs were comparable for both experiments and showed that, overall, participants were slower to respond in the contextual than in the standard tasks and that, generally, older adults showed higher reaction times than younger adults. Results were comparable when analyses were restricted to reaction times on correctly solved items only. While the age effect in mean reaction time data is a very common finding in cognitive aging research, the effect of longer reaction times in the contextual task than in the operation span task could indeed point to a strategy difference in solving the tasks. On the other hand, longer reaction times in the contextual task could also indicate that participants spent more time to memorize the target words. However, since there was no improvement in recall performance in the contextual tasks compared to the operation span tasks, seems unlikely. In conclusion, future work will have to directly address this issue. Additionally, manipulations of motivation to work on the respective tasks could further enhance our understanding of how motivational aspects may contribute to contextual material effects in age-related working memory performance. Finally, while in the present study compensatory effects in older adults may have resulted from contextualized information in general and/or visual support of the storing component, in particular, future research may disentangle the different routes that may result in specific benefits for older adults and find ways to examine, whether stable performance of older adults in standard and contextualized tasks may actually reflect compensatory processes. While the present research represents a first step into exploring the influence of contextualized material on working memory span task performance in younger and older adults, further systematic research is needed to increase our knowledge in this regard.

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