The role of inhibitory control in age-related operation span performance

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Published online: 11 October 2007
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Abstract The present study was conducted to examine the inhibitory deficit theory on cognitive performance in old age. An experimental manipulation was applied to investigate if the efficiency of inhibitory control directly affects age-related working memory performance as measured by the operation span task. Forty-two older ($M = 67$ years, $SD = 5.12$) and 42 younger adults ($M = 25$ years, $SD = 4.06$) performed two versions of the operation span task that differed in the inhibitory demands placed on working memory. Age effects were confirmed for both versions of the operation span task. Importantly, the age effect was qualified by an age $\times$ inhibitory demands interaction indicating that age differences in the high inhibitory-demands condition were even larger than in the standard condition. In conclusion, this supports the assumption that inhibitory deficits contribute to age-related working memory performance.

Keywords Working memory · Age effects · Inhibitory control · Operation span

Introduction

Working memory is a cognitive function that serves for the simultaneous storing and processing of information and plays a significant role in most tasks measuring complex cognition (Daneman and Merikle 1996; Phillips and Hamilton 2001). Thus, it has been argued that working memory represents an important cognitive resource for

independent living and the mastering of everyday life, as it is required in most complex cognitive activities one has to perform in everyday situations (Craik 2000; Harris and Qualls 2000).

Despite its importance for everyday life, there is growing evidence that working memory span considerably declines with advancing age. Correspondingly, age effects in different working memory span tests have been repeatedly confirmed in the cognitive aging literature (Bopp and Verhaeghen 2005; Dobbs and Rule 1989; Reuter-Lorenz et al. 2001). However, so far, the basic mechanism responsible for cognitive aging in complex functions like working memory is still under debate (Park 2000; Zacks et al. 2000).

In this context, Hasher and Zacks (1988) presented a prominent hypothesis with regard to the possible cause of age-related decline in cognitive functioning, especially in working memory performance. According to their view, the observed age effects in working memory performance can be explained by older adults' poorer inhibitory control over the contents of working memory. Specifically, inhibitory control is defined as a mechanism of attentional selection, which comprises three aspects: an access function, a deletion function, and a restraint function. While the access function prevents irrelevant information from entering the working memory system, the deletion function supports the updating of momentarily important information by suppressing the activation of no longer relevant information. Finally, the restraint function aims at suppressing strong, but irrelevant, information in order to enable the activation of weaker, but potentially more important, information. Acting in concert, the three functions ensure a proper functioning of working memory. Within the inhibitory deficit view, it is assumed that the ability of inhibitory control declines with advancing age

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and that, therefore, older adults' working memory tends to be preoccupied by task-irrelevant information, which makes the access and retrieval of task-relevant information more difficult (Stoltzfus et al. 1996; Zacks and Hasher 1997). The inhibitory deficit view has been supported by several studies, e.g., applying paradigms such as negative priming (Hasher et al. 1991), flanker tasks (Shaw 1991), or reading tasks (Connelly et al. 1991). However, the role of inhibitory control in cognitive aging is still under debate, as there are also studies demonstrating little or no effect of inhibitory processes on age-related cognitive performance (McDowd 1997).

While other mechanisms of working memory functioning are currently discussed (e.g., selection mechanisms and rehearsal control mechanisms; Botvinick et al. 2001; Mueller et al. 2003), the inhibitory deficit view directly relates to working memory functioning in older adults. Thus, it has been argued that it is essential to examine the role of inhibitory control in age-related working memory performance (May et al. 1999). One possibility to address this question is to vary the inhibitory demand within typical working memory tasks. Several studies found evidence of age-related susceptibility to proactive interference, i.e., interference from previously presented information, within different types of working memory span tasks (Bowles and Salthouse 2003; Bunting 2006; Chiappe et al. 2000; Lustig et al. 2001). For instance, such studies varied the presentation order of the different span lengths (ascending vs. descending), included breaks between span task administrations, or varied the type of to-be-remembered stimuli across trials. Consequently, these studies mostly examine the deletion function of inhibitory control as they focus on the build-up of proactive interference within a task. In order to expand our understanding of the role of inhibitory control in age-related working memory performance, we aimed at examining the access function of inhibitory control in the context of a typical working memory test.

One way of experimentally increasing inhibitory demands are flanker tasks: Previous research on flanker tasks involving semantic categorization has shown that older adults appear to be more distracted than younger adults by irrelevant information that is visually displayed close to the relevant information (Shaw 1991). Such results have been explained by an impaired inhibitory control in older adults (McDowd et al. 1995). Across the entire lifespan, working memory performance is often measured by working memory span tasks assessing the capacity of a person to closely follow and store recently presented information while simultaneously processing current information (Conway et al. 2005; Jarrold and Towse 2006; Turley-Ames and Whitfield 2003). A frequently used measure of working memory span is the operation span task (Turner and Engle 1989), which requires solving

simple math problems and concurrently memorizing additionally presented words (e.g. Conway and Engle 1996). So far, this approach to examining inhibitory deficits in the access function in old age has not been applied in a working memory span test.

Therefore, the aim of the present study was to vary the inhibitory demands on the access function within the operation span task by using the following two versions of the task: a standard version representing a typical operation span task (Turner and Engle 1989) and a distractor version in which additional stimuli were presented (next to the relevant stimulus), which had to be ignored and to be prevented from entering the working memory store. We chose the operation span task, because it represents a very frequently used psychometric test of working memory performance in normal and clinical samples (Dougherty and Hunter 2003; Kliegel et al. 2005; Miyake et al. 2000) and allows to restrict the verbal interference to the storage component. Because the processing component does not contain any verbal information, it does not contribute to any build-up of proactive interference (i.e., demand on the deletion function). Since we focus on the access function of inhibitory control, we aimed at restricting to a minimum the build-up of proactive interference (May et al. 1999). Furthermore, we used a fixed randomized format for the presentation of span lengths in order to avoid effects of presentation order (Chiappe et al. 2000). Therefore, we conclude that the distractor manipulation applied largely involves the access function of inhibitory control.

According to the inhibitory deficit view, we hypothesized that (1) an overall age effect in operation span performance should be confirmed in the operation span task. Furthermore, due to the additional inhibitory demands in the distractor version we expected (2) an interaction of age and inhibition on operation span performance with the age effect in the distractor version being larger than in the standard version.

Methods

Sample and design

The sample consisted of 42 younger ($M = 25$ years, $SD = 4.06$; range 19–34 years; 26 women) and 42 older ($M = 67$ years, $SD = 5.12$; range 60–80 years; 25 women) adults. Comparing both age groups on verbal intelligence, older adults achieved even higher results in the MWT-B (Lehrl 1977) than younger adults, $t(82) = -6.01$, $P < 0.001$, Partial $\eta^2 = 0.31$ (see Table 1). A 2 (between-subjects factor *age*: young vs. old adults) $\times$ 2 (within-subjects factor *inhibitory demands*: standard vs. distractor

Table 1 Descriptive information on younger and older adults

Demographic variables	Younger adults		Older adults	
	<i>M</i>	<i>SD</i>	<i>M</i>	<i>SD</i>
School education (in years)	13.0	0.0	10.9	1.7
Verbal intelligence (MWT-B)	113.4	9.9	128.3	12.6

The 42 younger participants consisted of 26 women and 16 men, the 42 older participants comprised 25 women and 17 men

version) mixed factorial design with randomized counter-balanced order was applied.

Instruments and procedure

Operation span task—standard version

Participants' performance in a standard version of the operation span task was assessed. In this standard task according to Turner and Engle (1989), participants were successively presented with simple math problems on a computer screen. A result was displayed for each problem. Additionally, a noun was written next to each presented arithmetic problem. Examples of two typical task items are “3 + 7 = 10? House” and “8 – 3 = 4? Apple”. Participants had to decide, if they considered the presented result correct or not by pressing a designated key for right or wrong on the computer keyboard. Immediately after a participant's response, the next stimulus was presented. Additionally, participants were supposed to read out the word that was written next to each math problem and to memorize it. After several problem-word strings, they were asked to name the memorized words in the same order as they had been presented. With regard to the two example tasks given above (“3 + 7 = 10? House” and “8 – 3 = 4? Apple”) the correct answer after working on both problems would be “House, Apple”. The number of successive problem-word strings in a sequence varied from two to six. Working memory span performance resulted from the number of sequences (out of five) a participant was able to reproduce completely and in correct order (see also Conway et al. 2005).

Operation span task—distractor version

This version required increased inhibitory control as it contained additional distracting words. The nouns to be memorized were each framed by two additional nouns that were written above and below each relevant word. The additional nouns were from the same semantic category as the target noun. For instance, the word “autumn” was

enclosed by the words “spring” and “winter”. Note that, in order to achieve physical comparability, in the standard version, the space above and below a noun consisted of *X*-rows. Except for the additional distracting words, which were not to be read out aloud by participants, the distractor version had exactly the same structure as the standard version.

Results

A 2 (age) × 2 (inhibitory demands) analysis of variance (ANOVA) was performed. The results show a significant overall age effect for participants' operation span performance ($F(1, 82) = 35.58$, $P < 0.001$; Partial $\eta^2 = 0.30$) indicating that, overall, younger adults performed better than older adults in the operation span test (see Table 2). Furthermore, there was no general effect of inhibitory demands ($F < 1$). However, we found a significant interaction of both factors (inhibitory demands × age) ($F(1, 82) = 5.18$, $P < 0.05$; Partial $\eta^2 = 0.06$).

Planned comparisons showed that younger adults performed significantly better than older adults in the standard version ($t(82) = 4.33$, $P < 0.05$; Partial $\eta^2 = 0.19$) as well as in the distractor version ($t(82) = 6.25$, $P < 0.05$; Partial $\eta^2 = 0.32$). Comparing effect sizes, the age effect was 1.68 times larger in the distractor version. Moreover, older adults showed a significantly worse performance in the distractor condition than in the standard condition ($t(41) = 2.10$, $P < 0.05$; Partial $\eta^2 = 0.10$), while younger adults' performance was almost the same in both conditions ($t(41) = -1.10$, n.s.).

As older and younger adults significantly differed in verbal intelligence, we further performed a 2 (age) × 2 (inhibitory demands) analysis of covariance (ANCOVA) with verbal intelligence scores as covariate.¹

The general result pattern did not change: we found a significant overall age effect for participants' operation span performance ($F(1, 81) = 29.37$, $P < 0.001$; Partial $\eta^2 = 0.27$) and a significant interaction of inhibitory demands × age ($F(1, 81) = 7.97$, $P < 0.01$; Partial $\eta^2 = 0.09$). Further, there were no general effects of inhibitory demands or verbal intelligence ($F < 1$) and no significant interaction effect of inhibitory demands × verbal intelligence.

In order to further explore the role of inhibitory control in the standard version of the operation span task, we additionally performed post-hoc analyses, in which we compared only the high-performing older adults of our sample with the young adults. High-performing older

¹ Due to a violation of homogeneity of regression, the variable years of education could not be used as covariate.

Table 2 Mean performance of younger and older adults in the operation span task versions

Operation span version	Younger adults		Older adults	
	<i>M</i>	<i>SD</i>	<i>M</i>	<i>SD</i>
Standard version	3.10	1.01	2.07	1.16
Distractor version	3.26	1.08	1.74	1.15

Operation span performance was assessed by the number of sequences (out of five) a participant was able to reproduce completely and in correct order

adults ($n = 18$) reached an operation span score that lay above the lower limit of one standard deviation of young adults (>2). Analysis of variance showed a significant general effect of inhibitory demands, $F(1, 58) = 7.39$, $P < 0.01$; Partial $\eta^2 = 0.11$, and a significant interaction of age $\times$ inhibitory demands, $F(1, 58) = 15.78$, $P < 0.001$; Partial $\eta^2 = 0.21$. The general age effect was not significant ($F < 1$). Single post-hoc analyses showed no significant difference between younger and high-performing older adults in the standard version of the operation span task, $t(58) = -0.69$, n.s.; however, younger adults performed significantly better than older adults in the distractor version of the operation span task, $t(58) = 3.09$, $P < 0.01$; Partial $\eta^2 = 0.14$.

Discussion

The results are in line with studies revealing adult age differences in operation span performance (Bopp and Verhaeghen 2005). In addition and more importantly, the results point to a differential age pattern with regard to the effect of inhibitory demands on operation span performance. Younger adults' performance was basically the same in both the standard and the distractor version, whereas older adults showed an even worse performance in the distractor condition than in the standard condition. Evidently, the increased inhibitory demands of the task could not be equally well met by older adults and led to an additional deterioration in operation span performance. In contrast, younger adults had no problems in mastering the distractor version. Thus, the results confirm our predictions that had been derived from the inhibitory deficit view (Hasher and Zacks 1988). To our knowledge, this is the first study that directly examines the influence of inhibitory access control on age effects in a working memory span task. Therefore, the present results are of particular theoretical relevance as they are consistent with the inhibitory deficit view and its predictions concerning age-related working memory functioning.

There are some limitations to the present study which future research will have to address. First, using a flanker

task, this study demonstrated that increasing inhibitory demands disproportionally affects older adults' working memory span. With regard to the underlying cognitive processes, this seems to mainly reflect an effect of the access function of inhibitory control as participants were supposed to hinder distracting words from entering the working memory store. However, one could argue that a weak access function might lead to a higher amount of irrelevant information within the working memory store. This, in turn, could result in higher demands on the deletion function of inhibitory control as there would be more (irrelevant) information to be deleted. Therefore, in the present study, it is not possible to clearly differentiate the relative contributions of the access and the deletion function. Still, we argue for a major involvement of the access function as the manipulation took place in the encoding phase of the working memory task and participants were explicitly instructed to ignore, i.e., not to read, the distracting words in order to prevent an automatic entering into the working memory store.

Second, in the present study, the distractor words came from the same semantic category as the relevant target word. Thus, research will have to investigate if the associativity between the to-be-ignored distractor words and the target word facilitated or further complicated operation span performance in the distractor version, or if it did not have an effect at all. So far, there is some first indication that the associativity between target and distractor words might not have a specific influence on age-related working memory performance (Zeintl and Kliegel 2007). However, further research is needed that exclusively addresses this question.

Third, the present results do not allow firm conclusions about the relevance of inhibitory control in the standard administration of the operation span task, as we already found a significant age effect in the standard condition. Our additional post hoc analyses comparing only high-performing old adults with young adults show that, while young and high-performing old adults do not differ in the standard operation span task, they significantly differ in the distractor version of the task. Thus, the post hoc analyses strengthen the conclusion that deficits in inhibitory control may play a part in working memory performance of older adults. Still, further research is needed that a priori addresses this question. Future studies will have to investigate if other paradigms, e.g., using recognition techniques or using arbitrary order recall (Rowe et al. 2006), might be successful in eliminating the age effect in the standard operation span version.

Finally, while we could exclude a confounding effect of verbal intelligence as demonstrated by our ANCOVA results, we are not able to rule out a potential confounding effect of years of education. Due to non-existent variance

of education scores in the young age group, we were not able to include this variable into our additional analysis of covariance. Therefore, it is important that future studies addressing this issue should better match for education level in the age groups.

In sum, the present results suggest that inhibitory control plays an important role in age-related operation span performance, and, therefore, might at least partly be responsible for the observed age effects in different working memory span tests.

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