Is there a decline in verbal working memory over age?

A study with the new standard computerized reading span test

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Abstract
In this study, the new standard computerized version of the reading span test was used to investigate the development of verbal working memory over age. A significant higher reading span and faster reaction times were expected for the young adults compared to the old adults, based on the processing resource theory (Just & Carpenter, 1992) and the theory of cognitive aging (Salthouse, 1994, 1996), and this hypothesis was confirmed. The new methodology made it possible to test whether there was an age-related increase in intrusion errors, which could be expected based on the inhibition theory of cognitive aging (Hasher & Zacks, 1988). The results showed that older adults made more intrusion errors than young adults thereby confirming the inhibition theory. Finally, the analysis of the memory-pattern showed a clear recency-effect for the young-, but not for the old adults. Interestingly, this has never been reported in literature before. Although more research is needed before any firm conclusions can be drawn, this decline in recency-effect shows that there are larger age-related effects in short term memory span than was expected on the basis of aging theories so far.
Keywords: Reading span test, methodology, working memory, aging

Introduction

Numerous studies on age-related decline have focused on cognitive functions. Some studies have been driven by the idea that working memory skill is critical in explaining the decline in cognitive performance of older people in comparison with young adults (De Beni & Palladino, 2004). Working memory has been found to require the simultaneous storage and processing of information. It can be divided into the following three subcomponents: 1) The "central executive", which is assumed to be an attentional-controlling system, is important in skills such as chess playing and is particularly susceptible to the effects of Alzheimer's disease; and two slave systems, namely 2) the "visuospatial sketch pad", which manipulates visual images and 3) the "phonological loop", which stores and rehearses speech-based information (Baddeley & Hitch, 1974; Baddeley, 1986, 2000).

Several span measures were designed to measure working memory capacity. These working memory span tasks are used by researchers in numerous areas of psychology (Miyake & Shah, 1999). One important contribution was the development of the reading span task by Daneman & Carpenter (1980). This working memory span task draws simultaneously on storage and computational aspects of working memory. In this task, participants are asked to read series of sentences aloud. Meanwhile, they must remember the final word of each sentence in a particular series. Sentences are presented on cards; there is one sentence on each card. At the end of a series, a blank card appears. This blank card is the participant's cue for recall of all sentence-final words of the series in the right order. The number of sentences in a series is gradually increased. The reading span is the maximum number of sentences of which the final words are correctly recalled (Daneman & Carpenter, 1980).

However, one should be careful with the results based on the original reading span task (Daneman & Carpenter, 1980) and/or versions based on it, since they are often far from perfect (Desmette, Hupet, Schelstraete, & Van der Linden, 1995). There are problems with the stimulus material, the way of presentation, the determination of the reading span, and the translations of the RST. In the past, a lot of different versions in different languages were developed. Some of them were truly improvements of the original Daneman and Carpenter (1980) version (see also Daneman & Hannon, 2001; Hannon & Daneman, 2001). However, all versions changed different things of the original RST, which made direct comparisons between different research groups and different languages almost impossible.

Recently, a new standard computerized version of the reading span test was developed in different languages (Van den Noort, Bosch, Hugdahl, 2005a, in press). The new version meets stricter methodological criteria than the previous versions. There is controlled for the number of syllables of the sentences. In addition, there is controlled for the number of syllables-, the number of letters-, and frequency of the sentence-final words. Finally, there is controlled for the number of verbs over the series and semantic relations. It is important to control for this over the five series to further improve the reliability of the test, and to make the five different series better comparable. Moreover, in controlling the above mentioned points over three languages; the test was created in such a way that results can be compared between the languages and between research groups. For a more detailed description see Van den Noort, Bosch, Haverkort, and Hugdahl (submitted).

What do we know about the development of short-term- and working memory over age? Previous neuropsychological research has consistently found that the holding function of short-term memory (its storage aspect) does not decline over age (Dobbs & Rule, 1989). It seems that aging has little effect on the relatively passive phonological loop (Craik, Morris, & Gick, 1990). Age changes in short-term memory must be related to the workings of the control system (the central executive). This is exactly what researchers have found. Working

memory capacity, which involves the temporal storage and processing of information, is strongly reduced by increasing age (e.g., Hultsch & Dixon, 1990; Kirasic, Allen, Dobson, & Binder, 1996; Park et al., 1996; Parkin & Java, 2000). As a result, age differences in memory span measures are expected by most still existing theories of cognitive aging (e.g., Hasher & Zacks, 1988; Just & Carpenter, 1992; Mayr & Kliegl, 1993; Salthouse, 1994, 1996). Many aging theories also predict larger age-related effects for working memory span than for short-term memory span. For instance:

1) Processing resource theories (e.g., Belleville, Rouleau, & Caza, 1998; Craik et al., 1990; Dobbs & Rule, 1989; Just & Carpenter, 1992) state that aging depletes the cognitive resources available for processing. The concomitant expectation is that working memory tasks, with their demands on both processing and storage, will yield larger age effects than short-term memory tasks, which require mere storage (Bopp & Verhaeghen, 2005).

2) The speed theory of cognitive aging (Salthouse, 1994, 1996; Tisserand, 2003). This theory predicts that age-related slowing of computational processes will cause a decrease in short-term memory span, because items are not encoded sufficient enough. Short-term memory spans are also called "simple" working memory tasks since they only tap the storage component of working memory, but not the processing aspect. Secondly, the theory of cognitive aging also predicts a decrease on "complex" working memory tasks (like the reading span test) that tap both the storage and processing component of working memory, because items that are stored away in a temporary visual or verbal buffer might have decayed from that buffer by the time they are needed for subsequent processing. Statistically controlling for speed has indeed been found to reduce the magnitude of age-related differences in short-term memory and working memory performance (Verhaeghen & Salthouse, 1997). Salthouse (1992), for instance, found a substantial decrease in age-related variance on working memory performance when the variance attributed to cognitive slowing is removed, suggesting that cognitive slowing underlies much of the age-related decline in working memory performance. The speed theory would predict age differences in mere storage tasks (where the limited-time mechanism operates), and larger age differences still in tasks requiring concurrent processing and storage (governed by both the limited-time and simultaneity mechanism). The existence of a simultaneity mechanism would furthermore lead to the prediction that tasks requiring both storage and processing (like in the reading span test) yield larger age differences than simple storage spans (Bopp & Verhaeghen, 2005).

3) Theories focusing on coordinative task requirements (e.g., Mayr & Kliegl, 1993), predict larger age differences in working memory span than in short-term memory span, because working memory tasks require the coordination of concurrent storage and processing demands, which is a demand absent in short-term memory tasks. Coordination theory furthermore predicts that span tasks can be separated into distinct categories, namely, tasks that do and do not require coordination (Bopp & Verhaeghen, 2005).

4) The inhibition theory of cognitive aging (Hasher & Zacks, 1988) states that an age-related breakdown in inhibitory control leads to an increase in the number of simultaneously active messages; thereby effectively shrinking the size of short-term memory or working memory. With regard to span measures, Hasher and colleagues have suggested that working memory tasks require successful management of previous information; that is, in order to be successful on a span task, it is necessary to effectively inhibit stimuli from previous sets (Lustig, May, & Hasher, 2001). Therefore, the inhibition theory would predict that span tasks with repeated information should yield larger age differences. Consequently, forward digit span and letter span should be more age sensitive than word span. In addition, tasks that use similar stimuli for storage and processing (i.e., reading span, listening span, sentence span, and computation span tasks) would be expected to yield larger age differences than tasks that use different stimuli for storage and processing (i.e., operation span tasks) (Bopp & Verhaeghen, 2005).

So far, little is known about the development of the reading span in aging. Is there a general decrease in the reading span over age (Van den Noort, Bosch, & Hugdahl, 2005b)? Previous research on aging, with non-standard versions of the reading span task, has shown that performances on the test are significantly different over age (Meguro et al., 2000). Moreover, Schelstraete and Hupet (2002) tested the hypothesis of the inhibition theory of cognitive aging (Hasher & Zacks, 1988); that the ability to inhibit already processed and actually irrelevant information influences performance in the reading span task. The results supported the idea that the working memory capacity undoubtedly involves some inhibitory control. However, because the participants' vulnerability to intruding responses is not clearly affected by age, the findings also suggest that some part of the age effects upon the working memory span has to be explained by another factor than a growing inefficiency in inhibitory control.

In this study, the new standard computerized version of the reading span test (Van den Noort et al., submitted) was used to investigate the development of verbal working memory over age. The standard reading span task gives both working memory- and reaction time results and meets stricter methodological criteria than previous versions of the test (Friedman & Miyake, 2004). Four different experimental groups: a student group, a young adult-, a middle-aged-, and an old-aged group participated in the study. A significant higher reading span and faster reaction times were expected for the young adults compared to the old adults, based on the processing resource theory (Just & Carpenter, 1992) and the theory of cognitive aging (Salthouse, 1994, 1996). It was expected that both a decrease in working memory and a general slowing down play a role in aging. The new methodology of the reading span test improved the ability to test whether there was an age-related increase in intrusion errors, which could be expected based on the inhibition theory of cognitive aging (Hasher & Zacks, 1988). So far, previous research with other tasks than the reading span task has shown an age-related increase in intrusion errors. Intrusions are considered as an indirect index of poor updating ability and are supposed to be due to inefficient suppression mechanisms (Chiappe, Hasher, & Siegel, 2000; De Beni & Palladino, 2004; De Beni, Palladino, Pazzaglia, & Cornoldi, 1998). Finally, the new methodology created the ability to look at possible recency effects. In line with previous neuropsychological research (Craik et al., 1990; Dobbs & Rule, 1989) recency effects were expected for both the young- and the old participants.

Method
Participants
Sixty participants, divided over four experimental groups, entered the study. All participants were native speakers of Dutch and had the same educational level (academic). The first group consisted of 15 university students. There were seven men and eight women and their mean age was 19.7 years (SD = .8). The second group consisted of 15 young adults and their mean age was 25.6 years (SD = 3.4). There were six men and nine women in this group. Moreover, 15 middle-aged adults (eight men/seven women) participated in the study and their mean age was 50.7 years (SD = 7.5). Finally, 15 old-aged adults participated in the study and their mean age was 74.6 years (SD = 6.1). There were six men and nine women in this group. Moreover, only those participants that had no visual- and/or hearing problems were selected. Finally, none of the 60 participants had serious health problems and were on medication at the time of testing. This is important since medication could induce drowsiness or influence cognitive functioning (De Beni & Palladino, 2004).

Materials
The standard computerized version of the reading span test was used (Van den Noort et al., submitted). The reading span test was programmed in E-Prime (Schneider, Eschman, & Zuccolotto, 2002) and consists of 100 sentences (five sets of 20). The sentences met stricter methodological criteria than previous versions of the reading span test: 1) the length of the

sentences was better controlled for, ranging from 20 to 22 syllables. Moreover, the number of syllables, the number of letters, and the frequency of the sentence-final words were controlled for, over the five series (see Table 1). Previous studies showed that it is easier to remember shorter words than longer words. Moreover, it is easier to remember frequent words compared to less frequent words (Baddeley, 1999). Therefore, it is important to control for this over the five series to further improve the reliability of the test, and to make the five different series better comparable. To determine the frequency of the sentence-final words, the CELEX lexical database (Baayen, Piepenbrock, & Van Rijn, 1993) was used. In addition, the number of verbs over the series was controlled for as a measure of syntactic complexity (on average: 2.3 verbs). Moreover, within the sets, the sentences and sentence-final words were controlled for semantic relations as much as possible. Three native speakers of Dutch independently rated all sentences and sentence-final words for their semantic relations. Changes in sentence order were made to control semantic relations within the sets and over the five series of the new reading span test as much as possible. This is necessary since previous research showed that it is easier to remember words that have close semantic relations compared to words that have less close semantic relations (Baddeley, 1999). Finally, in the new reading span test, the reading span score is determined by the total number of remembered words during the whole test with a maximum score of 100 (Van den Noort et al., submitted).

Table 1
Overview of the mean number of syllables of the sentences, mean number of syllables-, the mean number of letters-, and the mean frequency of the sentences final words per series of the new reading span test

Series	Syllables Sentences	Syllables Final words	Letters Final words	Frequency Final words
Series 1	21.0[a] (0.9)	1.9[a] (0.7)	6.0[a] (1.6)	2502[a] (3466)
Series 2	21.4[a] (0.9)	1.8[a] (0.8)	5.7[a] (1.8)	2426[a] (3063)
Series 3	21.3[a] (0.9)	1.7[a] (0.6)	5.6[a] (1.6)	2442[a] (2103)
Series 4	21.2[a] (0.9)	2.1[a] (0.9)	6.5[a] (1.6)	2430[a] (2340)
Series 5	21.6[a] (0.6)	2.0[a] (0.7)	6.2[a] (1.5)	2433[a] (2870)

Note. Different letters indicate significant difference at $p < .05$ level.

Procedure
All participants were tested individually. After receiving a verbal general instruction about the experiment, a both verbal- and written detailed instruction was given for the computerized reading span test. All participants were seated behind a computer screen. The test started with an instruction on the screen. The instruction emphasized the importance of reading the

sentences aloud as fast as possible while reading for content. This time restriction is important, because participants can otherwise read the sentences slower to improve their recall. In that case the reading span task might no longer be a strict working memory test (Friedman & Miyake, 2004; Saito & Miyake, 2003). Participants were able to ask questions if things were not completely clear after the instruction. This was in particular important for the older participants who felt more secure when they were given this opportunity. Then, two exercise trials were conducted to make the participants more familiar with the task. The first exercise trial was an example of a set of two sentences and the second exercise trial was an example of a set of three sentences. The first exercise trial started with a complete sentence that was presented in the middle of the screen. When participants had finished reading the first sentence aloud, the participants pressed the space bar and the sentence disappeared. Then, a second sentence appeared automatically in the middle of the screen. When participants had finished reading this second sentence aloud, they pressed the space bar. The second sentence disappeared and the word 'recall' appeared immediately in the middle of the screen. At that moment, participants had to recall the last word of each sentence in the set. In this example, they could recall two sentence-final words. The order of recall was during the whole reading span test free. This is important since free recall gives important information of possible primacy- and recency effects (Baddeley, 1999). After the exercise trials, again participants had the opportunity to ask questions. When all things were clear to the participants, the 100 experimental sentences were presented. The sentences were presented in different set sizes (two, three, four, five or six sentences), in random order, and were read aloud. The participants completed all sentences of the test. The remembered sentence-final words and the reaction time of all sentences were collected. After finishing the reading span test, participants received feedback about the aim of the experiment. The duration of the experiment was 20 minutes.

Results
The reading span scores were analyzed in an age group (students, young adults, middle-aged-, and old-aged) between-subjects MANOVA. As Table 1 shows, a significant main effect for age was found, $F(3, 56) = 6.66$, $p < .002$. Independent t-tests were conducted with a Bonferoni (Huberty & Morris, 1989) adjustment of the alpha level (.05) to examine if the mean reading span score of the younger groups would differ from the mean reading span score of the older groups. Significant differences were found for the reading span score between the student group and the middle-aged adult group ($t(1, 14) = 2.22$, $p < .05$) and between the student group and the old-aged group ($t(1, 14) = 3.17$, $p < .01$). The student group performed better on the reading span test than the middle-aged- and the old-aged group. Moreover, a significant difference in reading span score was found for the old-aged group compared to the middle-aged group ($t(1, 14) = -2.41$, $p < .04$) and between the old-aged group and the young adult group ($t(1, 14) = -3.37$, $p < .01$). The old-aged group performed worse on the reading span test than the middle-aged- and the young adult group.

Table 2

Overview of the mean total number of remembered words and mean reaction times per series for all four different age groups

	Mean reading span	Mean reaction time
Student group	69.5 (8.6)	4037.5 (108.5)
Young adult group	66.9 (7.3)	4037.8 (127.4)
Middle-aged group	63.3 (6.2)	6325.2 (1761.4)
Old-aged group	57.4 (9.2)	8039.4 (1493.3)

In addition, the reaction time scores were analyzed in an age group (students, young adults, middle-aged-, and old-aged) between-subjects MANOVA. As Table 2 shows, a significant main effect for age was found, $F(3, 56) = 42.37$, $p < .001$. To examine if the younger groups had faster reaction times than the older groups, independent t-tests with a Bonferoni (Huberty & Morris, 1989) adjustment of the alpha level (.05) were conducted. In all independent t-tests, the reaction times below and above two standard deviations from the mean were removed. The rationale behind this decision was that, if a participant read a sentence extremely fast or extremely slow in comparison with other sentences, one cannot be sure that this sentence was read in a normal way. Significant differences were found in the reaction times on the reading span task between the student group and the middle-aged group ($t(1, 14) = -4.92$, $p < .001$) and between the student group and the old-aged group ($t(1, 14) = -10.24$, $p < .001$). The students were much faster than the middle-aged- and the old-aged participants. Moreover, more individual variance was found in the middle-aged- and the old-aged group compared to the students. In addition, the old-aged adults were significantly slower than the middle-aged adults ($t(1, 14) = 2.75$, $p < .02$) and the young adults ($t(1, 14) = 10.22$, $p < .001$) on the reading span test.

Interestingly, over the whole reading span test, a difference in memory pattern was found for the younger groups compared to the older groups. As Figure 1 shows, a significant difference between the younger groups and the older groups was found for the sentence final words, which were in the fourth position ($t(1, 14) = -3.11$, $p < .008$), the fifth position ($t(1, 9) = -6.46$, $p < .001$), and in the sixth position of the set ($t(1, 4) = -8.20$, $p < .001$). In other words; a clear recency effect could be found for the younger groups, but not for the older groups (Baddeley, 1999).
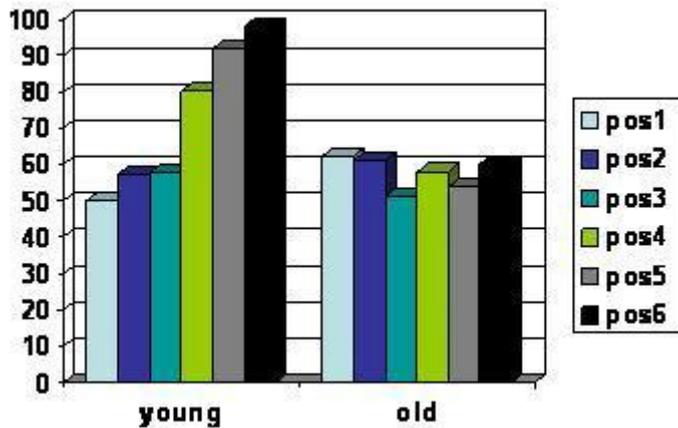
Figure 1. Percentage remembered words of the younger groups compared to the older groups divided over the six positions in the set.

In addition, an analysis of intrusion errors was carried out. As can be seen in Table 3, the results showed that the old-aged adults made significantly more intrusions than the students $(t(1, 14) = 2.69, p < .02)$. This result is in line with previous findings that demonstrated an age-related increase in intrusion errors. No other significant differences in number of intrusions between the students, the young adults, the middle-aged adults, and the old-aged adults were found.

In this study, the speed-accuracy score on the reading span test was analyzed. It is possible that on the one hand, young participants are more focused on speed of processing and on the other hand, older participants are more focused on the accuracy of processing. By using a speed-accuracy rate, it is possible to compare the results of the young- and the old group by taking this into account. Significant differences between the student group and the middle-aged adult group $(t(1, 14) = -5.21, p < .001)$ and between the student group and the old-aged group $(t(1, 14) = -8.27, p < .001)$ were found, indicating that it is not only the speed of processing that is affected by age, but also the accuracy of processing. Moreover, significant differences between the old-aged group and the middle-aged group $(t(1, 14) = 3.19, p < .008)$ and between the old-aged group and the young adult group $(t(1, 14) = 8.63, p < .001)$ were found.

Table 3

Overview of the mean total number of intrusion errors,

specified for all four different age groups

	Mean number of intrusion errors
Student group	1.0^a (0.9)
Young adult group	1.3^a (1.0)
Middle-aged group	1.3^a (0.9)
Old-aged group	2.1^b (1.0)

Note. Different letters indicate significant difference at $p < .05$ level.

Discussion

In this study, the new standard computerized version of the reading span test (Van den Noort et al., submitted) was used to investigate the development of verbal working memory over age. A comparison between a student group, a young adult-, a middle-aged-, and an old-aged group was made. A significant higher reading span and faster reaction times for the young adults compared to the old adults were expected, based on the processing resource theory (Just & Carpenter, 1992) and the theory of cognitive aging (Salthouse, 1994, 1996). The results showed a higher reading span score and faster reaction times for the younger adults compared to the older participants, suggesting that both a decrease in verbal working memory and a general slowing down play an important role in aging. However, it is important to note that based on these reading span test results it is not possible to draw any firm conclusions how much of this general slowing down in aging is related to executive functions, independent of memory. With respect to this more research needs to be done.

In this study, the speed-accuracy score on the reading span test was analyzed. It is possible that on the one hand, young participants are more focused on speed of processing and on the other hand, older participants are more focused on the accuracy of processing. By using a speed-accuracy rate, it is possible to compare the results of the young- and the old group by taking this into account. Still, significant differences between the student group and the middle-aged adult group and between the student group and the old-aged group were found. Moreover, significant differences between the old-aged group and the middle-aged group and between the old-aged group and the young adult group were found, indicating that it is not only the speed of processing that is affected by age, but also the accuracy of processing. Moreover, the new methodology of the reading span test enabled the possibility to test whether there was an age-related increase in intrusion errors, which could be expected based on the inhibition theory of cognitive aging (Hasher & Zacks, 1988). The results showed that the student group indeed made significantly fewer intrusions compared to the old-aged group. Finally, in line with previous neuropsychological research (Craik et al., 1990; Dobbs & Rule, 1989); recency effects were expected for both the young- and the old participants. The

analysis of the memory-pattern, however, showed a clear recency-effect only for the younger-, but not for the older groups. Interestingly, this has never been reported in literature before. It seems that aging has more effect on the relatively passive phonological loop that stores and rehearses speech-based information (Baddeley & Hitch, 1974; Baddeley, 1986, 2000), than was previously thought. Although more research is needed before any firm conclusions can be drawn, this decline in recency-effect shows that there are larger age-related effects in short term memory span than was expected on the basis of aging theories so far.

However, there is a restriction within the present study. It would have been better to have larger sample sizes. More data with the computerized reading span test is therefore needed (De Beni & Palladino, 2004; Waters & Caplan, 2003). This could give us more reliable data on the development of the reading span and reaction times over the whole age spectrum.

In future research, it would be interesting to test if the standard computerized reading span test could be used for clinical purposes. Just and Carpenter's work has been extremely successful in explaining aphasic data (MacDonald & Christiansen, 2002), but could the new reading span test also be used for other clinical areas (Van den Noort et al., 2005b)? It is crucial to note that in contrast with the original reading span task (Daneman & Carpenter, 1980), the new standard computerized reading span test gives both reaction time- and memory results.

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