

On the Relative Role of Inhibition in Age-Related Working Memory Decline

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ABSTRACT

In this cross-sectional study, the mediating role of inhibition relative to speed in age-related working memory decline on different tasks was investigated. It was hypothesized that the role of inhibition is marginal or absent in a relatively “passive” or simple working memory task, but present in a relatively “active” or complex task in which the processing, rather than the storage capacity of working memory, is addressed. This hypothesis was tested with a structural equation model that was fitted on a subsample ($N = 213$) of the Maastricht Aging Study (MAAS). The first trial of the Verbal Learning Test (VLT) served as the passive test and the Self-Paced Auditory Serial Addition Task (SPASAT) as the active test. Results showed that the role of inhibition was absent in predicting VLT performance, whereas it was comparable to the role of speed in predicting SPASAT performance. These findings suggest a relative, task-dependent role of inhibition in explaining age-related memory decline.

It is well established that general processing speed is an important, if not the most important, determinant of cognitive aging (e.g., Fisk & Warr, 1996; Salthouse, 1993, 1996, 2000). The core message of research in this field is that processing speed mediates the role of age in explaining cognitive decline. This means that the direct influence of the factor age on, for instance, working memory is considerably attenuated if processing speed is statistically controlled for. The notion of speed as the major determinant of cognitive aging has not only rivaled the view that a decline of storage capacity accounts for cognitive aging (e.g., Salthouse & Babcock, 1991), but also the more dissident view that its main cause is a lack of inhibitory control

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(Hasher, Tonev, Lusting, & Zacks, 2001; Hasher & Zacks, 1988; McDowd, 1995). Yet, this latter position seems to receive renewed attention in recent years (e.g., Persad et al., 2002).

The *inhibitory view*, as it is often referred to (e.g., Stoltzfus, Hasher, & Zacks, 1996), claims that aging is accompanied by a declining ability to discard irrelevant information from working memory. The consequential memory overflow causes a decline in cognitive performance. There is ample support for a deterioration of inhibitory function with old age. For example, elderly individuals showed reduced suppression of distracting stimuli (Connelly et al., 1991), were more susceptible to proactive and retroactive interference than young individuals (Chiappe et al., 2000; Hedden & Park, 2001, 2003), showed reduced negative priming (Earles et al., 1997; Kane et al., 1994), and were less able to ignore irrelevant memory sets in a modified Sternberg task (Oberauer, 2001). Research on inhibition as a mediator between age and memory has yielded mixed results, however. In some studies, the mediating role of inhibition was found to be marginal (e.g., Salthouse et al., 2003; Verhaeghen, 1999). Other studies report a moderate role of inhibition relative to processing speed (e.g., Salthouse & Meinz, 1995; Salthouse & Miles, 2002; Shilling et al., 2002), whereas still other studies report a substantial contribution of inhibitory processes (e.g., Kwong See & Ryan, 1995; Persad et al., 2002). In this article, there is an attempt to shed more light on the ambiguous role inhibition seems to play in explaining age-related working memory decline.

A possible explanation for this ambiguous role lies in the diversity of tests that are used to assess working memory. In this article, a distinction is made between “passive” and “active” tests. Tests can be considered *passive* if they merely appeal to the storage capacity of working memory. Examples of passive tests are simple digit- or word-span tests, which are often used as part of an IQ test. The label “passive” is of course relative, because short-term storage of information in working memory requires basic activity, for instance, in the form of rehearsal within the phonological loop (Baddeley, 2003). On the other hand, tests can be considered *active* if they do not only appeal to the storage capacity of working memory, but also to its processing capacity. Examples of active tests are Daneman and Carpenter’s (1980) reading-span test and Salthouse and Babcock’s (1991) computation-span test. These tests require the participant to simultaneously store and process information, for instance, by reading aloud sentences or performing mental arithmetic. Passive and active tests not only differ in the type of activity they trigger in working memory, but also in the level of complexity: active tests can be considered more complex than passive tests, because they involve the coordination of multiple tasks (i.e., storage and processing).

In both types of tests, performance is determined by the simultaneous availability of different information elements in working memory. However,

it may occur that the activation of earlier presented information elements has decayed below a critical threshold by the time later presented information elements are processed, a principle known as the “simultaneity mechanism” (Salthouse, 1996). According to Salthouse and colleagues (e.g., Salthouse & Babcock, 1991), this is primarily a matter of speed: the faster the activation of information in working memory, the smaller the chance of simultaneity problems. In this article, it is argued that performance on *active* tests is not only determined by processing speed, but also by inhibitory control processes. Where in passive tests, all presented information is relevant because it has to be completely reproduced, in active tests only part of the information that passes through working memory has to be reproduced, whereas other, only temporarily relevant information, has to be inhibited to prevent overload or interference with other information. This line of reasoning is supported by the current focus on the role of inhibition in task switching (e.g., Koch et al., 2004; Monsell, 2003), which shows age-related decline (e.g., Salthouse et al., 1998). That is, in active tests, there is frequent switching from one task (short-term storage) to the other (information manipulation). For example, in the computation-span test, a series of simple arithmetic sums has to be solved. At the same time, the last digit of every sum has to be memorized. Thus, the participant is constantly switching between solving the sums and retaining the to-be-remembered digits. Furthermore, he or she has to suppress the results of the calculations to prevent them from interfering with the retention process. Under these circumstances, it is conceivable that failures of inhibition inevitably result in poor test performance.

Thus, it can be expected that inhibition plays a greater role in active tests than in passive tests. From the perspective of adult development, this has profound implications. It is generally recognized that the performance of older adults is disproportionately impaired relative to younger adults when the complexity of a task is raised. This so-called *complexity effect* is reflected by an interaction between age and task complexity in that performance differences between young and older people become larger when the complexity of the task increases (Craik & Byrd, 1982; Perfect & Maylor, 2000; Salthouse, 1985). The complexity effect has already been demonstrated in both passive and active tests (e.g., Wingfield et al., 1988) as well as in tasks that involve memory search (e.g., Oberauer, 2001; Van Gerven et al., 2004). In the context of the “speed-versus-inhibition debate,” the complexity effect predicts that the relative contribution of inhibition in explaining age-related memory decline increases with the complexity of the task. If active tasks are considered more complex than passive tasks, this again supports the hypothesis that inhibitory ability is a relatively strong determinant of active test performance and a relatively weak determinant of passive test performance. Speed, on the other hand, is a relatively strong and stable determinant of either type of test performance.

The aim of the current study is to evaluate this hypothesis by focusing on the Verbal Learning Test (VLT; Brand & Jolles, 1985) as a typical example of a passive task and the Self-Paced Auditory Serial Addition Task (SPASAT; Gronwall, 1977; Klein, 1997) as a typical active task. The VLT is “passive” in the sense that a maximum number of words have to be stored and reproduced in a nonrestricted order. The SPASAT is “active” in the sense that it is aimed at information manipulation, rather than on storage and reproduction.

To test this hypothesis, a path analysis was performed on a sample drawn from the Maastricht Aging Study (MAAS; Jolles et al., 1995). The model included direct paths from age to VLT and SPASAT performance. In addition, speed and inhibition served as mediators between age and working memory performance, an approach that is comparable to the work of Salthouse and colleagues (e.g., Salthouse, 1993; Salthouse et al., 1998; Salthouse & Meinze, 1995).

METHOD

Participants

Participants in the MAAS were recruited from the Dutch Registration Network Family Practices (RNH; Metsemakers et al., 1992), which is a sample frame for research in primary care. Persons with chronic neurological pathology (e.g., dementia, cerebrovascular disease, epilepsy, Parkinsonism, and malignancies related to the nervous system), mental retardation, major psychiatric disease (including depression), or chronic psychotropic drug use were excluded. The original sample contained 1,823 individuals and was stratified according to age (collapsed into 5-year age groups: 24–35, 36–45, 46–55, 56–65, 66–75, and 76–83 years), sex, and general ability. A more elaborate description of the sample is given by Jolles et al. (1995) and Van Boxtel et al. (1998). The SPASAT was administered to a MAAS subsample of 237 participants ranging in age from 24 to 81 years. Five individuals (2.1%) with MMSE (Mini-Mental State Examination; Folstein, Folstein, & McHugh, 1975) scores of 23 or lower and 19 individuals (8.0%) with unreliable test results were excluded, leaving 213 individuals (106 men and 107 women) for the analysis. Descriptive statistics of this subsample can be found in Table 1.

Measures

Stroop Color-Word Test (SCWT)

The SCWT was used as a measure of speed and inhibition, although the test is usually administered to assess selective attention or resistance to interference (Houx et al., 1993). In the critical condition, the participant has

TABLE 1. Descriptive Statistics of Demographic and Dependent Variables

	Age Group (Years)							
	24-35 (n = 51) 25/26	36-45 (n = 39) 21/18	46-55 (n = 44) 20/24	56-65 (n = 33) 20/13	66-75 (n = 30) 12/18	76-83 (n = 16) 8/8	M	(SD)
Men/women ratio	M	M	M	M	M	M	M	(SD)
Age (years)	29.5 (3.9)	40.9 (3.1)	51.1 (3.2)	62.1 (2.7)	71.5 (2.9)	78.6 (1.6)	78.6	(1.6)
Education (range 0-8)*	4.7 (1.6)	4.2 (1.6)	3.5 (1.8)	3.0 (1.8)	2.6 (1.5)	2.5 (2.0)	2.5	(2.0)
Speed (s)	45.5 (5.5)	46.3 (6.8)	47.7 (6.6)	52.0 (8.9)	55.2 (8.5)	60.6 (9.3)	60.6	(9.3)
Inhibition (s)	35.6 (13.1)	36.4 (14.2)	45.7 (15.2)	48.4 (13.7)	56.4 (18.4)	78.8 (27.4)	78.8	(27.4)
VLT	6.4 (1.5)	6.2 (1.3)	5.5 (1.5)	4.9 (1.6)	3.9 (1.4)	4.1 (1.5)	4.1	(1.5)
SPASAT	53.5 (5.2)	52.8 (4.7)	50.0 (7.3)	46.3 (7.9)	45.6 (6.4)	43.4 (6.6)	43.4	(6.6)

*Education ranges from 0 (no education), via 1 (elementary) to 8 (academic).

VLT = Verbal Learning Test; SPASAT = Self-Paced Auditory Serial Addition Task.

to name the ink color of a word, which itself is the name of another color. This incongruity causes interference between the more or less automatic reading process and the more controlled color naming process. The interference results in longer response latencies. Thus, long response latencies indicate high interference and less adequate inhibition, whereas short response latencies indicate low interference and more adequate inhibition. The SCWT involved three cards, which each displaying a hundred stimuli. The first card (Card 1) contained random sequences of the color names *red*, *blue*, *yellow*, and *green* printed in black ink. The participant was required to read the names as quickly as possible. The second card (Card 2) contained random sequences of colored patches, representing the colors red, blue, yellow, and green. The participant was required to name the color patches as quickly as possible. The third card (Card 3) again contained random sequences of the color names *red*, *blue*, *yellow*, and *green*, but printed in an incongruent ink color. In this condition, the participant was required to name the ink color (and not to read the color name). The dependent measures were the reading or naming times (in seconds) for every card. Both reading and color naming were considered as basic speed measures, although color naming is usually slower than reading. Therefore, processing time was defined as the average time spent on Card 1 and 2. Interference, which is defined as the delay caused by the competition between reading and naming in the incongruent condition (Card 3), was determined by subtracting the average time on Card 1 and 2 from the time on Card 3 (after Houx et al., 1993). The extra time needed to process the incongruent stimuli is considered to be the best approximation of interference. Interference is inversely proportional to inhibition. That is, low interference reflects high inhibition, whereas high interference reflects low inhibition. A similar definition holds for speed, which is inversely proportional to processing time.

Verbal Learning Test (VLT)

The VLT (Brand & Jolles, 1985) is based on the Rey Auditory Learning Test (Rey, 1964), which is commonly used for assessing the ability to acquire and retain new verbal information (Van der Elst, Van Boxtel, Van Breukelen, & Jolles, 2005). A list of 15 commonly used, monosyllabic words was verbally presented to the participant. Words were separated by a short time interval. Immediately after presenting the words, the participant was required to recall as many words as possible in his or her own order. This procedure was repeated five times, including a 20-min, delayed-recall trial. In the current study, only the number of correctly recalled words in the first trial was used as a simple measure of short-term storage capacity.

Self-Paced Auditory Serial Addition Task (SPASAT)

This is a self-paced version of the Paced Auditory Serial Addition Task, which was originally devised by Gronwall (1977) to assess recovery

from mild head injury. The SPASAT (Klein, 1997) was administered by means of an IBM-compatible computer with a soundcard and a loudspeaker. The sound level was adjusted to an optimal individual level, that is, until the participant was able to correctly repeat a list of randomly presented numbers. Sixty-one single-digit numbers were pseudo-randomly presented to the participant, that is, with the restriction that two consecutive digits were never the same. The participant's task was to calculate the sum of the last two digits that were presented to him or her and immediately give the answer aloud. For example, if the sequence was "6, 1, 8, 7, . . .," the participant had to respond "7" after hearing "1," "9" after hearing "8," "15" after hearing "7," and so on. Prior to the test, the participant was presented with a 10-digit practice sequence. In the original version of the task (Gronwall, 1977), the digits were presented at fixed intervals. In this version, a new digit was presented after every response. If the participant forgot the last digit, four new digits were presented. The same procedure was followed if the response latency was longer than 5 seconds. The number of correct responses was registered as the dependent variable.

RESULTS

The path model was analyzed with LISREL 8.7 (Scientific Software International, Lincolnwood, IL) structural equation modeling software (Jöreskog & Sörbom, 2004). Descriptive statistics of the variables included in the model can be found in Table 1. Age was the main predictor. The VLT and SPASAT performances were the dependent working memory variables. Speed and inhibition served as mediators between age and working memory performance. No latent variables were included. A correlation matrix of observed and residual correlations can be found in Table 2.

TABLE 2. Observed and Residual Correlations of Variables Included in the Path Model

Variable	1	2	3	4	5
1. Age	–	.00	.00	.00	.01
2. Speed	.50*	–	.28	.00	–.05
3. Inhibition	.54*	.55*	–	–.04	–.06
4. VLT	–.53*	–.38*	–.32*	–	.03
5. SPASAT	–.49*	–.47*	–.46*	.32*	–
<i>M</i>	50.7	49.6	46.0	5.4	49.7
<i>SD</i>	16.6	8.6	19.8	1.7	7.2

Note: The bottom-left segment of this table contains the observed correlations among the variables in the path model. The top-right segment contains the residuals of the correlations reproduced by the initial path model.

* $p < .01$.

VLT = Verbal Learning Test; SPASAT = Self-Paced Auditory Serial Addition Task.

The initial model described above did not fit the data, $\chi^2(2, N = 213) = 30.86, p < .00001$. From the residual correlations in Table 2 it can be concluded, however, that the model reproduces all correlation very well, except for the correlation between speed and inhibition ($r_{\text{residual}} = .28$). Therefore, a correlational connection between these factors was added. This led to a good model-to-data fit, $\chi^2(1, N = 213) = 0.40, p = .53$.

The standardized path coefficients of the final model can be found in Figure 1. The figure shows that a substantial part of the age-related decline of working memory is mediated by both speed and inhibition. Of major importance is the finding that, in contrast to the path coefficient between inhibition and SPASAT (-0.19), which is comparable to that between speed and SPASAT (-0.23), the path coefficient between inhibition and VLT is very low (0.01) and statistically insignificant, $t = 0.19, p > .05$. These results imply that inhibition only has a significant impact on SPASAT performance, not on VLT performance. Speed, on the other hand, has a considerable impact on both SPASAT and VLT performance. These results are clearly in line with our hypothesis.

DISCUSSION

The aim of the present study was to test the hypothesis that inhibition is a weak mediator between age and working memory if the task merely appeals to the—“passive”—storage capacity of working memory, but a relatively strong mediator if the task primarily appeals to its—“active”—processing capacity. The first trial of the VLT served as a measure of storage capacity, whereas the SPASAT served as a measure of processing capacity.

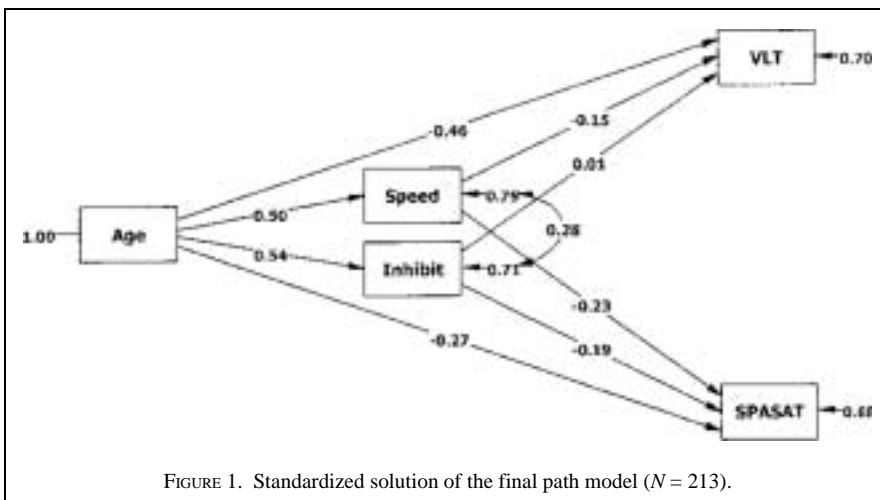


FIGURE 1. Standardized solution of the final path model ($N = 213$).

The structural equation model depicted in Figure 1 reveals that a considerable part of the negative correlation between age and working memory performance is mediated by both speed and inhibition. With respect to speed, this outcome is in accordance with Salthouse's (1996) processing speed theory. The mediating role of inhibition, however, is less univocal. Given that the model in Figure 1 is valid, its impact on SPASAT performance is comparable to that of speed, whereas its impact on VLT performance is virtually nonexistent. This outcome provides clear support for our hypothesis.

There are a few issues that need to be addressed before a clear-cut conclusion can be drawn from these results. A first issue concerns the specificity of the speed and inhibition measures. Although the SCWT is a commonly used instrument for gauging both cognitive speed and inhibition, it is essentially a test of interference or, more specifically, *resistance* to interference. It seems reasonable, however, to assume that resistance to interference involves inhibition of an automatic response (word reading) in favor of a controlled response (color naming). Moreover, recent studies have shown that Stroop interference is strongly related to other tasks which are supposed to involve inhibition of prepotent responses, such as the anti-saccade task and the stop-signal task (Friedman & Miyake, 2004; Verbruggen, Liefoghe, & Vandierendonck, 2004).

A second issue is that the speed and inhibition measures are substantially correlated (Kwong See & Ryan, 1995; Salthouse & Meinz, 1995; Shilling et al., 2002; Verhaeghen, 1999). Thus, one could question to what extent these measures represent separate cognitive functions. Indeed, speed and inhibition were moderately correlated in the present study ($r = .55$). In the final path model, however, this correlation was accounted for. Moreover, speed and inhibition show a different pattern of results with respect to their relation to the working memory measures, which suggests that they reflect distinct cognitive functions.

A third issue is whether speed and inhibition are the most prominent mediators in tasks that are aimed at the processing capacity of working memory. Since Gronwall (1977) designed the task as a measure of "information processing," it is conceivable that SPASAT performance additionally requires other elementary working memory processes, such as searching and updating, which might as well mediate age-related working memory decline. Mayr, Kliegl, and Krampe (1996), for instance, already indicated that performance on so-called "coordinatively complex tasks" is—beside speed—determined by the ability to *coordinate* different processes in working memory. Although the existence of multiple mediators between age and complex working memory performance would not alter the conclusions from the current study, it definitely warrants further investigation, for instance, by looking at multiple tasks and including latent variables that represent "passive" and "active" working memory tasks.

A final issue concerns recent findings in functional imaging studies demonstrating the involvement of the inferior frontal junction area (posterior frontolateral cortex) in both inhibitory control, as measured with the Stroop task, and working memory, as measured with the *n*-back task (e.g., Derrfuss et al., 2004). The *n*-back task (Dobbs & Rule, 1989) is similar to the SPASAT in that it also involves a serially presented array of items (words, digits, or pictures). The goal of the task is to judge whether the current item is the same as the item that was presented *n* items before. Thus, like the SPASAT, the *n*-back task requires the participant to actively manipulate, rather than passively store, the presented information, although it does not involve addition of the target digits. The finding that inhibition and active working memory draw on the same cortical area may explain the relation between the two in the current study, especially if one considers that the frontal lobes are particularly vulnerable to age-related brain decline (see, e.g., Tisserand & Jolles, 2003). It is unclear, however, whether it should be considered an alternative explanation of the current findings. After all, we do not yet have a complete picture of how the different substructures of the frontal lobes relate to different executive control functions, such as inhibition and coordination. Moreover, if the inferior frontal junction area were the only region that is essential to both inhibition and working memory, these functions would most likely show a higher correlation than the moderate correlation found in the current study ($r = -.46$). On the other hand, a common cortical region might actually indicate that Stroop and SPASAT performance are both dependent on inhibitory control, which is exactly in line with our hypothesis.

In sum, the current results support the hypothesis that the mediating role of inhibition in explaining age-related working memory decline depends on the characteristics of the task. Where its role was obvious in a task that merely appealed to the processing capacity of working memory, it was virtually absent in a task that merely appealed to its storage capacity. Speed, on the other hand, turned out to be a stable, task-independent mediator between age and working memory. These findings provide an initial impetus to explaining the mixed results reported in the literature with respect to the mediating role of inhibition in age-related working memory decline. Further research might reveal whether this relative role of inhibition emerges from a broader range of tasks.

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