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Effect of a simple experimental control: The recall constraint in Sternberg's memory scanning task

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This study was aimed at determining how a simple experimental control—recalling the sequence of digits in the order they were presented—may affect quantitative and qualitative performance in Sternberg's short-term memory scanning paradigm. First, the presence or absence of this constraint was shown to have practically no effect on the relationship between sequence length and mean response time: the two general laws proposed by Sternberg were found to hold true in both experimental conditions. However, subjects who had to recall the digit sequence were consistently slower than those who did not, and the *yes* response curves of the two experimental conditions differed in shape. Moreover, correlations between parameters of the linear function and various aptitude scores showed that this task was linked to the memory span only when the participants had to recall the digit sequence. If our results are confirmed, they should help to improve the interpretation of the data collected in many studies that use this paradigm in cognitive psychology as well as in neuroscience of memory.

The aim of this paper is to study how a simple experimental control may affect quantitative and qualitative performance of participants.

In his initial study on mental scanning, Sternberg (1966) showed participants a sequence of digits and asked them first to say whether a given test digit was in the sequence, and then to recall the digits in the order in which they had been presented. Since then, most studies using this paradigm did not ask any recall of the sequences, or at least did not mention doing so.

With his experimental procedure, Sternberg defined the task as a memory task. All results and conclusions drawn from them by Sternberg as well as by other authors are thus based on this definition. But would not the nature of the task be different if the recall constraint—a serial recall task which is well known for having particular effects—were not applied? If so, should the

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conclusions of studies using the Sternberg paradigm without the recall constraint be questioned? This question is all the more important that this paradigm has not only been used in the past in traditional experimental psychology but is presently used by numerous studies in neuroscience.

Three lines of research have used this paradigm: studies conducted in general cognitive psychology, studies attempting to demonstrate links between this task and certain abilities, and more recently studies in cognitive neuroscience of memory.

STERNBERG'S PARADIGM

Sternberg presented his "memory scanning" paradigm in the framework of memory retrieval. The varied-set procedure consists of presenting a sequence of one to six digits defined as "the positive set". These digits are drawn at random from the set of all digits between 1 and 9. They are shown one by one and participants are instructed to memorise them. The rest of the digits (the ones not shown) constitute the "negative set". After a signal, a test digit is presented and the subject has to decide as quickly and accurately as possible whether or not the test digit had occurred in the memory set. Then, to make sure the participants did in fact memorise the sequence, they are asked to recall the digits in their order of presentation.

Based on an analysis of mean response times, Sternberg derived two general laws (1966, 1969): (1) mean response time increases linearly with sequence length, and (2) the slope of the line is the same for the *yes* responses ("the digit was in the sequence") and the *no* responses. These results have been obtained for a wide variety of visual and auditory stimuli, including letters, symbols, colours, and words (Sternberg, 1975).

On the basis of these two general laws, Sternberg proposed his exhaustive serial search model of short-term memory retrieval. He explained the results by drawing an analogy with the computer. In the model, the digits 1 to 9 could be regarded as locations in memory. During sequence presentation, a marker is placed in the location assigned to each digit in the sequence. The test digit is then compared to each marked location. If it is identical to one of the locations, the match is detected by a comparator and a *yes* response is activated. The linear increase in response time (first law) was explained on the assumption that the rate of checking locations was constant and is estimated by calculating the slope of the function. According to Sternberg (1975), the slope ranges from 35 ms to 45 ms per item.

Since the *yes*-response slope is the same as the *no*-response slope (second law), Sternberg assumes that the search is exhaustive: i.e., it continues until all marked locations have been checked, even if a match has already been detected. A *yes* response is not given until the memory scanning process has been completed. If the process stopped when a match was detected, i.e., if the search were self-terminating, the slope of the *yes* responses would be lower than that of the *no* responses.

In addition to the slope, the regression of response time on sequence length is used to determine the zero intercept, which Sternberg interprets as the duration of the encoding and motor response process, which is independent of sequence length.

STUDIES USING STERNBERG'S PARADIGM

Studies in general cognitive psychology

Numerous general cognitive psychology studies have used the memory scanning paradigm in the past. The first line of research was to replicate and generalise Sternberg's results (e.g., Atkinson, Holmgren, & Juola, 1969; Burrows & Okada, 1973; Chase & Calfee, 1969; Harris & Fleer, 1974; McCauley, Kellas, Dugas, & de Vellis, 1976; Swanson, Johnsen, & Briggs, 1972; Wingfield, 1973; Wingfield & Branca, 1970). The second line of research was to find evidence of phenomena that are incompatible with Sternberg's results (e.g., Burrows & Okada, 1971; Corballis, Kirby, & Miller, 1972; Klatzky & Smith, 1972; Monsell, 1978; Roznowski & Smith, 1993; Theios, Smith, Haviland, Traupmann, & Moy, 1973). Finally, the third line was to look for other models to account for the findings (e.g., Anderson, 1973; Baddeley & Ecob, 1973; Corballis et al., 1972; Theios et al., 1973). To sum up, despite much research using Sternberg's paradigm, there is no consensus on the processes really implemented in this task (e.g., Monsell, 1978; Townsend & Ross, 1973). More specifically, there still is an active discussion about the kind of research that this task implies: serial exhaustive (e.g., Sternberg, 1966, 1975; Wingfield & Branca, 1970), serial self-terminating (e.g., Theios et al., 1973; Townsend & Ross, 1973), parallel with resource limited search (e.g., Anderson, 1973; Ashby, Tein, & Balakrishnan, 1993; Atkinson et al., 1969; Ratcliff, 1978; Townsend & Ross, 1973; Van Zandt & Townsend, 1993) or direct access (e.g., Baddeley & Ecob, 1973; Burrows & Okada, 1971; Corballis et al., 1972; Monsell, 1978).

In most of these numerous studies, the authors do not mention that the participants were asked to recall the sequence.

Correlation studies

Correlation-based differential psychology, particularly research on the cognitive correlates of abilities (Pelligrino & Glaser, 1979), has also taken an interest in the memory scanning paradigm. This research trend attempts to provide evidence of a link between performance on classic information processing paradigms in psychology, and scores obtained by the same participants on psychometric tests. As early as 1973, and then again in 1975 and 1978, Hunt used Sternberg's paradigm to relate short-term memory retrieval speed to participants' scores on verbal-ability tests, thought to be the best predictors of various kinds of human cognitive performance. The recall requirement was never used in these studies either (Hunt, 1978; Hunt, Frost, & Lunneborg, 1975; Hunt, Lunneborg, & Lewis, 1975).[1]

The existence of a link between information-retrieval speed in short-term memory and participants' scores on verbal-ability tests became a topic of discussion. Hunt et al. (1973) showed that high-ability participants apparently manipulate information in short-term memory faster than low-ability ones do. According to Hunt (1978), Sternberg (1975), on the contrary, had stated that there was no correlation between scanning speed and ability measures.[2] Hunt (1978) answered by presenting a summary of the results of several studies demonstrating this relationship in various populations differing in overall verbal ability. Note that the correlations never went above what Hunt called the ".30 barrier", as is often the case in differential cognitive psychology.

Another interest in this line of research focuses on the relationship between scanning rate and memory span (Brown & Kirsner, 1980; Cavanagh, 1972; Chiang & Atkinson, 1976; Dempster, 1981; Puckett, 1982; Puckett & Kausler, 1984). Cavanagh (1972) was the first to compare memory processing rate, measured by the slope of Sternberg's task, and memory span across several classes of stimuli. By a review of literature, Cavanagh reported high correlations between scan rate and the reciprocal of memory span across material types. The greater the memory span for any material, the faster its processing rate. The follow-up studies replicated overall Cavanagh's results but also showed several conflicting correlational analyses in a within individual design across material.

We examined the results of studies concerning the relation between span and scan rate within the same class of material. Chiang and Atkinson (1976) found no significant correlation for their overall sample. Nevertheless, they showed different patterns of correlations by gender with significant correlations between slope and span only for males. We can notice that in this study, the slope parameter is a computed parameter between the slopes of the memory search task and the visual search task. Similarly, Brown and Kirsner (1980), Puckett (1982), and also Puckett and Kausler (1984) found no significant correlation between scan rate and span within each stimulus class they used (digits, letters, words, nonsense syllables, etc.). Contrary to

[1] Experimental condition certified by Hunt (personal communication).

[2] We were not able to find any conclusion of this kind in Sternberg's (1975) paper.

the results of Chiang and Atkinson, none of these studies found differences in correlations according to the sex. In line with the results of these studies which did not require participants to recall the sequence, within stimulus class, individuals with high memory spans appeared to be no more likely to have rapid memory search rates than individuals with low memory spans in the recognition task.

Research in cognitive neuroscience of memory

Nor is the sequence-recall part of the task mentioned in the neuroscience research studies that use this paradigm, whether they are aimed at determining what evoked potentials best reflect the memory processes involved in this task in healthy participants (e.g., D'Esposito, Postle, & Rypma, 2000; Jensen, Gelfand, Kounios, & Lisman, 2002; Pelosi, Hayward, & Blumhardt, 1998; Wolach & Pratt, 2001), at examining deficits and alterations of short-term memory in normal ageing (e.g., Pelosi & Blumhardt, 1999; Rypma, Berger, Genova, Rebbechi, & D'Esposito, 2005), or in disorders like schizophrenia (e.g., Ahn et al., 2003), Alzheimer (e.g., Karrasch et al., 2006), depression (e.g., Pelosi, Slade, Blumhardt, & Sharma, 2000), and multiple sclerosis (e.g., Archibald et al., 2004; Pelosi, Geesken, Holly, Hayward, & Blumhardt, 1997), or at determining the effects of certain types of medication on memory (e.g., Allain, Bentue-Ferrer, Tarral, & Gandon, 2003; Moulton, Boyko, Fitzpatrick, & Petros, 2001; Verster, Volkerts, & Verbaten, 2002).

In the present study, we will focus on the serial recall, an experimental constraint assumed to be an additional task in the item-recognition paradigm. The serial recall has been considerably studied in the past and it has been emphasised that particular characteristics and mechanisms are underlying this type of recall (e.g., Conrad, 1964; Cowan, Baddeley, Elliot, & Norris, 2003; Cowan, Chen, & Rouder, 2004; Ebbinghaus, Ruger, & Bussenius, 1913; Estes, 1972; Farell & Lewandowski, 2003; Klein, Addis, & Kahana, 2005; Lewandowsky & Murdock, 1989; Nairne & Kelley, 2004; Shiffrin & Cook, 1978; Waugh, 1961). According to Lewandowsky and Murdock's review of the literature (1989), the four most important results regarding serial order memorisation are: (1) "the serial learning curves", that showed both a U-shaped serial position curve with primacy and recency effects and a general improvement in performance over trials; (2) "the memory span functions", that showed a reverse S-shaped function decreasing as the list length increases, with the same main features regardless of the materials; (3) "the partial report effects", showing different patterns in serial position compared to serial learning curves, with more recency and less primacy effects than in whole report recall. Moreover, differences between these two kinds of recall—the absolute level of recall being higher in the partial than in the whole report—suggested an “output interference” in the latter condition, where recalling one thing interfered with the potential recall of something else; (4) “the delayed recall effects” showing different manifestations of interference when very short lists must be recalled after varying delays with, among others, a build-up of proactive interference as participants go along trials. In the literature, other empirical phenomena are also associated and considered to be crucial features of short term serial recall, such as phonological similarity effects and modality effects (e.g., Conrad, 1964; Cowan, Saults, & Brown, 2004; Cowan, Saults, Elliott, & Moreno, 2002; Farell & Lewandowski, 2003; Li & Lewandowsky, 1995). Phonological similarity effect refers to the well-replicated finding according to which lists composed of similar sounding items are recalled less accurately than lists in which items do not sound alike. Modality effect refers to another well-known effect that is auditory presentation leading to better memory for the last few items than visual presentation.

These empirical benchmarks show that the serial recall task involves specific processes of memorising that are different from those involved in free recall or in recognition. Indeed, the serial recall task requires participants to memorise not only the items but also the order in which they occurred. In comparison, the recognition task normally requests memory only for item information. We can thus assume that participants, who are instructed to do a serial recall after the recognition task, must memorise not only the item information but also the order information, whereas subjects whom do not have this constraint only have to memorise information on items. We can also suppose that this additional information to memorise consequently extends the time to perform the recognition task. If this effect exists, which stage will be affected by this constraint, the encoding, the comparison stage, or both?

The first goal of the present study was to look at the effect of having a serial sequence-recall condition on Sternberg’s two laws, on the validity of the exhaustive serial search model, and on the participants’ memory scanning speed. The second goal was to study the effect of the serial sequence-recall condition on the nature of the task, based on an analysis of the relationships between memory scanning speed and scores on various psychometric tests.

METHOD

The experiment consists of two sessions each lasting about 45 minutes. The first session was used to obtain participant scores on a number of ability tests; the second was devoted to the Sternberg paradigm. To avoid a task-interference bias, the two sessions were held at least 2 weeks apart.

Participants

Seventy-two third-year psychology students at Paris Descartes University volunteered to participate in the experiment (66 woman and 6 men). They were between 20 and 35 years old (mean age 22.3 years, standard deviation 3.23) and all were native speakers of French.

Psychometric tests

All participants took Thurstone's PMA (Primary Mental Abilities, 1958/1964), which measures five primary mental abilities: V (verbal meaning), S (spatial), R (reasoning), N (numerical), and W (verbal fluency). The participants' memory was assessed using the WAIS-III digit span subtest (Wechsler Adult Intelligence Scale; Wechsler, 1997/2000), which has two parts: recall digits in the forward order and recall digits in the backward order.

It was assumed that participants would use different strategies to perform the digit span subtest (WAIS-III). For this reason, they were asked a number of preprepared questions right after the test, and their verbalisations were recorded. The questions were designed to determine as precisely as possible what strategy each subject had used to carry out the task. The experimenter did not request any inferences from the participants, and stressed that they should only say what they were sure of and should not make anything up (Kail & Bisanz, 1982).

Given the potential link between this subtest and Sternberg's task, we established two groups paired on the strategies used as well as on the scores obtained in the digit span subtest. We made sure that the mean scores on this subtest did not differ significantly between the two groups (17.06 vs. 16.5), $F(1, 70) < 1$, *ns*.

Sternberg's paradigm

During the second experimental session, the participants performed Sternberg's memory scanning test. To examine the potential effect of having or not having to recall the digit sequence, participants were divided into two experimental groups that were equivalent on the WAIS subtest. One group worked in the conditions defined by Sternberg (condition C1: digit-sequence recall condition); the other group was not asked to recall the sequence (condition C2: no-recall condition). The two groups were the same age (21.9 vs. 22.6), $F(1, 70) < 1$, *ns*.

Experimental procedure

The participants were seated comfortably at about 60 cm from the computer screen. First, the experimental task instructions were displayed on the screen. The experimenter allowed the participant enough time to read the instructions carefully. When the subject had finished reading the instructions, the experimenter went over the important points to make sure he/she understood the task.

The procedure was as follows. At the beginning of each trial, the word "Attention" was displayed, after which the subject saw a sequence one to six digits long (*L*). The items in the sequence were presented one by one in the middle of the screen for 1.2 s each. Sequence length varied randomly across trials. After the last digit in the sequence, a warning signal was displayed in the centre of the screen for 2 s and was then replaced by a test digit. Participants had to decide as quickly and as accurately as possible whether this digit was in the sequence just presented. To answer, they had to use their dominant hand to press a key on the standard keyboard if they thought the test digit was in the sequence, and another key with their other hand if not. As soon as one of the keys was pressed, a one-word feedback message about the answer ("correct" or "incorrect") appeared on the screen to encourage participants to respond quickly while keeping their error rate as low as possible. To complete the trial, participants in the recall condition (C1) had to recall the sequence aloud in the order in which the digits had been presented. Participants in the no-recall condition (C2) went directly on to the next trial. In the recall condition, the duration of the intertrial interval is thus longer than in the no-recall condition. We decided to not provide an equivalent intertrial interval in the no-recall condition in order to be closest to the experimental procedures of usual research which does not apply the recall condition. Indeed, in research using Sternberg's paradigm without the restitution constraint, the participants take trials one after the other without any delay. We made this choice, among others possibilities, in order to be able to compare our results and conclusions with those of this type of research.

Each subject was trained on a practice block of 24 trials, and then performed three experimental blocks of 48 trials. For each value of *L*, items for which the answer was *yes* and items for which the answer was *no* were equally frequent. Each digit appeared the same number of times in each block and was the test digit equally often, both for the *yes* responses and for the *no* responses. Every sequence in every block was drawn at random from the list of items. Thus, for each subject, there was a random item-presentation order that was different each time.

The response time (RT) of each subject was measured on each item. RT began when the test digit appeared on the screen and ended when the subject responded by pressing a key. The correctness or incorrectness of each answer was recorded.

RESULTS

For each experimental block, only the response times (RT) for which a correct answer was given were retained for analysis. Response times three standard deviations or more above or below the mean were discarded (i.e., RTs greater than 2000 ms or less than 100 ms). The discarded RTs represented only 1.35% of the total number of items in the three experimental blocks. All statistical tests were computed with the same *MSE* to attain greater comparability across conditions.

Effect of sequence recall on accuracy

Analysis of response accuracy showed relatively low error rates in both conditions. As in Sternberg's experiment, in the recall condition, the accuracy data differed significantly according to sequence's length, $F(5, 175) = 20.20$, $p < .0001$. This result was explained by the significant linear decrease of the accuracy data, $F(1, 35) = 41.39$, $p < .0001$, ordered from 97.9% for *L1* to 91.0% for *L6* (see Figure 1). The same pattern of accuracy data was found in the no-recall condition (see Figure 1). Even if the accuracy was each time slightly higher for *L*2 to *L*6 in the recall condition, differences were not significant, $F(1, 70) = 3.27$, $p > .05$. Discarded item-error represents 3.72% and 4.82% respectively for the recall and the no-recall condition.

Concerning the restitution accuracy, in the recall condition, the participants well recalled in 99.3% of the items for *L1* to 53.8% of the items for *L6* (see Figure 1). Overall, errors occurred on 13.52% of the items. Nevertheless, this relevant error rate of restitution is explained, in majority, by the strong rate found for *L5* and *L6* lengths (the percentage of well recalled does not below 90% of the items until the *L4* length).

Effect of sequence recall on Sternberg's laws

First law. Sternberg's first general law stipulates that RT (averaged over the two types of responses) is directly proportional to sequence length. The Sternberg's results indicated a linear fit that explained 99.4% of the variance

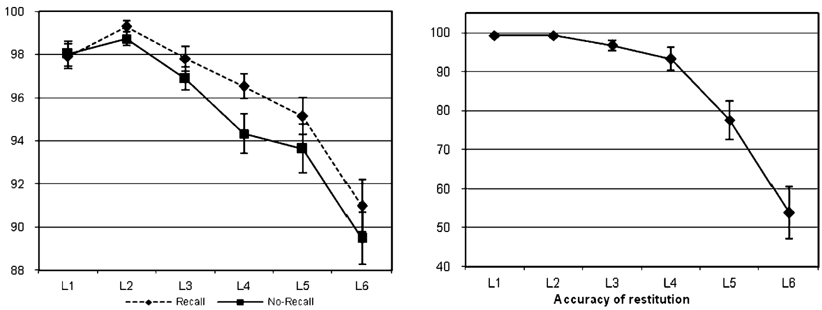

Figure 1. Left: percentage of accuracy, by sequence length, and experimental condition; right: percentage of accuracy of restitution for the recall condition (vertical bars indicate standard errors of the mean).

over the set of mean RTs, with a slope of 37.9 ± 3.8 ms per item and a zero intercept of 397.2 ± 19.3 ms. Remember that the slope of the regression line and its zero intercept correspond respectively to the average time needed to retrieve an element in short-term memory, and the mean duration of the encoding and motor response process. In our study, we first replicate Sternberg's results. We find a slope of 62.15 ± 3.52 ms per item; a zero intercept of 583.13 ± 13.72 ms and the linear fit explain 98.7% of the variance.

Second, we studied the effect of the recall constraint. The main effect of the condition was significant, $F(1, 70) = 6.14$, $p < .05$. Moreover, Figure 2 shows that participants in the no-recall condition had significantly shorter mean response times than participants in the recall condition, regardless of sequence length.

The interaction between the condition factor and the sequence-length factor was the only significant interaction, $F(5, 350) = 3.37$, $p < .01$. The slopes of the regression lines, which were 47.20 ± 3.32 ms for the no-recall conditions, differ significantly according to the condition. However, this interaction cannot be explained by a difference between the conditions in the fit of Sternberg's model: in the no-recall and recall conditions alike, only the linear trend was significant, $F(1, 175) = 369.64$, $p < .0001$; $F(1, 175) = 566.26$, $p < .0001$, respectively. This trend accounted for 98.1% in the no-recall condition (see Figure 2).

In summary, when the two response types were pooled, Sternberg's model fit equally well in the two conditions. On the other hand, whether for the overall RT mean or RT slope, participants in the no-recall condition answered faster than the ones in the recall condition. An analogous difference was found for the zero intercept (538.69 ± 12.92 ms for the no-recall condition).

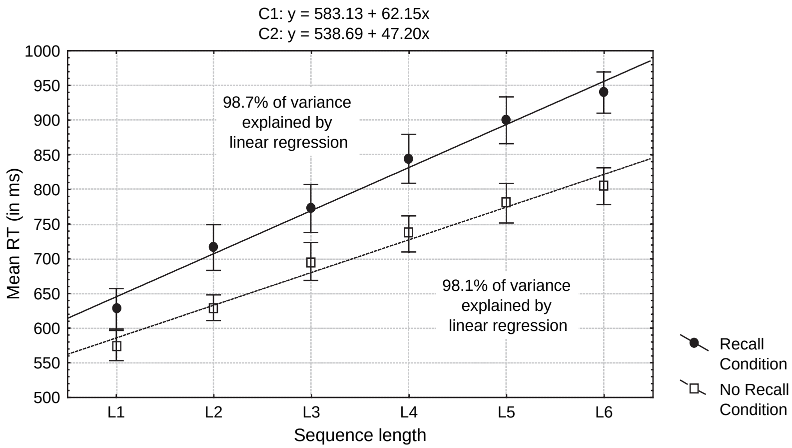

Figure 2. Mean response time (in ms), by sequence length and experimental condition (vertical bars indicate standard errors of the mean).

Second law. Sternberg's second law stipulates that the slope of the regression line is the same for both types of responses. Here, the *yes*-response slope differed from the *no*-response slope by only 9.6 ± 2.3 ms per item.

The recall condition data indicated a difference of 4.23 ± 0.34 ms between the two slopes and a nonsignificant interaction between sequence length and type of response (64.27 ms vs. 60.04 ms), $F(5, 175) < 1$, *ns.* So, with the same experimental conditions as Sternberg, our data are consistent with the second law.

In the no-recall condition, the data revealed a difference of 1.93 ± 0.83 ms between the two slopes, which is less than that obtained for participants in the recall condition, and also less than in Sternberg's results. The interaction between sequence length and type of response was not significant either (46.23 ms vs. 48.16 ms), $F(5, 175) < 1$, *ns.* Thus, our data followed Sternberg's second law even when the participants did not have to recall the digit sequence.

However, the interaction between the condition factor and the sequence-length factor, which was significant when the two types of responses were pooled, $F(5, 350) = 3.37$, $p < .01$, was in fact only significant for the *yes* responses: *yes* responses, $F(5, 350) = 3.56$, $p < .005$; *no* responses, $F(5, 350) = 1.54$, *ns* (see Figure 3).

This finding can be probably identified with the differences in trends. In the no-recall condition, the linear trend was significant for the *yes* responses, $F(1, 175) = 354.72$, $p < .0001$, and accounted for 97.1% of the variance. But the residue of this trend was significant too, $F(4, 175) = 2.68$, $p < .05$. This being the case, we tested other tendencies: the quadratic trend turned out to

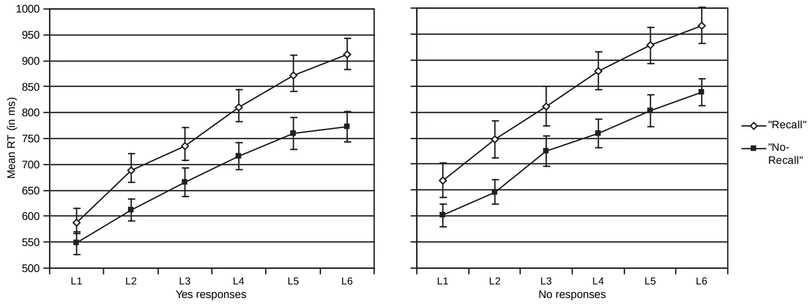

Figure 3. Mean response time (in ms), by experimental condition, sequence length, and type of response (vertical bars indicate standard errors of the mean).

be significant also, $F(1, 175) = 9.71$, $p < .005$. Although this trend only accounted for 2.7% of the variance, this quadratic coefficient was stronger than those for the other data set (recall condition: 0.90% and 1.28% for respectively *yes* and *no* responses and 1% for the *no* responses of the no-recall condition). However, the difference between the two conditions of this quadratic coefficient for the *yes* responses was not significant. For the *no* responses, the results were comparable to those in the recall condition: the linear trend was significant, $F(1, 175) = 384.86$, $p < .0001$, and accounted for 98.3% of the variance, but the residue of this trend was nonsignificant, $F(4, 175) = 1.69$, $p > .05$, *ns.*

It seems that in the no-recall condition, the RT increase for the *yes* responses decreased as the sequences got longer, approaching a plateau (see Figure 3). For this condition and for this type of response, the logarithmic fit was as good as the linear fit. It would thus be interesting to check for this phenomenon in a new experiment using sequences of more than six digits. An interpretation in terms of exhaustive serial memory scanning may not be the only possible one as suggested by the literature.

In conclusion, according to our first two analyses, the experimental condition in which participants were tested had little effect on Sternberg's two general laws. In both conditions, the data were compatible with his model, which states that participants perform an exhaustive serial scan of information in short-term memory. This may be why authors who have reused this paradigm have not taken an interest in the impact of the recall requirement.

However, the comparison between the two conditions showed that this factor had an effect on mean RT. No-recall participants were much faster at carrying out the task than recall participants were. Moreover, the significant interaction between the condition factor and the sequence-length factor on the *yes* responses, and the significant quadratic trend in the no-recall condition for this same type of response, raise the question of whether the nature of the task is the same in the two experimental conditions.

Effect of the recall constraint on the nature of the task: Link between memory scanning speed and various abilities

A correlational approach was used to explore this question. By relating memory scanning speed to verbal-ability scores, this approach should first tell us whether our data replicates Hunt.

Link between memory scanning speed and verbal abilities. First, the memory scanning speed of each subject was computed for each type of response; this speed was equal to the slope of the line representing the regression of individual RTs over sequence length. Then, correlation coefficients between these individual slopes and PMA test scores on the V (verbal meaning) and W (verbal fluency) factors were calculated. Also, partial correlations between the slopes and the V scores while keeping W scores constant, and partial correlations between the slopes and the W scores with V scores held constant, were computed (the partial correlation coefficients were in fact very close to the nonpartial ones).

As Table 1 shows, none of the partial correlation coefficients were significant in the recall condition. The correlations between factor V and the *no*-response slope, and between factor W and the *yes*-response slope, were close to zero. Slightly higher correlations in the expected direction were found between factor V and the *yes*-response slope, and in the opposite direction between factor W and the *no*-response slope. For the no-recall condition, significant partial correlations that crossed Hunt's .30 barrier were found between factor W and the slopes of both types of responses.

TABLE 1
Partial correlations between individual slopes and verbal-ability scores in each experimental condition; significant differences in correlation between the "recall" and "no-recall" conditions at $p/2 < .05$ are in bold

	Partial correlation between slopes and verbal meaning scores (verbal fluency scores held constant)		*Partial correlation between slopes and verbal fluency scores (verbal meaning scores held constant)*	
	Yes	*No*	*Yes*	*No*
Recall condition (C1)	–0.24	0.00	**0.09**	**0.17**
No-recall condition (C2)	0.11	0.02	**–0.38***	**–0.33***

*Significant correlations at $p/2 \leq .025$ (one-sided).

Moreover, the differences in correlation between the two conditions were significant: $r = .09$ vs. $r = -.38$, $p/2 < .05$ for yes response, and $r = .17$ vs. $r = -.33$, $p/2 < .05$ for no response, for the "recall" and "no-recall" conditions, respectively (see Table 1). The correlations obtained for factor V were weaker and nonsignificant.

Thus, the link between RT slope and verbal ability differed across experimental conditions: memory scanning speed increased with verbal ability in the no-recall condition only, and for verbal fluency only.

Comparisons across groups contrasted on each ability score supported the above results. As in Hunt's (1973, 1978) studies, high and low verbal-ability groups were compared by selecting participants whose scores fell respectively in the upper and lower quartiles of the score distributions. A slope difference between the high and low groups, i.e., a significant interaction between ability and sequence length, was found only for the no-recall groups contrasted on W: C1 contrasted on V, $F(5, 75) = 1.028$, $p > .10$; C1 contrasted on W, $F(5, 65) < 1$, *ns*; C2 contrasted on V, $F(5, 75) < 1$, *ns*; C2 contrasted on W, $F(5, 65) = 2.49$, $p < .05$.

These results allow us to resolve the so-called debate between Sternberg (1975) and Hunt (1978; Hunt et al., 1973). Indeed, for our participants who had to recall the sequence (the condition used by Sternberg in his initial 1966 experiment), there was no link between memory scanning speed and verbal ability. By contrast, for participants in the no-recall condition, memory scanning speed and verbal fluency were linked, which is in line with Hunt's (1978; Hunt et al., 1973) results. The following hypothesis can thus be set forth. Sternberg most likely asked participants to recall the sequence in his experimental procedure, as he mentioned in 1966, but Hunt did not. The results showed by Hunt may therefore be based on a difference in the experimental procedure, in such a way that Hunt was correct for the condition he used.

The existence or nonexistence of an association between memory scanning speed and verbal ability thus appears to depend on the conditions under which participants are tested, and seems to suggest that the nature of the experimental task differs according to whether the sequence has to be recalled. In order to further validate this trend, we calculated correlation coefficients between the various parameters in Sternberg's model and participants' other abilities and particularly with memory span.

Link between Sternberg's parameters and other abilities. Table 2 shows that the correlations between the slopes and the ability scores were weak. None of these correlations reached the corrected significance level of .05. However, there were a few differences across conditions. For the *yes* responses, reasoning and short-term memory capacity had a greater impact on scanning speed for participants in the recall condition than for

TABLE 2
Correlations between individual slopes and various abilities, by experimental condition

	Digit span task	*Forward digit span task*	*Backward digit span task*	*Spatial*	*Reasoning*	*Numerical*
Recall condition						
Slope—*yes* responses	−0.21	−0.20	−0.18	−0.23	−0.28	−0.04
Slope—*no* responses	0.01	0.05	−0.03	0.04	0.09	0.10
No-recall condition						
Slope—*yes* responses	0.10	0.07	0.11	−0.13	−0.01	−0.19
Slope—*no* responses	−0.11	0.02	−0.20	−0.08	−0.15	−0.19

participants in the no-recall condition (–.28 vs. –.01, and –.21 vs. .10, respectively).

Correlations were also calculated between the ability scores and (1) the zero intercept (Int) of the regression line, the second parameter of Sternberg's model, and (2) the mean RTs for each type of response (*M*). As Table 3 shows, the correlation coefficients considerably differed across the experimental conditions and factors considered. Here again, we find substantial differences between the two conditions, particularly regarding the involvement of short-term memory capacity, which was much greater in

TABLE 3
Correlations between the zero intercept (Int) and the various ability scores, and between mean response time (*M*) and those same abilities, by experimental condition; significant differences in correlation between the "recall" and "no-recall" conditions at $p/2 < .05$ are in bold

	Digit span task	*Forward digit span task*	*Backward digit span task*	*Spatial*	*Reasoning*	*Numerical*
Recall condition						
Int—*yes* responses	−0.32	−0.31	−0.26	−0.22	−0.06	−0.21
Int—*no* responses	−0.36	−0.36	**−0.29**	−0.32	−0.20	−0.26
M—*yes* responses	**−0.43***	−0.42*	−0.35	−0.34	−0.21	−0.23
M—*no* responses	−0.39	−0.36	−0.33	−0.33	−0.18	−0.23
No-recall condition						
Int—*yes* responses	−0.10	−0.14	−0.04	−0.27	−0.35	−0.07
Int—*no* responses	0.00	−0.15	**0.15**	−0.22	−0.01	−0.07
M—*yes* responses	**−0.03**	−0.08	0.03	−0.30	−0.30	−0.17
M—*no* responses	−0.06	−0.14	0.02	−0.26	−0.10	−0.18

M = mean response times; Int = intercept. *Significant correlations at the corrected level $p/7 = .005$.

the recall condition. Moreover, two of the differences in correlation between the two conditions were significant: $r = -.43$ vs. $r = -.03$, $p/2 < .05$, and $r = -.29$ vs. $r = .15$, $p/2 < .05$, for the "recall" and "no-recall" conditions, respectively (see Table 3).

These results were confirmed for the groups contrasted on memory capacity. A mean RT difference between participants with a high- and low-short-term memory capacity—and thus a significant effect of the contrasted-group factor—was only found in the recall condition: C1, $F(1, 23) = 5.22$, $p < .05$; C2, $F(1, 22) < 1$, *ns*. This finding is no doubt due to the similarity of the tasks: in both the WAIS subtest and the present recall condition, participants had to retrieve a sequence of digits in their order of presentation (see Figure 4).

In summary, it seems that certain nonverbal abilities also enter into this memory scanning test. And their impact appears to vary across experimental conditions and according to what model parameter is considered. It is thus possible that the nature of the task differs in these two experimental conditions. Indeed, the results showed that the memory scanning task was

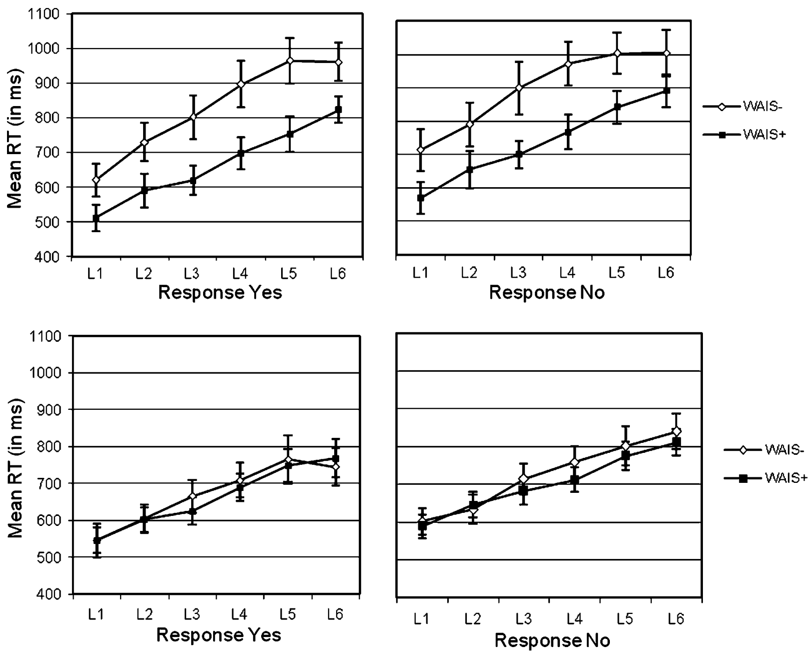

Figure 4. Mean RT (in ms) by sequence length and type of response, for the two groups defined on the basis of their WAIS digit span subtest scores, in "recall" (top) and "no recall" conditions (bottom). Vertical bars indicate standard errors of the mean.

only linked to the memory span test when the participants had to recall the digit sequence.

DISCUSSION

It was shown here on a task involving information scanning in short-term memory that a simple experimental control—the constraint of having to recall the sequence of digits in order—had practically no effect on the two general laws demonstrated by Sternberg: mean RTs increased linearly with sequence length, and the regression line slope was the same for the two types of responses. The exhaustive serial search model of information scanning in short-term memory thus seems to be a valid model of the behaviour assumed to be shared by all individuals. These results could explain why authors who have used the Sternberg paradigm, most of whom have not included the recall requirement, have never taken an interest in the role of this constraint.

However, the present study showed that participants in the no-recall condition responded much faster than did participants in the recall condition. The lesser rapidity of the serial recall-condition participants can of course be explained by the fact that this constraint slows down execution of the main task by requiring participants' additional attention to information order. Our results showed that the slowness occasioned by the serial recall affects not only the encoding stage but also the comparison stage. These findings indicate that the serial recall task changes the nature of digits' encoding by directing participants' attention on order, which is not of particular use in probe recognition.

The increase effect on slope of the recall constraint suggests that the serial exhaustive model was not the better framework to account for this result. The difference in slope between the two conditions can be more easily explained in a parallel with limited capacity model. Indeed, if the search proceeds in parallel but with limited capacity, the memorisation of additional order information might extend the processing load and thus slow the speed of search (e.g., Ashby et al., 1993; Atkinson et al., 1969; Ratcliff, 1978; Townsend & Ross, 1973).

Furthermore, the significant interaction between the condition and sequence-length factors on the *yes* responses—which can be interpreted by the presence of a strongest quadratic tendency in the no-recall condition—led us to wonder whether the experimental task might not differ in nature in the two experimental conditions.

In an attempt to answer this question, correlations were computed between the parameters of Sternberg's general laws and scores on various ability tests. The first step was to try to decide whether Hunt was right about the existence of a link between verbal ability and memory scanning speed.

It turned out here that this link depended on the experimental condition: as in the comparison of groups contrasted on verbal ability, the correlations obtained here were compatible with Hunt's results in the experimental condition he used (without recall) but not in the condition described in Sternberg's initial experiments (with recall).

However, some issues can be raised from these results. Significant correlations observed with verbal ability in the no-recall condition were only found with verbal fluency. We can notice that these correlations were not the more expected correlations because the verbal fluency test was not the more representative of the verbal ability tests. Rosen and Engle (1997) showed that verbal fluency was related to working memory capacity, more precisely to executive control. In this view, how can we explain the link between verbal fluency and scan rate in the no-recall condition? This issue needs further investigations. Furthermore, another possible interpretation is that this test was also speed-dependent. This characteristic alone might explain the correlations we found. If so, why these correlations were only found with the no-recall condition?

The next step was to show that not all of the abilities involved in this task are verbal, and that the impact of these other abilities differs across experimental conditions. In the recall condition, the links were the strongest and concerned a wider range of abilities. In particular, the association between the memory scanning test and the WAIS digit span subtest only existed when participants had to recall the sequence. These results are congruent with those of preceding research which did not used the recall constraint and found no significant correlations between span and scan rate within a class of material. This link in the recall condition can be explained by the similarity between the two tasks: in both Sternberg's "with recall" task and the WAIS subtest, participants must memorise order and item information to recall digits in their order of presentation. The serial recall probably increased participants' focusing on order information. Thus, this serial recall may be responsible for the stronger correlation with the WAIS digit span subtest. Focusing on order information can also explain why participants in the recall condition descriptively make fewer errors than those in the no-recall condition. We can therefore conclude that in the recall condition—and only in this condition—the task has a memory span component. To go further, several other experiments could be done.[3] For example, it would be interesting to compare the effect of a condition of serial recall to a condition of free recall. This would enable us to know if the results highlighted in our research are due to the fact of recalling the sequence or more particularly to the fact of recalling it in the order. Another experiment

[3] We thank J. Rouder for his relevant suggestions.

can consist in forcing participants to process the digits semantically to necessitate a semantic level encoding. If the serial recall affects the same stage of encoding, then the addition of this task may have very little effect.

The experimenter-imposed recall constraint thus had an impact on task execution. Even if at first, this constraint did not seem to have much of an effect from a quantitative standpoint, the results obtained in the correlation analysis suggested that this constraint changed the very nature of the task. In the recall condition, the task was mainly a memorisation task involving both short-term memory capacity and working memory capacity. By contrast, in the no-recall condition, participants apparently relied on different processes, not only verbal fluency processes, for example, but also other processes, which an additional study should allow us to determine. Further research examining this variability from both the quantitative and qualitative angles should provide insight into how participants organise these processes into cognitive strategies and whether or not those strategies are the same in the two experimental conditions (see Marquer, 1990, or Marquer & Pereira, 1990, for examples of studies that use this type of methodology).

However, concerning RT and accuracy data, we report unusually high RT and error rates. Nevertheless, the unusual RT only exists for the recall condition. In fact, the results found in the no-recall condition are closed to those found in the literature (see Cavanagh, 1972, for a review of the literature). As we did not find any research that request participants to recall the sequence, we cannot compare our results in the recall conditions to those of the literature except with Sternberg's findings. Yet, it would be interesting to replicate this experiment by providing more incentive for faster response rate to the participants. For example, feedback about response speed could be provided.[4] Thereafter, we can analyse the effect of this procedure. Concerning accuracy data, research which found error rates higher than those found by Sternberg can be frequently found in the literature (e.g., Baddeley & Ecob, 1973; Burrows & Okada, 1971; Chase & Calfee, 1969; Chiang & Atkinson, 1976; Hunt et al., 1975; McCauley et al., 1976; Wingfield & Branca, 1970).

Furthermore, regarding correlational analyses, our data showed some differences between correlations in the two conditions, yet only few differences were significant. It will be interesting to replicate this experiment with a larger sample to confirm this pattern of correlations. Moreover, even if our analyses on the relationship between span and scan do not show significant different correlations according to participants' gender within a class of material, the pattern of correlation seems to be different. Thus, if

[4] We also thank Nelson Cowan and an anonymous reviewer for their relevant suggestions.

this experiment is replied, it will be relevant to balance conditions by gender and to analyse the results by gender.

To conclude, we will underline the fact that the memory scanning paradigm is widely used today in cognitive neuroscience of memory. Currently, many studies use Sternberg's paradigm to investigate the role of different cerebral areas (see D'Esposito et al., 2000, for a review of the literature) or brain oscillations (e.g., Jensen et al., 2002; Raghavachari et al., 2001) in working memory. However, these studies use the item-recognition task without the recall condition, yet the conclusions drawn are generally based on Sternberg's interpretation (with recall) of the different processes involved in this task. If our results are confirmed, interpretations of the findings of this type of study and also the conclusions of the research on short-term memory or working memory deficits and impairments that uses this task should be reconsidered.

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REFERENCES

Ahn, K. H., Youn, T., Cho, S. S., Ha, T. H., Ha, K. S., Kim, M. S., & Kwon, J. S. (2003). N-Methyl-D-aspartate receptor in working memory impairments in schizophrenia: Event-related potential study of late stage of working memory process. *Progress in Neuro-Psychopharmacology and Biological Psychiatry*, *27*, 993–999.

Allain, H., Bentue-Ferrer, D., Tarral, A., & Gandon, J. M. (2003). Effects on postural oscillation and memory functions of a single dose of zolpidem 5 mg, zopiclone 3.75 mg and lormetazepam 1 mg in elderly healthy subjects: A randomized, cross-over, double-blind study versus placebo. *European Journal of Clinical Pharmacology*, *59*(3), 179–188.

Anderson, J. A. (1973). A theory for the recognition of items from short memorized list. *Psychological Review*, *80*, 417–437.

Archibald, C. J., Xingchang, W., Scott, J. N., Wallace, C. J., Zhang, Y., Metz, L. M., et al. (2004). Posterior fossa lesion volume and slowed information processing in multiple sclerosis. *Brain*, *127*, 1526–1534.

Ashby, F. G., Tein, J., & Balakrishnan, J. D. (1993). Response time distributions in memory scanning. *Journal of Mathematical Psychology*, *37*(4), 526–555.

Atkinson, R. C., Holmgren, J. E., & Juola, J. F. (1969). Processing time as influenced by the number of elements in a visual display. *Perception and Psychophysics*, *6*, 321–327.

Baddeley, A. D., & Ecob, J. R. (1973). Reaction time and short-term memory: Implications of repetition effects for the high-speed exhaustive scan hypothesis. *Quarterly Journal of Experimental Psychology*, *25*, 229–240.

Brown, H. L., & Kirsner, K. (1980). A within-subjects analysis of the relationship between memory span and processing rate in short-term memory. *Cognitive Psychology*, *12*(2), 177–187.

Burrows, D., & Okada, R. (1971). Serial position effects in high-speed memory search. *Perception and Psychophysics*, *10*, 305–308.

Burrows, D., & Okada, R. (1973). Parallel scanning of semantic and formal information. *Journal of Experimental Psychology*, *97*, 254–257.

Cavanagh, J. P. (1972). Relation between the immediate memory span and the memory search rate. *Psychological Review*, *79*(6), 525–530.

Chase, W. G., & Calfee, R. C. (1969). Modality and similarity effects in short-term recognition memory. *Journal of Experimental Psychology*, *81*, 510–514.

Chiang, A., & Atkinson, R. C. (1976). Individual differences and interrelationships among a select set of cognitive skills. *Memory and Cognition*, *4*(6), 661–672.

Conrad, R. (1964). Acoustic confusions in immediate memory. *British Journal of Psychology*, *55*(1), 75–84.

Corballis, M. C., Kirby, J., & Miller, A. (1972). Access to elements of a memorized list. *Journal of Experimental Psychology*, *94*, 185–190.

Cowan, N., Baddeley, A. D., Elliott, E. M., & Norris, J. (2003). List composition and the word length effect in immediate recall: A comparison of localist and globalist assumptions. *Psychonomic Bulletin and Review*, *10*(1), 74–79.

Cowan, N., Chen, Z., & Rouder, J. N. (2004). Constant capacity in an immediate serial-recall task: A logical sequel to Miller (1956). *Psychological Science*, *15*(9), 634–640.

Cowan, N., Saults, J. S., & Brown, G. D. A. (2004). On the auditory modality superiority effect in serial recall: Separating input and output factors. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *30*(3), 639–644.

Cowan, N., Saults, J. S., Elliott, E. M., & Moreno, M. V. (2002). Deconfounding serial recall. *Journal of Memory and Language*, *46*(1), 153–177.

Dempster, F. N. (1981). Memory span: Sources of individual and developmental differences. *Psychological Bulletin*, *89*(1), 63–100.

D'Esposito, M., Postle, B. R., & Rypma, B. (2000). Prefrontal cortical contributions to working memory: Evidence from event-related fMRI studies. *Experimental Brain Research/Experimentelle Hirnforschung/Experimentation Cerebrale*, *133*(1), 3–11.

Ebbinghaus, H., Ruger, H. A., & Bussenius, C. E. (1913). *Memory: A contribution to experimental psychology.* New York: Teachers College, Columbia University.

Estes, W. K. (1972). An associative basis for coding and organization in memory. In A. W. Melton, & E. Martin (Eds.), *Coding processes in human memory* (pp. 161–190). New York: Halsted Press.

Estes, W. K. (1997). Processes of memory loss, recovery, and distortion. *Psychological Review*, *104*(1), 148–169.

Farrell, S., & Lewandowsky, S. (2003). Dissimilar items benefit from phonological similarity in serial recall. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *29*(5), 838–849.

Harris, G. J., & Fleer, R. E. (1974). High speed memory scanning in mental retardates: Evidence for a central processing deficit. *Journal of Experimental Child Psychology*, *17*, 452–459.

Hunt, E. (1978). Mechanics of verbal ability. *Psychological Review*, *85*, 109–130.

Hunt, E., Lunneborg, C., & Lewis, J. (1975). What does it mean to be high verbal? *Cognitive Psychology*, *7*, 194–227.

Hunt, E. G., Frost, N., & Lunneborg, C. L. (1973). Individual differences in cognition: A new approach to intelligence. In G. Bower (Ed.), *Advances in learning and motivation, Vol. 7*. New York: Academic Press.

Jensen, O., Gelfand, J., Kounios, J., & Lisman, J. E. (2002). Oscillations in the alpha band (9–12 Hz) increase with memory load during retention in a short-term memory task. *Cerebral Cortex*, *12*(8), 877–882.

Kail, R. V., & Bisanz, J. (1982). Cognitive strategies. In C. R. Puff (Ed.), *Handbook of research methods in human memory and cognition* (pp. 229–255). New York: Academic Press.

Karrasch, M., Laine, M., Rinne, J. O., Rapinoja, P., Sinerva, E., & Krause, C. M. (2006). Brain oscillatory responses to an auditory-verbal working memory task in mild cognitive impairment and Alzheimer's disease. *International Journal of Psychophysiology*, *59*(2), 168–178.

Klatzky, R. L., & Smith, E. E. (1972). Stimulus expectancy and retrieval from short-term memory. *Journal of Experimental Psychology*, *94*, 101–107.

Klein, K. A., Addis, K. M., & Kahana, M. J. (2005). A comparative analysis of serial and free recall. *Memory and Cognition*, *33*(5), 833–839.

Lewandowsky, S., & Murdock, B. B. (1989). Memory for serial order. *Psychological Review*, *96*(1), 25–57.

Li, S., & Lewandowsky, S. (1995). Forward and backward recall: Different retrieval processes. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *21*(4), 837–847.

Marquer, J. (1990). Reaction times and verbal reports in the study of cognitive strategies: A reply to Evans. *Quarterly Journal of Experimental Psychology: Human Experimental Psychology*, *42*(1A), 171–172.

Marquer, J., & Pereira, M. (1990). Reaction times in the study of strategies in sentence-picture verification: A reconsideration. *Quarterly Journal of Experimental Psychology*, *42*(A), 147–168.

McCauley, C., Kellas, G., Dugas, J., & de Vellis, R. F. (1976). Effects of serial rehearsal training on memory search. *Journal of Educational Psychology*, *68(4)*, 474–481.

Monsell, S. (1978). Recency, immediate recognition memory, and reaction time. *Cognitive Psychology*, *10*, 465–501.

Moulton, P. L., Boyko, L. N., Fitzpatrick, J. L., & Petros, T. V. (2001). The effect of ginkgo biloba on memory in healthy male volunteers. *Physiology and Behavior*, *73*(4), 659–665.

Nairne, J. S., & Kelley, M. R. (2004). Separating item and order information through process dissociation. *Journal of Memory and Language*, *50*(2), 113–133.

Pelligrino, J. W., & Glaser, R. (1979). Cognitive correlates and components. *Intelligence*, *3*, 187–214.

Pelosi, L., & Blumhardt, L. D. (1999). Effects of age on working memory: An event-related potential study. *Cognitive Brain Research*, *7*, 321–334.

Pelosi, L., Geesken, J. M., Holly, M., Hayward, M., & Blumhardt, L. D. (1997). Working memory impairment in early multiple sclerosis: Evidence from an event-related potential study of patients with clinically isolated myelopathy. *Brain*, *120*, 2039–2058.

Pelosi, L., Hayward, M., & Blumhardt, L. D. (1998). Which event-related potentials reflect memory processing in a digit-probe identification task? *Cognitive Brain Research*, *6*, 205–218.

Pelosi, L., Slade, T., Blumhardt, L. D., & Sharma, V. K. (2000). Working memory dysfunction in major depression: An event-related potential study. *Clinical Neurophysiology*, *111*, 1531–1543.

Puckett, J. M. (1982). The span-scan relation and aging. *Dissertation Abstracts International*, *42*, 3852B. (University Microfilms No. 82-05, 415).

Puckett, J. M., & Kausler, D. H. (1984). Individual differences and models of memory span: A role for memory search rate? *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *10*(1), 72–82.

Raghavachari, S., Kahana, M. J., Rizzuto, D. S., Caplan, J. B., Krischen, M. P., Bourgeois, B., et al. (2001). Gating of human theta oscillations by a working memory task. *Journal of Neuroscience*, *21*(9), 3175–3183.

Ratcliff, R. (1978). A theory of memory retrieval. *Psychological Review*, *85*(2), 59–108.

Rosen, V. M., & Engle, R. W. (1997). The role of working memory capacity in retrieval. *Journal of Experimental Psychology: General*, *126*(3), 211–227.

Roznowski, M., & Smith, M. L. (1993). A note on some psychometric properties of Sternberg task performance: Modifications to content. *Intelligence*, *17*, 389–398.

Rypma, B., Berger, J. S., Genova, H. M., Rebbechi, D., & D'Esposito, M. (2005). Dissociating age-related changes in cognitive strategy and neural efficiency using event-related fMRI. *Cortex*, *41*(4), 582–594.

Shiffrin, R. M., & Cook, J. R. (1978). Short-term forgetting of item and order information. *Journal of Verbal Learning and Verbal Behavior*, *17*(2), 189–218.

Sternberg, S. (1966). High speed scanning in human memory. *Science*, *153*, 652–654.

Sternberg, S. (1969). Memory-scanning: Mental processes revealed by reaction-time experiments. *The American Scientist*, *57*, 421–457.

Sternberg, S. (1975). Memory scanning: New findings and current controversies. *Quarterly Journal of Experimental Psychology*, *27*, 1–32.

Swanson, J. M., Johnsen, A. M., & Briggs, G. E. (1972). Recoding in a memory search task. *Journal of Experimental Psychology*, *93*, 1–9.

Theios, J., Smith, P. G., Haviland, S. E., Traupmann, J., & Moy, M. C. (1973). Memory scanning as a serial self-terminating process. *Journal of Experimental Psychology*, *97*, 323–336.

Thurstone, T. (1964). *Batterie Factorielle PMA*. Paris: Editions du CPA. (Adaptation of *Manual for the SRA primary mental abilities*, 3rd ed., 1958)

Townsend, J. T., & Ross, R. N. (1973). Search reaction time for single targets in multiletter stimuli with brief visual display. *Memory and Cognition*, *1*(3), 319–332.

Van Zandt, T., & Townsend, J. T. (1993). Self-terminating versus exhaustive processes in rapid visual and memory search: An evaluative review. *Perception and Psychophysics*, *53*(5), 563–580.

Verster, J. C., Volkerts, E. R., & Verbaten, M. N. (2002). Effects of Alprazolam on driving ability, memory functioning and psychomotor performance: A randomized, placebo-controlled study. *Neuropsychopharmacology*, *27*, 269–269.

Waugh, N. C. (1961). Free versus serial recall. *Journal of Experimental Psychology*, *62*(5), 496–502.

Wechsler, D. (2000). *Echelle d'intelligence pour Adultes (WAIS)*. Paris: Editions du CPA. (Adaptation of *Manual for the WAIS*, 3rd ed., 1997)

Wingfield, A. (1973). Effects of serial position and set size in auditory recognition memory. *Memory and Cognition*, *1*, 53–55.

Wingfield, A., & Branca, A. A. (1970). Strategy in high-speed memory search. *Journal of Experimental Psychology*, *83*, 63–67.

Wolach, I., & Pratt, H. (2001). The mode of short-term memory encoding as indicated by event-related potentials in a memory scanning task with distractions. *Clinical Neurophysiology*, *112*, 186–197.

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