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THE ROLE OF WORKING MEMORY IN A DOUBLE SPAN TASK

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This paper introduces a double span task to activate all three components of Baddeley and Hitch's working memory model simultaneously. Subjects were presented with sequences of words or pictures which appeared one by one at a different, randomly chosen location on a 4 x 4 grid. Subsequently they were asked for the serial recall of content, location or both. A dual task paradigm was used to investigate the effects of articulatory suppression, visuo-spatial tapping and a central executive suppression task on the three types of recall. In addition to classical interference effects of verbal and visuo-spatial suppression on recall of content and location respectively, a triple dissociation between all three working memory subsystems was found.

Having ascertained that the view of a unitary short-term memory system was no longer justified, Baddeley and Hitch (1974) proposed a multi-component working memory model to provide an adequate account of temporary storage and manipulation during information processing. For the past two decades, the model has generated a vast amount of research efforts. Over the years it has proved fruitful in accommodating a wide range of short-term memory phenomena arising from the experimental laboratory, and has been successfully incorporated within neuropsychological and developmental areas of research. The concept of working memory has also been shown to play an important part in aspects of everyday cognition, such as mental arithmetic (Logie, Gilhooly, & Wynn, 1994), problem solving (Gilhooly, Logie, Wetherick, & Wynn, 1993), reasoning (Klauer, Stegmaier, & Meiser, 1997; Vandierendonck & De Vooght, 1997), language processing (Gathercole & Baddeley, 1993) and comprehension (Just & Carpenter, 1992).

The tripartite working memory model comprises a central executive (CE) and two slave systems, the phonological loop (PL) and the visuo-spatial sketchpad (VSSP). The CE is an attentional control system with flexible but limited resources. Its tasks include the transfer of information from short-term memory to long-term memory and the integration of information from other sources, such as the two slaves.

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The PL is responsible for the storage and processing of verbal material and comprises two subsystems: a passive phonological store which is directly accessible for auditory presented material and an articulatory rehearsal process based on inner speech. The phonological store can hold a limited amount of speech-based information. Memory traces within the phonological store decay rapidly after about 1.5 to 2 seconds (Schweikert & Boruff, 1986) unless they are refreshed by the process of articulatory subvocal rehearsal. The articulatory control process is also capable of converting visually presented material into a phonological code and registering it in the phonological store.

The VSSP is involved in the temporary storage and manipulation of visuo-spatial information. It operates independently from the PL (e.g., Brooks, 1967; Logie, Zucco, & Baddeley, 1990) and is susceptible to both visual and spatial interference (Baddeley, Grant, Wight, & Thomson, 1975; Logie, 1986; Logie & Marchetti, 1991). Recent work sustains the idea that the VSSP plays a role in movement planning and control (Quinn, 1994; Smyth, Pearson, & Pendleton, 1988; Smyth & Pendleton, 1989). Furthermore, visual material has obligatory access to the system (Logie, 1986; Quinn & McConnell, 1996).

The objective of this paper was to bridge a gap in working memory research. Despite the vast amount of research efforts generated from Baddeley and Hitch's working memory model, thus far, no experimental task has been designed in which all three components of the model can be studied at the same time. Experiments on working memory have only reported tasks that load the CE and one of the slave systems. For example, the reading span task requires subjects to read a series of sentences and subsequently recall the last word in each sentence (Daneman & Carpenter, 1980). Reading span is defined as the maximum number of sentences which are read while correctly remembering the final words. This task draws on the resources of the PL and the CE, but makes no demands on the VSSP. In order to activate the three components of working memory simultaneously, a double span task was constructed, based on a task created by Loisy and Roulin (1992).

Double Span Task

Two versions of the double span task were constructed, one with pictures (line drawings of common objects) and one with written words[1]. Twenty stimuli were selected from a set of 216 pictures for which normative data on five variables are available (Martein, 1995). The choice of the pictures was based on the following criteria. The chosen pictures have a high name, concept and

[1] Separate versions of the double span task for pictures and for words may be of importance in research on working memory in children and elderly adults.

image agreement, are highly familiar and were rated low on visual complexity. Furthermore, the associated words consisted of one or two syllables, similar to numerals used in the digit span task. The frequency of the words in Dutch was also taken into account. The twenty words/pictures along with their values on the criteria used for selection are shown in Appendix A.

Subjects were presented with sequences of these words or pictures which appeared one by one at a different, randomly chosen location on a 4 x 4 grid. Subsequently they were asked for the serial recall of either the words/names of pictures ("content"), the locations ("location") or both ("content + location"). Subjects were not informed in advance which of these they would have to reproduce; they were instructed to memorise both content and location. On a given trial no two words/pictures were the same or appeared in the same location, nor were identical stimuli and locations used on consecutive trials. Examples of grids are shown in Figure 1.

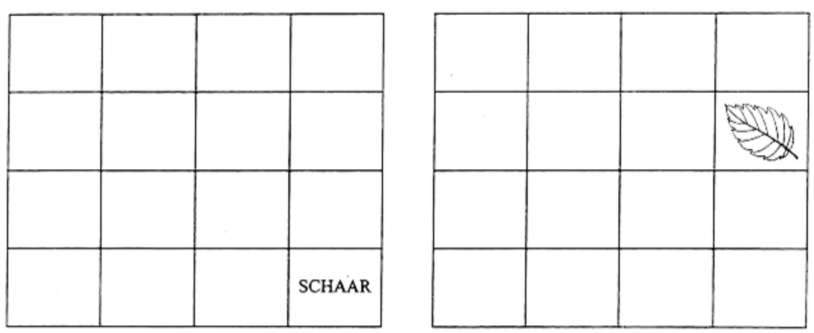

Figure 1. Examples of grids used in the double span task, left for words, right for pictures.

Within the context of the working memory model, the following assumptions can be made. Firstly, during the presentation of the grids, subjects use their entire working memory to memorise the contents, the locations, and their combinations. Secondly, at each type of recall the CE plays a crucial role as co-ordinator of the different types of information and as manager in charge of retrieval from a specific slave system, or combination of slave systems. Recall of content and recall of location are essentially the same as the standard verbal and visuo-spatial memory span tasks respectively. Several studies have shown the CE to be involved in a normal span procedure (e.g., Baddeley, 1986; Della Sala, Logie, Marchetti, & Wynn, 1991). Consequently, recall of content is assumed to depend on the PL and the CE, recall of location to involve the VSSP and the CE, and the double recall (content + location) to require the activation of the entire working memory.

Experiment

In line with studies in the working memory tradition a dual task paradigm was used to identify the contribution of the different components of working memory. Adding a suppression task during presentation will disrupt the functioning of working memory. Deficient storage of information will lead to a decline in recall. The type of recall that suffers most, will depend on the nature of the interference task. A verbal suppression task interferes with the articulatory rehearsal process, allowing less information to be refreshed and hence retained in the phonological store. Consequently, it is expected to result in poorer performance when recall requires content. A visuo-spatial suppression task interferes with visuo-spatial coding, resulting in the poorer retention of visuo-spatial material. Such a secondary task should lead to lower scores when recall requests location. Last but not least, an attentional (CE) interference task draws on the resources of the CE which will cause a decrement in all three types of recall.

Method

Subjects and design. Forty first-year students at the faculty of psychology and educational sciences of the University of Ghent participated for course requirements and credit. They volunteered for this experiment. Subjects were randomly assigned to the conditions of a 4 (suppression: control, verbal suppression, visuo-spatial suppression, attentional suppression) x 2 (stimuli: pictures vs. words) x 3 (type of recall: content, location, content + location) factorial design with repeated measures on the last two factors.

In the control condition, only the double span task was administered. The verbal suppression task consisted of articulatory suppression. Subjects were required to repeat "universiteit Gent" once every second during presentation. Articulatory suppression disrupts the operation of the PL (e.g., Baddeley, Lewis, & Vallar, 1984). In the visuo-spatial suppression task subjects were requested to tap the four outside corners of a grid during presentation. This task disturbs the functioning of the VSSP (e.g., Farmer, Berman, & Fletcher, 1986). The attentional suppression task entailed the random time interval generation task. Subjects were instructed to tap a random temporal pattern with their finger on the table. Generation of random time intervals has been shown to interfere with executive functions, without drawing on verbal or visuo-spatial resources (Vandierendonck, De Vooght, & Van der Goten, 1998).

Procedure. Subjects were tested individually in a quiet room. Instructions about the procedure of the double span task were given, followed by a practice session. The interference task was demonstrated to subjects assigned to the respective suppression condition, and they were given additional practice.

The order in which the two versions of the double span task (pictures and words) were administered was counterbalanced across subjects. Per trial subjects were presented with a series of grids, at a rate of one grid per second. They were instructed to encode both the stimuli and the locations. Immediately following presentation they were asked to recall either the content, the locations or both. Recall of content required subjects to give spoken recall. Reproduction of locations requested subjects to point to the locations of the items on a blank grid. For the double recall, subjects were instructed to repeat the names of the items while pointing to their locations on a blank grid. The importance of recall in the correct serial order was stressed. The three types of recall were asked for in a random order to ensure the type of recall requested could not be predicted. In the dual task conditions subjects performed the suppression tasks during the presentation of the grids.

A modified span procedure was used. Subjects were given six trials for each span length from 2 to 6 items. At every span level each recall type was requested on two of the six trials. Performance was scored as the average number of correctly recalled items per type of recall condition.

Results

In accordance with suggestions formulated by McCall and Appelbaum (1973) for the analysis of repeated measures designs, a multivariate analysis was performed with contrasts in the dependent variables, the span scores in each of the stimuli x type of recall cells. The between-subjects effect of suppression, and the within-subjects effects of stimuli and type of recall were analysed.

There was a main effect of suppression, $F(3, 36) = 8.60$, $p < 0.001$. The average level of performance was 4.31 in the control condition, 3.30 under articulatory suppression, 3.27 under VSSP-suppression and 3.13 under CE-suppression. Planned comparisons revealed a significant difference in performance between the control condition and the suppression conditions, $F(1, 36) = 25.33$, $p < 0.001$. All pair-wise contrasts of the control condition to the suppression conditions were also statistically significant: $F(1, 36) = 14.89$, $p < 0.001$ for articulatory suppression, $F(1, 36) = 15.79$, $p < 0.001$ for visuo-spatial tapping, and $F(1, 36) = 20.21$, $p < 0.001$ for random time interval generation. However, no differences were found among the interference conditions.

The analysis also yielded a main effect of type of recall, $F(2, 35) = 23.79$, $p < 0.001$. The highest scores were obtained when subjects were asked for content ($M = 3.95$); the lowest scores were registered for content + location ($M = 3.08$). Recall of location was intermediate ($M = 3.48$). Planned contrasts demonstrated that the content-scores and the location-scores were significantly higher than the scores on the double recall, $F(1, 36) = 42.44$, $p < 0.001$. The difference between recall of content and recall of location was statistically reliable too, $F(1, 36) = 11.59$, $p < 0.01$.

There was also a significant suppression x type of recall interaction, $F(6, 70) = 5.83$, $p < 0.001$. Mean results as a function of suppression conditions and type of recall are shown in Figure 2. Articulatory suppression impaired performance on recall of content, $F(1, 36) = 24.40$, $p < 0.001$, and on recall of content + location, $F(1, 36) = 13.70$, $p < 0.001$, but had no effect on recall of location, $F < 1$. Concurrently tapping the four corners of a grid caused a substantial impairment in the retention of locations, $F(1, 36) = 18.18$, $p < 0.001$, and in the double recall, $F(1, 36) = 11.63$, $p < 0.01$, but had no disruptive effect on recall of content $F(1, 36) = 2.61$, $p > 0.10$. The random time interval generation task interfered with performance on all three types of recall: $F(1, 36) = 8.12$, $p < 0.01$ for recall of content; $F(1, 36) = 15.55$, $p < 0.001$ for recall of location, and $F(1, 36) = 14.17$, $p < 0.001$ for the combined recall.

Another way of looking at the data is by calculating the mean decline in performance in the suppression conditions compared to the control condition. This provides a more precise indication of the effect of the various suppression

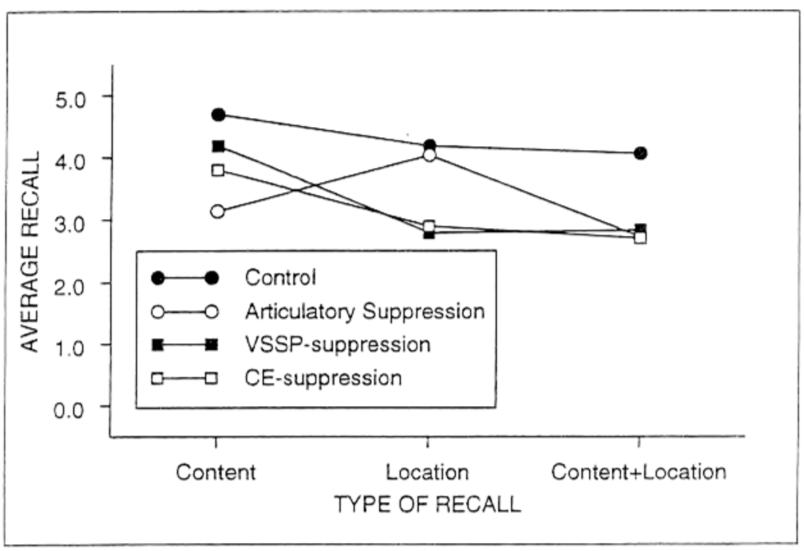

Figure 2. Average number of correctly recalled items as a function of suppression conditions and type of recall.

conditions on the respective types of recall. Table 1 displays these averages in terms of percentage as a function of type of recall. When recall required content, articulatory suppression caused a significant drop in performance, 33.2% and 32.9% for recall of content and recall of content + location respectively. When recall required location, VSSP-suppression impaired performance by 33.3% for recall of location and by 30.3% for recall of content + location. In line with what these percentages lead one to suspect, articulatory suppression had no differential effect on the recall of content than on the double recall, $F < 1$. Similarly, the effect of VSSP-suppression was not significantly different on the retention of locations than on the combined recall, $F < 1$. Furthermore, the attentional interference task had a non-differential disruptive effect on all three types of recall: under CE-suppression content-scores decreased by 19.2%, location-scores by 30.8% and content + location scores by 33.5%. The effect of CE-suppression was not reliably more detrimental on the double recall than on either simple task: $F(1, 36) = 1.60$, $p > 0.20$, in comparison with recall of content, and $F < 1$ in comparison with recall of location. Moreover, there was no statistically reliable difference between the visuo-spatial and the attentional suppression tasks regarding recall of location, $F < 1$. By contrast, articulatory suppression was found to have a much larger detrimental effect on recall of content than CE-suppression, $F(1, 36) = 4.37$, $p < 0.05$.

Table 1
Mean Decline in Performance Between the Suppression Conditions and the Control Condition as a Function of Type of Recall

	Type of Recall		
Suppression	Content	Location	Content+Location
Articulatory suppression	33.23**	3.58	32.90**
VSSP-suppression	10.86	33.33**	30.31*
CE-suppression	19.17*	30.82**	33.46**

Note. In percentages.
* p < 0.01. * p < 0.001.

No differences were found between the performance on the picture and word variants of the task, $F(1, 36) = 1.94$, $p > 0.15$, nor did stimulus form interact with any of the other factors. None of the other interactions among the independent variables were statistically reliable either.

Discussion

Results did not confirm the picture superiority effect: the well-known finding that pictures are easier to memorise than words representing those pictures (Paivio, 1971). It seems the pictures in this study were transformed into a verbal code and stored in the PL. Therefore, their subsequent cognitive processing was similar to that of the written words. Because of this lack of difference in performance on the two variants of the task, the factor stimulus will be ignored in the following discussion.

Performance was higher on the recall of content and location alone than on the double recall. Retention of either content or location requires a smaller amount of information to be processed than their combined recall, because each unit (stimulus) is less complex. In terms of Baddeley's working memory model, recall of content and location alone depend primarily on the respective subsystems, the PL and the VSSP. In the combined recall it is necessary to match content and location correctly, attesting to its greater difficulty; it requires the co-ordination of verbal and visuo-spatial encoding and therefore draws on the resources of the CE. Nevertheless, serial recall of either content or location also requires the contribution of the CE. Verbal serial recall is argued to depend on both the PL and the CE (e.g., Baddeley, 1986, 1992; Vallar & Papagno, 1986). Keeping track of the order in which verbal items were presented and which have been reproduced already during recall is not a purely passive process, but rather a process that requires active manipulation of information in working memory (Light & Anderson, 1985). The PL is able to retain only a limited number of items in the correct order more or less automatically; the CE may increase this number either by improving the working of the slave system or by using its own storage capacity. Similarly, temporary storage of visuo-spatial input in the scratch pad is augmented by the CE store (Morris, 1987). But, whereas the double recall is heavily dependent on the activity of the CE, recall of content and location alone rely on the CE to a lesser extent, which accounts for their greater facility.

Furthermore, the number of correct items was higher for recall of content than location. This result can be understood from the fact that the PL is a relatively strong and autonomous subsystem within working memory, capable of independently storing a number of elements. The larger impact of articulatory suppression on the content-scores as compared to CE-suppression lends support to this interpretation. The VSSP, however, makes heavier demands on the CE than the PL, as visuo-spatial tasks have been found to require more attention than verbal tasks (e.g., Salway & Logie, 1995; Morris, 1987). The substantial impairment in recall of location observed with both the tapping and the random time interval generation tasks confirms the notion that central executive resources are required to operate the VSSP. Also, given the strong tendency in humans to rely on verbal codes, it is intuitively easy to understand that the use of a verbal code is a more efficient and better practised strategy. Moreover, unlike spatial locations, words and pictures provide a semantic code.

The suppression techniques employed in this study produced clear patterns of selective interference. The data are consistent with the dissociation predicted by the working memory model. Articulatory suppression disrupted recall of content but not recall of location, whereas visuo-spatial suppression had the converse effect. These findings are in line with selective interference effects on recall of verbal and visuo-spatial material, and support the uncontroversial dissociation between verbal and visuo-spatial processing (e.g., Brandimonte, Hitch, & Bishop, 1992; Farmer et al., 1986). In addition, a triple dissociation in working memory was established. Articulatory suppression had a detrimental effect when recall required content (i.e. recall of content and recall of content + location). VSSP-suppression had a disruptive effect when recall requested location (i.e. recall of location and recall of content + location). CE-suppression impaired performance on both the simple and the double tasks undifferentially, and thus provides further evidence for the involvement of the CE in all three types of recall. Finally, the large decrements on the double recall in all three suppression conditions suggests that the entire working memory system is operating during the encoding of the double span task. Each component has its own contribution in the successful completion of the double span task: contents are stored in the PL, locations are retained in the VSSP. Assisting the PL and the VSSP in their storage functions and establishing the exact correspondence between a picture/word and its location depends on the operation of the CE.

Conclusion

The double span task proves to be a fruitful technique for activating all three components of the working memory model at the same time. The results of the present study demonstrate the usefulness of the double span task as an instrument for future research on working memory. Successful performance on the double span task requires the entire working memory to be used. As such, the task constitutes an extension of working memory assessment procedures which are limited to a measure of executive loading and phonological storage, such as reading span (Daneman & Carpenter, 1980) and computational span (e.g., Salthouse, Mitchell, Skovronek, & Babcock, 1989). The latter task requires subjects to perform a series of arithmetic operations and then recall the last digit in each problem. The double span task complements these tasks in that it provides a measure of working memory capacity that includes a measure of the VSSP as well.

Furthermore, the double span task provides an alternative to the dual task paradigm for measuring the capacity of the CE, thus allowing problems intrinsic to dual tasks to be circumvented. For example, the double span task might offer a solution to the conflicting results on dual task performance due to inconsistencies in methodology (e.g., Salthouse, Fristoe, Lineweaver, & Coon, 1995). In addition, it presents a straightforward method for studying working memory in populations for whom a dual task paradigm is less appropriate, such as children, elderly, and patients suffering from neurological impairments.

Another advantage of the double span task is the clarity with which results can be interpreted within the working memory framework. Moreover, lags in development, age-related cognitive decline, and neurological disorders can easily be located within the model. For instance, a notably poor result on recall of content, along with normal performance on recall of location and a subnormal score on recall of content + location can be attributed to an impairment in the PL in the absence of deficits in the VSSP and the CE. Conversely, performance somewhat below the normal range on the simple tasks in combination with a pathological score on the double recall, argue for an apparent deficit in the CE while the slave systems are intact. However, further research will be required to confirm these issues.

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Appendix A

Criteria taken into account in the selection of the stimulus material: the frequency of the word in Dutch, the percentage of name (NA) and concept agreement (CA), the means and standard deviations for familiarity (FA), visual complexity (VC) and image agreement (IA). Familiarity, visual complexity and image agreement were rated on a 7-point scale.

Picture/Word Dutch	English	Freq.	%NA	%CA	FA M	FA SD	VC M	VC SD	IA M	IA SD
Appel	Apple	17	100.0	100	6.80	0.51	2.24	1.26	4.56	1.69
Auto	Car	208	94.17	100	6.57	0.83	3.28	1.87	4.35	1.63
Blad	Leaf	114	95.68	100	6.10	1.25	2.00	1.14	4.83	1.80
Eend	Duck	24	100.0	100	4.98	1.61	4.05	1.64	5.03	1.43
Hond	Dog	168	100.0	100	6.09	1.43	3.94	2.13	4.48	1.29
Laars	Boot	27	96.34	100	5.44	1.58	2.37	1.15	4.73	1.41
Ladder	Ladder	14	100.0	100	5.70	1.48	1.89	1.16	6.46	0.98
Oog	Eye	820	98.78	100	6.80	0.76	3.98	2.16	5.95	1.26
Peer	Pear	10	100.0	100	6.38	1.07	2.10	1.29	4.48	1.58
Pijl	Arrow	16	98.78	100	4.33	2.12	2.01	1.12	5.14	1.60
Pijp	Pipe	25	100.0	100	4.91	2.11	2.54	1.47	5.11	1.46
Potlood	Pencil	12	100.0	100	6.88	0.45	1.87	1.18	5.86	1.32
Schaar	Scissors	7	100.0	100	6.68	0.73	2.32	1.46	6.52	0.80
Schoen	Shoe	68	97.56	100	6.79	0.68	2.60	1.46	4.51	1.72
Sleutel	Key	49	96.67	100	6.91	0.39	2.58	1.86	5.19	1.84
Stoel	Chair	151	100.0	100	6.72	0.93	3.11	1.81	5.10	1.38
Vlag	Flag	29	98.78	100	4.96	1.81	2.04	1.12	5.05	1.63
Vlinder	Butterfly	10	93.33	100	5.65	1.42	2.87	1.61	5.19	1.38
Vork	Fork	12	100.0	100	6.88	0.39	1.98	1.09	4.64	1.63
Zaag	Saw	3	100.0	100	4.80	1.82	2.28	1.23	6.27	1.12

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