Multiple Short-Term Storage: A Task to Evaluate the Coordination Function of the Executive Central

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MULTIPLE SHORT-TERM STORAGE: A TASK TO EVALUATE THE COORDINATION FUNCTION OF EXECUTIVE CENTRAL

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The working memory is an important aspect of mental activities (*e.g.*, Baddeley & Hitch, 1974; Case, 1985; Cowan, 1988; Engle, Carullo & Collins, 1999). It refers to different aspects of on-line cognition and assumes the existence of a limited short-term cognitive system for processing and storing information. All authors admit that the function of working memory is not only memorization, but is also in the service of complex cognition (Miyake & Shah, 1999). In this paper, we focus on one of the multiple aspects of working memory, namely maintaining and coordinating different sorts of information.

The most often cited model of working memory is probably the multi-components system proposed by Baddeley (1986). In this model, a central executive is responsible for control processes. Two other temporary memory systems actively maintain memory traces within a particular area (verbally coded information and visuospatial information and/or imagery). These components or slave systems serve different functions and have specific properties.

The most extensively explored slave system is the Phonological Loop involved in speech production and short-term retention of speech-based material (*e.g.*, Baddeley, 1986; Henry, 1991b; Hulme, Maugham & Brown, 1991; Pickering, Gathercole, Hall & Lloyd, 2001). There appears to be an overlapping between the overt speech system and verbal short-term storage. This latter system is divided into two components: a phonological store that is a passive subsystem in which information declines with time and a rehearsal mechanism implied in refreshing the decaying representation. The visuospatial working memory has received less attention than the verbal working memory but this is changing (*e.g.*, Smyth & Scholey, 1992; Jones, Farrand, Stuart & Morris, 1995; Logie, 1995; Pickering et al., 2001). As there was evidence for some form of visual short-term memory and for a separation of visual and verbal processes (Paivio, 1971), the first studies explored the role of working memory in mental imagery and a component was thought to be responsible for visual material, temporary retention and processing. But experimental results are also consistent with a temporary storage system for spatial information that could be involved in the retention of movement sequences (*e.g.*, Smyth & Pendleton, 1989). The existence of a specific slave system integrating these different aspects is accepted (Logie 1995): it probably implies a visuospatial store for visual form and color linked to the visual perceptual system and a rehearsal mechanism for information about movement sequences linked to the planning and execution of movement. Logie (1995) has developed in detail the concept of a visuospatial working memory supposed to function in a way analogous to verbal working memory.

The separation of the components of working memory and of the sub-components of slave systems is supported by clinical and empirical studies and there is an abundant literature concerning it. The first evidence comes from researches showing neuropsychological double dissociation in brain-damaged patients (De Renzi & Nichelli, 1975; Della Sala & Logie, 1993). For example, Vallar and Baddeley (1984a) describe a patient showing verbal short-term memory deficit without visuospatial impairment whereas Humphreys and Riddock (1987) describe a patient who was able to locate and draw objects but could not recognize them. Empirical studies use dual-task paradigms (*e.g.*, Baddeley, 1986; Kyllonen & Christal, 1990; Logie & Salway, 1990; Quinn & McConnell, 1996). The Working Memory model assumes that a limited resource is shared between the simultaneously stored and/or processed information: the addition of a concurrent memory load takes away a part of the resources available for the main task with detrimental consequence on performance. This interference effect exists only if common resources underlie the two tasks: the interference effect in dual-task studies is selective and related to the nature of the tasks. For each slave system specific tasks are used and specific interference effects can be identified. In the case of the phonological loop, verbal span tasks implying to maintain a series of verbal items are impaired by articulatory suppression (repeating aloud an irrelevant word or sound) but not by visuospatial interference (*e.g.*, Farmer, Berman & Fletcher, 1986). To study visuospatial sketchpad, two different types of tasks are used: memory span tasks where participants have to recall a sequentially presented series of targets (squares in a matrix or separate blocks like in the Corsi block test, *e.g.* Milner, 1971) and recognition or recall of patterns (*e.g.*, Wilson, Scott & Power, 1987). These different tasks are impaired by different visuospatial tasks but they are not disrupted by articulatory suppression (*e.g.*, Smyth & Pendleton, 1990). These neuropsychological and experimental findings have been developed because the studies of Phonological Loop and Visuospatial Sketchpad refer to a pool of specific tasks and because precise hypotheses underlie experiments and observation. These hypotheses concern the functional characteristics of the slave systems and they enable the development of adequate interference tasks showing the relation between their nature and the effect they produce.

The Central Executive component of working memory was studied later and it remains the least known. It is a sort of theoretical ragbag useful for containing all that cannot be accounted for otherwise. Baddeley postulates that the processes and structure of the central executive system are open to empirical investigation (Baddeley & Logie, 1999). It could reflect multiple control processes hierarchically coordinated or independent, the overall control forming an emergent feature. Nevertheless, specific functions are associated to the central executive system. These executive functions are: (i) attentional control of action (capacity of overriding habitual response patterns when initiating a new behavior is necessary); (ii) selective attention (capacity to attend selectively to one stimulus and to discard non-pertinent stimuli); (iii) long term memory activation; (iv) control and coordination of the tasks and, as a probable result, of the two slave systems.

The tasks used to determine the role and the functions of Central Executive are not as well specified as the tasks used to test slave systems. Three approaches could be defined. The first considers tests random generation as a task depending directly on Central Executive functioning. Baddeley, Emslie, Kolodny and Duncan (1998) explore random generation through a random key pressing task requiring participants to generate at different rates random sequences of presses on 10 keys, each key being located under one finger. The authors tested random generation of locations with different interference tasks (articulatory suppression, serial recall, verbal fluency task, concurrent random digit generation, and measure of fluid intelligence). Random generation was disrupted only when interference tasks depended on the Central Executive and proportionally to their attentional demand, even when memory load was low. Randomness decreased as generation speed increased. The interpretation of this effect was that random generation disrupts the operation of the Central Executive by its demand to switch retrieval plans and inhibit repetition.

The second approach studies the role of the Central Executive in complex tasks using the interference task paradigm in order to disrupt its implication. Secondary tasks are used to disrupt the strategies implied in arithmetic, syllogisms, language comprehension and so on. The most often disrupting task used is precisely random generation considered as implying supervisory or executive functions (*e.g.*, Dienes, Broadbent & Berry, 1991; Gilhooly, Logie & Wynn, 1999; Robbins et al., 1996; Vandierendonck, De Vooght & Van der Goten, 1998).

The third approach seeks to evaluate the interdependence between processing and storage activities. Numerous working memory span tasks have been developed in this context.

Generally, these tasks imply performing one specific mental activity (mental arithmetic, reading, counting...) while attempting to retain a series of verbal items. For example, the reading span requires reading a series of sentences of varied length and recalling subsequently either the last word of each sentence (*e.g.*, Daneman & Carpenter, 1980) or an unrelated word presented after each sentence (*e.g.*, Turner & Engle, 1989). To our knowledge, the only example with visuospatial material to be retained is proposed by Daneman and Tardif (1987). Contrary to the other approaches, the Central Executive is not evaluated alone here. The measured performance implicates the capacities of the Central Executive and one of the slave systems, but performance also depends on the efficiency of the processes implied in the complex task to be tested. This group of tasks probably measures the balance of mental resources divided between attention and retention. This is an interesting aspect of the function of the Central Executive but these types of tasks do not include all the functions of the central components of Working Memory.

Therefore, the results obtained through these studies do not concern all the aspects of the Central Executive. The aim of the present study is to find tasks relying on the two slave systems in order to evaluate another aspect of the Executive, its coordination function. In literature, slave systems are studied separately and this first approach was certainly necessary to discover details about how they function. Although in problem solving different sorts of information are generally taken into account (Gilhooly, Logie, Wetherick & Wynn, 1993; Oakhill & Johnson-Laird, 1984), studying the slave systems like separate aspects of working memory has never been questioned. A complex task with simultaneous verbal and visuospatial aspects was developed by Loisy and Roulin (1992) in order to make a triple dissociation and was taken up by Martein, Kemps and Vandierendonck (1999). Initially, this procedure was assumed to differentiate the three slave systems (Loisy, 1998). Now, we intend to establish whether this task, implying the same mechanisms as separate tasks (PL and VSSP) and preserving the sensitivity to specific interference, is suitable for testing the coordination function of the executive. This assumption has never been experimentally supported. Actually, coordination is a rarely tested attribution of the executive: Towse and Houston-Price (2001) through a developmental approach and Fournet, Moreaud, Roulin, Naegele and Pellat (2000) in neuropsychology studied a task combining verbal and spatial coordination

The coordination task proposed here is a double-stimuli task in which the participants must encode and maintain words localized on a grid randomly followed either by a single recall of words, or a single recall of locations, or a double recall of localized words. Its originality is that these three kinds of recall are included in the same task. This task implies the coordinated maintenance of verbal and visuospatial information in order to be able to respond. In the double-stimuli task, the storage of words is considered to be dealt with by the verbal working memory, the storage of locations is considered to be dealt with by the visuospatial working memory and the coordination of stimuli is considered to be dealt with by the central executive functioning. In the present research, we verify primarily that this task is supported by the same mechanisms as those supporting the classical verbal and visuospatial tasks. This will be done by observing the sensitivity to classical interference of word recall and location recall performed in the frame of the double-stimuli task. In a second stage, we compare the double-stimuli task performance with performance on classical short-term memory tasks (word recall and location recall). We expect a significant but not drastic decrease in performance, as it is the case in any comparison between short-term and working memory tasks. Finally, we try to find an independent indicator of coordination capacities. This indicator may be the comparison of the decrease of performance in the single-recall and double-recall tasks for each interference condition. We expect the emergence of a modified pattern of data showing that the indicator is not sensitive to the nature of interference tasks (verbal or visuospatial) but to their attentional requirements.

METHOD

MATERIAL

Stimuli are displayed in the middle of the screen (15") of a computer monitor compatible PC. A set of 15 series of words is constructed, each one consisting of 9 single-syllable words. All the words are different and their frequency is controlled (Mousty & Radeau, 1990). The mean word-frequency for one series was 8927 occurrences per million, range between 8819 and 9594 occurrences per million). A location is a cell of a 6x7 cells grid. A set of 15 series of 9 locations is randomly selected on the grid.

Double-stimuli task. The sets of words and the sets of locations associated one by one constitute the lists of stimuli. Stimuli are presented successively: each word appears in a particular location for 1,5 second with an inter-stimuli interval of 0,5 second and then is replaced by the next word presented in another location. At the end of the presentation of the sequence, a 4 second retention interval is managed. The end of the retention interval is signaled by an auditory tone and the empty grid appears. Immediately after hearing the tone, the participants are orally invited to restitute either the words, or the locations or both. Each subject performs 12 trials comprising 4 trials per condition in a random order. No instruction is given about the order of recall and there is no limitation of recall time. To perform the word recall task, participants have to repeat the words aloud. To perform the location recall task, they have to point to the locations on the grid. To perform the double recall task, they have to repeat each word aloud while simultaneously pointing to its location on the grid.

Interference tasks. Different interference conditions are tested: no interference, articulatory suppression, Moar Box tracking, and standing balance position.

The articulatory suppression condition requires the participants to count "1, 2, 3, 4, 5, 1, 2, 3, 4, 5" throughout the retention interval. The research worker verifies the beginning of the interference task and incites participants to maintain their articulation rate.

The Moar box tracking (Moar, 1978) is a box with an array of 5x5 keys. Participants are required to press down the keys one by one on each row until the retention interval ends. They are required to backtrack up the last row if they have pressed every key before the end of the retention interval. Practice on the tracking task is given at the beginning of the experiment to familiarize the participants with the apparatus. The research worker verifies the beginning of the interference task and keeps a close eye on the depressing rate.

The standing balance position requires to stand with the toe of the back foot placed as close as possible to the heel of the front foot (*e.g.*, Kerr, Condon & McDonald, 1985). Participants are instructed to stand as still as possible with the knees extended. This task is performed in stocking feet. Participants who perform the standing balance position maintain the position on a dense rubber rag. The research worker verifies the beginning of the interference task and keeps a close eye on the knees extension and the feet contact.

Control tasks. Material is the same as in the main task (double-stimuli task) but only the sets of words or the sets of locations are presented.

PARTICIPANTS

Seventy-two voluntary students with a mean age of 20 years 6 months (range 18 years to 28 years) participated in the experiment. They were five men (one in each condition excepted verbal interference and Moar box tracking interference conditions). All the participants are university students.

Participants were randomly distributed in six groups. Four groups were affected to the double-stimuli task. Group one was designated as a control condition group without interference task. Three groups of participants performed dual-task: the main task (double-stimuli task) coupled with an interference task. Two groups of participants were affected to control tasks. Group 5 performed a classical verbal short-term memory task and group 6 performed a location task. The different conditions in the experiment are presented in Table 1.

< *Insert Table 1 about here* >

PROCEDURE

Participants are run individually. Each participant begins with three practice trials. Twelve lists of stimuli constitute the core of the experiment. Interference tasks are introduced only during the retention interval so that they do not impair the encoding of the items. After encoding and maintenance, all the participants perform one of the 3 categories of recall task: a word recall task in which they are asked to recall only the words, a location recall task in which they are asked to recall the locations, and a double recall task in which they are asked to recall each word with its associated location. In order to force participants to maintain all the material (words, locations and word-location coordination) they are not informed of the kind of material they will have to restitute until the end of the retention interval. Performance is scored in terms of correct response means.

RESULTS

Effects of interference in double-stimuli task

A two way analysis of variance is carried out with one between-participant factor, interference task (no interference, articulatory suppression, Moar box tracking and standing balance position) and one repeated measure, recall condition (location, word or localized word recall). The main effect of interference task approaches significance ($F(3,44) = 2.75$, $p<.10$), whereas the effect of recall condition ($F(2,88) = 200.96$, $p<.001$) and of interaction ($F(6,88) = 6.23$, $p<.001$) are significant. This means that the interference effect varies according to the material to be restituted. Results are reported in Table 2 and Figure 1.

< Insert Table 2 about here >

< Insert Figure 1 about here >

Articulatory suppression impairs the retention of words ($F(1,44) = 8.79$, $p<.005$) but has no effect on the retention of locations ($F(1,44) = .85$, *NS*). With spatial interference tasks the reverse is true. Moar box tracking and standing balance position impair the retention of locations ($F(1,44) = 11.66$, $p<.005$) but they have no effect on the retention of words ($F(1,44) = .58$, *NS*). There is no significant difference between standing balance position and Moar box tracking ($F(1,44) = .47$, *NS*). Therefore, this experiment reproduces the classical double dissociation between two types of interference, verbal interference (articulatory suppression) and spatial interference (Moar box tracking and standing balance position) and two types of tasks (retention of words and retention of locations).

These first data can be interpreted as follows. When participants are engaged in a dual-task (double-stimuli task plus interference task), a specific interference effect can be observed with spatial and verbal material that is classically interpreted as reflecting the competition for a special-purpose system between main task and interference task. No effect can be observed when the required mechanisms are not identical. Here, an additional conclusion can be drawn: mechanisms involved in the double-stimuli task are similar to those involved in simple tasks. In the literature, it is generally admitted that a subvocal rehearsal mechanism maintains verbal information in store. Articulatory suppression prevents the participants from subvocally rehearsing the relevant words and impairs the recall of words. Words recall in the double-stimuli task relies on verbal working memory. In the same way, in the working memory model the maintenance of visuospatial information is supposed to rely on the visuospatial WM and an active rehearsal mechanism could maintain visuospatial information in store (Logie, 1995). It is generally admitted that this rehearsal mechanism is related to the control of movement: movements impair the recall of locations (*e.g.*, Smyth & Pendleton, 1990). Location recall in the double-stimuli task relies on visuospatial working memory.

Coordinating word and location cannot depend on a quasi-automatic rehearsal mechanism: it needs attention. We expect that it is depending on attentional resources, the central executive functions. In consequence, on the one hand we hypothesize a performance decrease on word and location recall when the double-stimuli task will be compared to the control tasks (single-conditions tasks). On the other hand we hypothesize a general decrease in performance and a differential effect of interference when double recall will be required. Standing balance position is expected to have no attentional cost and as a consequence to produce no interference effect on the word-location coordination.

Comparison with the classical short-term memory tasks

Two analyses of variance are carried out with one between-participant factor, type of task (classical short-term memory task and double-stimuli task).

For the words and the locations, we observe a significant effect of type of task, respectively $F(1,22) = 9.56$, $p<.01$ and $F(1,22) = 33.09$, $p<.01$. Results are reported in Table 3.

< *Insert Table 3 about here* >

When participants are engaged in classical short-term memory tasks (recall of words or locations) performance is higher than when they have to restitute words or locations in the double-stimuli task. The decrease in performance is of 0,21 % for the words and of 0,33 % for the locations.

Interference effect on double recall

We hypothesize that interference effect on double-recall will no longer depend on the interference task nature but on the interference task cost: we expect that the interference effect of standing balance position (considered as a non-attentional task) will be less important than the interference effect of other interference tasks. In general, performance on double-recall is very low (about one item, average: 1.052).

Nevertheless, a question about the performances to be compared is to be raised. According to the concept of general working memory, we consider that performance on double-recall is necessarily related to performance on single recall. In consequence we should compare double-recall performance with the lowest performance obtained on single recall (either on word or on location recall). Table 4 shows the number of participants who obtained the lowest performance for each interference condition.

< *Insert Table 4 about here* >

We note that the lowest performance is related to the interference condition. This presentation provides another way of observing the specificity of interference effect by a qualitative approach: the number of participants for which the performance is lower in the different conditions. In the condition without interference, performance is lower on location recall for 8 participants, on word recall for 3 participants, and identical for one participant. In articulatory suppression condition, most of the participants obtain the lowest performance on word recall. In Moar Box tracking condition, most of the participants obtain the lowest performance on location recall. In standing balance condition, performance is lower on location recall for all the 12 participants.

In the double-recall condition, each kind of interference will have a minimal effect related to its effect on the single-recall condition. Therefore, at this point, it is useful to calculate a performance decrease score that takes into account performance on single-recall. We have constructed the corrected score as follows: lowest performance minus double-recall performance multiplied by 100, and divided by the lowest performance. (i) If the score obtained is equal to 0 %, performance on double-recall is identical to performance on single-recall. (ii) If the score obtained is equal to 100 %, performance on double-recall is equal to 0: this means that localized words are impossible to recall. (iii) A negative score would mean that performance on double-recall is higher than performance on single-recall. It ought to be impossible unless double-recall relies on an unknown mechanism.

The observed scores vary between 49,91 (standing balance condition) and 69,40 (articulatory suppression). Except for one participant having a negative score (no-interference condition), performance on double-recall is always worse than performance on single-recall. Table 5 presents the scores for each experimental condition.

< *Insert Table 5 about here* >

An ANOVA was carried out with one between-participant factor, interference task (no interference, articulatory suppression, Moar box tracking and standing balance position) on arcsines corrected score.

We observe a general effect of interference task ($F(3,44) = 2.80$, $p=.05$). Partial comparisons indicate that there is no significant difference between no-interference condition and standing balance condition ($F(1,44) = 0.81$, *NS*), no significant difference between Moar box tracking and articulatory suppression ($F(1,44) = 0.06$, *NS*), and a significant difference between these two groups of tasks ($F(1,44) = 4.42$, $p<.05$).

When single-recall is required we mentioned -§1- that articulatory suppression interferes with word recall and has no effect on location recall and that Moar Box tracking and standing balance position interfere with location recall and have no effect on word recall. The last data indicate that when double-recall is required, the interference effect obtained is different from the specific interference effect observed on single-recall. The most disruptive tasks are articulatory suppression and Moar box tracking while no-interference condition and standing balance position are not significantly different.

Double-recall implicates the executive functions responsible of coordination: task cost seems to become the important interference factor. Nevertheless the performance on double-stimuli task is very low especially when double-recall is required. Performance on this task would likely be improved by reducing the number of cells of the grid (in the literature a grid of 5x5 cells is generally used) and by simplifying the reference space (Kemps, 1999). A simplified version would be useful to test a brain-damaged population.

DISCUSSION AND CONCLUSION

We use the interference task paradigm in order to test a special task: a double-stimuli task, which is a coordinating task. Even if a double-stimuli task seems close to classical word and location STM tasks, it differs from them because coordination is always required during encoding and maintenance. When participants are engaged in the double-stimuli task, they ignore what they will have to restitute. In consequence, from encoding to restitution time they have to maintain localized-words, i.e. to coordinate words and locations. Coordination continues up to the end of the task with double-recall but we hypothesize that it is abandoned when single recall is required. Similar tasks have been previously used (Fournet et al., 2000; Towse & Houston-Price, 2001) but it seems that specific studies have never been carried out on this task. The main interest of this task is precisely that it will allow one aspect of the executive function (coordination of subsystems) to be focused on.

The first reported interaction indicates the sensitivity of double-stimuli task to classical interference when single-recall is required: articulatory suppression disrupts word recall and has no effect on location recall, Moar box tracking and standing balance position disrupt location recall and have no effect on word recall. These results confirm that a double-stimuli task implicates the same mechanisms or subsystems as the simple tasks classically used in the literature. Furthermore, the results question the role of the episodic buffer as postulated by Baddeley (Baddeley 2000). According to the latter, verbal and visuospatial information could be integrated in the episodic buffer. Whether or not this buffer is involved in the double-stimuli task has not been tested in the present experiment, but the observed specific effects of both the verbal and spatial interference tasks at the very least indicates that this episodic buffer mechanism is completely dependent on the capacities of the slave systems.

The second analysis indicates that performance decreases with double-stimuli task compared to short-term memory tasks. Free recall of one type of item is required in both cases but when participants are engaged in double-stimuli task, they have to store and to maintain all the encoded information (each word with its associated location) until they know what they have to restitute, i.e. from the task beginning to the end of retention interval. Double-stimuli task is not merely a short-term memory task. It must be considered as a working memory task requiring word and location maintenance and word-location coordination.

This task is complex and the classical interpretation of the fact that decrease in performance is far from catastrophic when participants are engaged in a complex task is that the cognitive demands of working memory measure are supported by separate components. On the contrary, short-term memory tasks load on one factor (Kail & Hall, 2001). The double-stimuli task offers the advantage of allowing working memory tasks in comparison with short-term memory tasks to be tested directly.

The third analyze concerns only the double-stimuli task. We observe a modified sensitivity to interference when single-recall is compared to double-recall. Performance decreases significantly with double-recall but the interference effect is different from the classical specific interference effect. Here, verbal interference and Moar box tracking lead to similar decrease of performance. On the other hand, the standing balance position leads to the same performance decrease as the Moar box-tracking task does on location recall, and both do not significantly differ from the no-interference condition on double-recall. These results confirm that double-recall may be related to central executive because the cost of interference tasks explains the observed pattern of data.

A complementary interest of the double-stimuli task is, as we have shown, to enable us to elaborate a corrected score in relation to capacity of central executive. It would be useful to conduct two types of studies in further researches: a general and differential study in order to discover the underlying performance factors, and a neuropsychological one which could provide confirmation of the observed dissociation in patients with central executive impairment.

The multicomponent model refers to the storage and the processing of information. It has been successful in accounting for a wide range of data and could also account for the results of the present experiment. Verbal WM is involved in word retention. Visuospatial WM is involved in location retention. The present experiment shows in addition that executive control is involved in the task general control and in word-location coordination, in conformity with the hypothesis of central executive multiple functions (Baddeley, 1996). These results are obtained by using a double-stimuli task that offers the advantage of involving both storage (words and locations) and processes (coordinating) clearly identified and easy to dissociate.

ACKNOWLEDGEMENTS

We are grateful for comments from anonymous reviewers and from Laura Hernandez. We thank Gillian Porter and Yvette Hatwell for their help in revision.

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