Psychologica Belgica
1995, 35-4, 241-251.

STIMULUS INDEPENDENT THOUGHTS AND WORKING MEMORY: THE ROLE OF THE CENTRAL EXECUTIVE

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A recent article by Teasdale, Proctor, Lloyd, and Baddeley (1993) has shown the usefulness of the working memory paradigm for the research on stimulus independent thoughts (SIT). SIT are thoughts that come into our minds without elicitation by immediate external sensory input. The results of the four experiments reported, converged to suggest that the central executive (CE) plays an important role in the production of SIT. However, no hard evidence could be obtained, as the task used to suppress CE resources, also interferes with the activity of the phonological subsystem. The present experiment used a random interval generation task (Vandierendonck, De Vooght, & Van der Goten, submitted), which is a CE suppression task that is "pure", in the sense that the task interferes with the CE but not with the phonological or the visuo-spatial slave system. The influence of a slow and a fast version of the "pure" CE task was compared with the effect of a control condition and with a random letter generation task. The results showed that the three interference tasks reduced the production of SIT, with the largest effect created by the random letter generation task. The results corroborated the finding of Teasdale et al. (1993) that the disruptive effect of tasks that involve the CE, is restricted to thought segments that are part of a stream of connected thoughts. The results allowed for the conclusion that the production of connected sequences of SIT requires the involvement of the CE.

Introduction

Stimulus Independent Thoughts

Stimulus independent thoughts (SIT) are streams of thoughts that arise without direct external stimulus input. This mind wandering is most commonly experienced when we are not engaged in demanding tasks. Teasdale, Proctor, Lloyd, and Baddeley (1993), give an enumeration of psychological processes in which these SIT are believed to be involved: daydreaming (Singer, 1966), worry (Borkovec, Robinson, Pruzinsky, & DePree, 1983), clinical depression (Beck, 1976), and insomnia (Borkovec & Boudewyns, 1976).

The research reported in this paper was supported by "Inter-university Attraction Poles" grant nr. 31 from the Department of Science Policy to André Vandierendonck.

The authors wish to express their gratitude to André Vandierendonck, who made the software available for the registration and calculation of the statistics for the random interval generation task, and for the valuable comments to an earlier version of this paper. The authors also wish to thank Antoine Tavernier for his technical support.

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Previous Experiments

The experiments of Teasdale et al. (1993) have made clear the usefulness of the working memory paradigm (Baddeley & Hitch, 1974; Baddeley, 1986, 1990) for the study of SIT, and ruled out the alternative model of Antrobus (1968).

Both models hypothesise a central cognitive operator of limited capacity which deals with information from both internal and external sources. This central operator is believed to be involved in the production of SIT. The essential limitation on capacity in Antrobus's model lies in the maximum rate at which the central operator can process the available information. In the Working Memory model, the limit depends on the extent to which the central executive can control and coordinate the subprocesses involved in the execution of novel or complex tasks (Teasdale et al., 1993).

Teasdale et al. (1993) contrasted the two models in a dual task paradigm in which the effect on SIT (implicit primary task) of five secondary tasks were compared. Their first experiment compared the effects of presenting digits at a slow and fast rate with a (quiet) control condition. The digits either had to be repeated immediately (shadow condition) or had to be repeated after an interval (memory condition). The memory condition differed from the shadow condition only in the insertion of a brief delay between receiving stimulus input and producing an appropriate response. This delay does not increase the rate of information processing, which constitutes the essential limitation on capacity in the Antrobus's model. Consequently, this model would predict very limited interference from the memory load on the production of SIT. By contrast, the Working Memory model predicts an increase in demands on the central executive resources, because rehearsal or recycling processes have to be maintained. Consequently, a decrease in the production of SIT under memory load conditions is expected. The results which were replicated in a second experiment were inconsistent with Antrobus's model and favoured the working memory model.

In two additional experiments the authors investigated the effects of variations in the size of memory load (Exp. 3 and 3A). A significant difference between a single-digit and a five-digit load was found only in Experiment 3A, which had a more sensitive procedure. Teasdale et al. acknowledge that the effect of size of memory load is considerably less than in the studies of sentence verification (Baddeley, Lewis, Eldridge & Thomson, 1984), and syntactic reasoning reported by Baddeley and Lewis (cited in Baddeley, 1986). They concluded that the size of the memory load was not the most important factor. The mere presence of a memory load requires the control of the central executive to switch between the components of the task.

Moreover, the detrimental effects of digit load on the production of SIT were limited to thought segments that were part of larger connected sequences of thoughts. This corroborated the authors' assumption that working memory provides a temporary workspace into which the products of cognitive operations are delivered and then subsequently become themselves the basis for further cognitive operations. The authors conclude that the results are consistent with the hypothesis that the central executive component of the working memory model is involved in the production of connected sequences of SIT.

Experiment 1 and 2 showed that an additional memory load increases the effect of a simple shadowing task on the production of SIT. In Experiment 3A, a significant difference in SIT frequency between the one-digit and the five-digit memory load was found, which points in the direction of involvement of the central executive, as previous studies have suggested that demands on the central executive increase with size of memory load (Baddeley et al., 1984). In addition, Baddeley (1993, pp. 22–28) reports unpublished experiments in which the visuo-spatial subsystem alone, the visuo-spatial subsystem in combination with the central executive, and the phonological subsystem in combination with the central executive were interfered with. This series of experiments led the authors to conclude that the central executive is needed for the production of SIT.

We agree with the authors that these results converge to suggest that the central executive component of the working memory model plays an important role in the production of stimulus independent thoughts. However, in all the experiments mentioned, the tasks used to suppress the resources of the central executive also interfere with one of working memory's subsystems. We believe that these additional loads on the slave systems complicate the situation, so that clean-cut decisions are not easy to obtain.

A "Pure" CE Interference Task

In the study of the central executive subsystem of the working memory model, several tasks have been proposed and have been used to suppress the activity of this component, e.g.: avoiding automaticity in verbal reaction task (Greenwald & Shulman, 1973), random digit generation (e.g., Gilhooly, Logie, Wetherick, & Wynn, 1993), random letter generation (e.g., Baddeley, 1966), tapping a random key pattern (Rapee, 1993), random pursuit tracking (Dalrymple-Alford, Kalders, Jones, & Watson, 1994), free recall (Rusted, 1988), counting backwards (e.g., Glanzer, Dorfman, & Kaplan, 1981), and generation of category members (e.g., Baddeley et al., 1984). All these tasks have the drawback of also interfering with either the visuo-spatial or the phonological slave subsystem, so that clean-cut conclusions are not easy to obtain.

Vandierendonck et al. (submitted) have developed and tested a "pure" central executive task which does not interfere with either of the slave systems. Recently, Baddeley (1990) has reinterpreted the function of the central executive as some kind of supervisory attentional system in the line of the SAS-model proposed by Norman and Shallice (1986). This supervisory system is assumed to regulate fast alternation between available resources, and interrupts automatic processing to enable controlled processing of the information. According to this view, people have to interrupt the automatic generation of familiar letter sequences (e.g., acronyms or alphabetic order) when performing the random letter generation tasks. This form of control implies the involvement of the central executive.

On logical grounds, the task of producing random time intervals may be considered to have the same load on the central executive, while there is no reason to suppose that there is a concurrent load of this task on either of the slave systems.

Empirically, Vandierendonck et al. (submitted) have shown that the random time interval generation task loads on the central executive component of the Working Memory model. In a first experiment, a supra-span presentation procedure was used and serial recall was scored. It appeared that performance was significantly lower when the supra-span was combined with the random interval generation task than in the control condition. This was true as well when digits as when consonants had to be remembered. The second experiment used a span procedure and compared performance in the control condition with performance under four different dual-task conditions: random interval generation, fixed interval generation, random digit generation and articulatory suppression. The authors found that the fixed interval tapping task had no effect, while the effect of the random interval generation was significant. This effect was smaller than the effects of random digit generation and articulatory suppression.

The aim of the present experiment is to study the effect of a "pure" central executive interference task on the frequency of connected sequences of SIT. To that end a slow and a fast version of the random interval generation task were compared with a control (quiet) condition. As the random letter generation task is one of the tasks most often used to suppress the resources of the central executive, this task was included to serve as a baseline.

Method

Subjects

Twenty first-year psychology students (17 female, 3 male) of the University of Ghent (Belgium) participated for course requirements. They volunteered for this particular experiment.

Design and Procedure

This experiment can be considered a replication of the experiments of Teasdale et al. (1993). The effects of the experimental treatments were compared in a within-subjects design in which every subject performed each of the four secondary tasks: a random letter generation task (Baddeley, 1966), a slow and a fast random time interval generation task (Vandierendonck et al., submitted), and a quiet control condition. A fast version of the random time interval generation task was included because previous investigations (Vandierendonck et al., submitted) indicated that the interference effect of this task is reliable but rather small. It seemed plausible that a faster version would rely more heavily on central executive resources, thus producing more interference with the production of SIT.

The experiment was administered in blocks of average duration 120 sec (range 100–140 sec). Each subject received eight blocks in each of the conditions being compared. Two different randomised sequences of eight blocks of the four secondary tasks were constructed. The subjects were equally and randomly assigned to one of these conditions.

Each of the secondary tasks was announced by a separate sound-signal. Each signal consisted of one, two, three or four short beeps (500 Hz, duration and interval of 500 msec). The signals were presented on a headphone connected to a IBM compatible PC. One additional beep (1200 Hz, 1500 msec) was included to indicate that subjects had to report their thoughts.

The experiment was conducted by the first author in a darkened and quiet room. The subjects were tested individually in sessions lasting approximately 100 min. Subjects laid down, had their eyes closed, and were wearing headphones during all sessions in which thoughts were sampled.

After subjects had been instructed about the content of each secondary task and knew the procedure of thought report, they practised each condition in a randomised sequence. When it was clear that subjects knew the auditory signals and understood the procedure, each subject received eight blocks of each of the four experimental conditions: (1) quiet, (2) slow random interval generation, (3) fast random interval generation, and (4) random letter generation. In the quiet condition, subjects were required just to "let the mind do what it wants to do". In the tapping conditions subjects had to tap the zero key on the numeric keypad in a completely "random" and "unpredictable rhythm". In the slow tapping condition subjects were instructed to tap at a rate of approximately 1 hit per sec, in the fast tapping condition the requested rate was approximately 2 hits per sec. In the random letter generation task, subjects were asked to produce a random sequence of letters at a rate of 1 per sec. In order to be able to measure the degree of randomness achieved in the random interval tasks, the tapping behaviour was registered.

The dependent variable of interest in this experiment was the frequency of SIT. Each block was terminated by a report-signal, after which the subjects reported what was passing through their mind at the moment the signal was given. It was made clear to the subjects that they did not have to reconstruct thoughts that had occurred during the block. If the subjects judged a thought as being too personal, they could categorise it as a "private thought". If this was the case, the subjects were asked whether the thought just reported was a stimulus independent one. SIT were defined as "thoughts with no apparent connection with the experiment or with the experimental situation". In all cases subjects were asked whether the thought reported was an element of a stream of connected thoughts, or a fragmentary thought.

Thoughts as "I am hungry", "my foot aches", or "nothing", were categorised as stimulus dependent. Each thought was registered and, with exception of the private thoughts, afterwards categorised as SIT or as a stimulus dependent thought. The experimenter and a judge blind both to the experimenter's categorisation and to the experimental condition categorised each thought report, except for the "private thoughts", which were judged only by the subject. Inter-judge agreement was calculated by dividing the frequency of agreement between the two judges (on categorising a particular thought as SIT) by the sum of times they agreed plus the times they disagreed (on categorising as SIT). Agreement amounted to 96%.

Results

Analysis of Randomness in the Generated Intervals

One of the problems that arises when tasks in which subjects have to generate random behaviour are used, is the control over the degree of emitted randomness. In view of the finding that it is difficult for humans to produce randomness (Teigen, 1983; Baddeley, 1990), we cannot expect perfect random tapping behaviour in the random time interval task. Although Vandierendonck et al. (submitted) stipulate that no special control on the randomness of the random production is needed, we chose to investigate the degree of randomness in order to have a control over the compliance of the subjects. For each series of intervals a subject produced, lag correlation 1–10 were computed and the confidence intervals were estimated by Monte Carlo methods. We refer to Vandierendonck et al. (submitted) for a more detailed description of the method and the appropriate statistical test. Three subjects were excluded from further analysis, because most of their series were found to deviate significantly (a= .05) from randomness.

The Frequency of SIT

The results were analysed by means of a MANOVA design with one between-subjects variable (the order in which the conditions were presented) and with the frequencies of the SIT under the secondary task conditions as the dependent variables. This procedure is conform to the suggestions of McCall and Appelbaum (1973) concerning the analysis of repeated measures designs.

Table 1 shows the mean frequency of SIT in the three experimental conditions and the control condition.

Because neither the order of the blocks ($F(1,15) < 1.$), nor the interaction between the order of the blocks and all the task conditions ($F(3,13) = 2.64$, $p > .05$) were statistically significant, the data were collapsed over the order factor.

Table 1
Average Frequency of SIT as a Function of Secondary Task Conditions[a]

	Quiet	Letter	Interval	
			Slow	Fast
SIT	6.41	2.41	5.12	4.65
	(1.50)	(2.14)	(1.75)	(1.68)

[a] The maximum possible score = 8. Standard deviations are given in parentheses.

The frequency of SIT reports was significantly lower in each of the three experimental conditions compared to the control condition: random letter generation: $F(1,15) = 35.24$, $p < .01$; slow random interval generation: $F(1,15) = 23.90$, $p < .01$; fast random interval generation: $F(1,15) = 15.84$, $p < .01$. Both the slow and the fast interval generation task affected the SIT production significantly less than the random letter generation task, respectively: $F(1,15) = 18.07$, $p < .01$, and $F(1,15) = 10.44$, $p < .01$. The frequency of SIT was not significantly lower in the fast interval condition than in the slow condition: $F(1,15) < 1$. This lack of difference could not be attributed to a failure on the part of the subjects to follow the instructions. Subjects' hit-frequency was significantly higher in the fast version (2.32 hits per sec) than in the slow version (1.38 hits per sec) of the random interval task: $F(1,16) = 55.68$, $p < .01$.

Each reported thought was categorised as either fragmentary or sequential.

Table 2 shows the average frequency of fragmentary SIT and SIT that were part of a connected sequence of ideas.

Table 2
Average Frequency of Sequential and Fragmentary SIT as a Function of Task Conditions[a]

	Quiet	Letter	Interval	
			Slow	Fast
Fragmentary SIT	1.82	1.59	1.53	1.59
	(1.25)	(1.37)	(1.38)	(1.47)
Sequential SIT	4.59	0.82	3.59	3.06
	(1.54)	(1.25)	(1.37)	(1.73)

[a]The maximum possible score = 8. Standard deviations are given in parentheses.

Overall, there was no significant effect of the task conditions on the frequency of fragmentary SIT: $F(3,13) < 1$. The pattern of results that emerged from the analysis of the sequential SIT was identical to the results of the previous analysis. The frequency of SIT reports was significantly lower in each of the three experimental conditions compared to the control condition: random letter generation: $F(1,15) = 61.40$, $p < .01$; slow random interval generation: $F(1,15) = 11.73$, $p < .01$; fast random interval generation: $F(1,15) = 10.28$, $p < .01$. Both the slow and the fast interval generation task affected the SIT production significantly less than the random letter generation task, respectively: $F(1,15) = 30.03$, $p < .01$, and $F(1,15) = 16.18$, $p < .01$. The frequency of SIT was not significantly lower in the fast interval condition compared to the slow version of the task: $F(1,15) < 1$.

Rate of Generation

In view of the lack of a significant difference between the effects of the slow and the fast random interval generation task, we decided to take a closer look at the rate of generation in the three experimental conditions.

Table 3

Mean Rate of Generation per Second in the Tasks, Kendall's Correlation Coefficient Between Rate of Generation and the Frequency of SIT, and the Probability[a]

	Letter	Interval	
		Slow	Fast
Generation rate	0.63	1.38	2.32
	(0.20)	(0.63)	(0.80)
Kendall's τ	-.11	.17	.06
Probability	.56	.39	.73

[a] Standard deviations are given in parentheses.

The mean rate of generation for the three secondary task conditions can be inspected in Table 3. Kendall's rank correlation coefficient τ (Siegel, 1956) between the frequency of SIT reports and the rate of random generation was calculated. As can be seen in Table 3, the correlations were low and non-significant in all three conditions.

Discussion

In this experiment a central executive suppression task, pure in the sense that it does not load on either of the slave systems, has been used. With this "pure" task the claim of Teasdale et al. (1993), that central executive suppression produces a decrease in the frequency of stimulus independent thoughts has been replicated. This central executive interference task only affected the occurrence of thoughts that were part of a larger connected stream of thoughts. In our opinion, it has become rather clear now that the CE is involved in the production of connected sequences of SIT.

In addition, the results of this experiment lend further support for the position of Teasdale et al. (1993) with regard to the Model of Antrobus (1968). In this experiment the slowest generation condition (random letter generation) was also the condition which interfered most with the production of SIT. This finding is inconsistent with Antrobus's model, as it assumes that it is the rate at which the central operator can process information, that constitutes the limitation on the system. From a Working Memory viewpoint, things are not so straightforward. In a random letter generation task, the subjects have to generate randomness (central executive), have to access long term memory for the letter production (central executive), and additionally have to pronounce the chosen letter (phonological subsystem).

The same line of thinking can be followed in the comparison between the letter generation and the interval generation tasks. Where it was clear that the interval generation task suppressed the central executive and hence the frequency of SIT reports, the effects of these tasks were substantially less pronounced than the influence of the letter generation task. We believe that the influence of the random letter generation task was more substantial because of the task requirements mentioned above. In addition, it seems plausible that subjects are more aware of the letter generation than of the interval generation task. In the former they have to pronounce the chosen letter. This can be seen as some kind of immediate feedback, whereas in the interval generation task this feedback is not so explicitly available. The data on the rate of generation in the secondary tasks are consistent with this hypothesis. A careful qualitative examination of the randomness of the intervals, revealed that an increase in hit rate often coincided with an increase of SIT reports. One tentative explanation could be that subjects sometimes "forgot" about the required randomness in the secondary interval task and admitted some automaticity. Subsequently, the probability of an SIT increased.

The prediction that a faster version of the interval task would influence the frequency of connected SIT more substantially was not confirmed, although the tendency existed (Table 1 and Table 2, bottom). This was not due to a failure to manipulate the rate of generation as can be seen in Table 3. However, with the above line of thought in mind, we believe some caution is in place. If we could find a way to increase the "awareness" of the random interval generation task, or find a way to give feedback about the randomness of the task performed, perhaps an effect of the rate of generation could be found.

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Received March, 1995
Revision November, 1995
Accepted November, 1995