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The role of executive processes in prospective memory tasks

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Prospective remembering refers to remembering and acting on behavioural intentions. Three experiments tested the hypothesis that prospective remembering requires the availability of executive processes. It was expected that this is more important when intentions are stated in categorical terms. Type of instruction (specific versus categorical), typicality of the cue in relation to the category specified, and executive load were manipulated. Results showed a general benefit of specific instructions. Furthermore, with categorical instructions, performance was better with typical cues. Although the data suggested that executive processes are responsible for the processing of cues, the load manipulation had no significant effect on the prospective memory measure. Thus, no evidence was found for the hypothesis that prospective remembering requires the availability of executive processes. It is argued that it is a matter of strategic choice whether executive processes are deployed: One does not need to monitor for cues but can choose to rely on bottom-up processes. Monitoring may be sufficient, but not necessary for successful prospective remembering.

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Prospective memory involves remembering and acting on behavioural intentions. For example, on your way to the kitchen to put a cake in the oven, someone might ask you to bring some sugar on the way back. However, after you have put the cake in the oven and did some other things, you might forget all about the sugar. Here we focus on prospective memory tasks that involve performing a simple action as soon as some prespecified event takes place (event-based intention).

Given that an intention is somehow represented in memory, how does it result in behaviour at the right time? Several models have been proposed. The Norman and Shallice (1986) theory of action control, which is a very general theory, states that when a new action has to be carried out and one needs to deviate from normal routine, the supervisory attentional system (SAS) is needed. The theory zooms in on a required task-switch: One has to stop doing what one is doing and initiate the required action. This model concurs with lay intuitions about action control: People report that when they make errors, most often they were distracted or absent-minded (Reason, 1983).

Other models, focusing particularly on prospective memory, lay emphasis on the link between the intended action and the event cues that were specified during intention formation. In the Noticing+Search model proposed by Einstein and McDaniel (1996), two separate stages in prospective remembering are identified. First, the target event should be noticed: It should not only be perceived but also create some internal response, for example a general feeling of familiarity or unexpected perceptual fluency. This internal response then instigates a search in memory for the meaning of the event. It is like seeing somebody jogging in the park: At first, you do not recognise her, but somehow she looks familiar. Then, after searching your mind, you recognise her as the woman who cleans your desk at the office twice a week. It is thought that this search in memory also applies to the retrieval of an intention. It is assumed that the noticing stage is relatively automatic, but the memory search is controlled and requires cognitive resources.

According to McDaniel, Robinson-Riegler, and Einstein (1998), prospective memory is supported by the medial-temporal/hippocampal module—a reflexive associative memory system—as described by Moscovitch (1994). This module supports the retrieval of an intended action when a target event is attended to by automatically producing interactions between the cues and memory traces previously associated with these cues. Only if there is sufficient interaction between the target event and the memory trace of the intended action will the intention spring to mind, rapidly, obligatorily, and with few cognitive resources. Whether there is sufficient interaction depends on the number of associations the cue has and on the strength of the associative link. Guynn, McDaniel, and Einstein (1998), for example, found that reminding people of the intended action facilitates prospective remembering, whereas reminding people of the target event

does not, but that the use of reminders referring both to the intended action and the target event facilitates performance even more. Successful prospective memory is also dependent on the degree of processing of the cue, and whether or not the retrieved intention is put into overt action, which is the responsibility of other processes (see Guynn, McDaniel, & Einstein, 2001).

All of the above models of prospective memory assume the need for cognitive resources but differ concerning what these are needed for. The Norman and Shallice model (1986) explicitly states the necessity of cognitive resources. They are always needed for an ''attentional check'' when departing from normal routine (Reason, 1990). Resources are needed at the time of departure from normal routine when the action needs to be carried out. In contrast, according to the Noticing+Search model, resources are needed for a controlled memory search. The automatic associative memory system model predicts that once a cue is processed well enough, no cognitive resources are needed for memory retrieval given a strong association. However, once retrieved, the intention needs to be held in working memory and the ongoing task needs to be interrupted and these processes might be susceptible for manipulations of cognitive load (Guynn et al., 2001).

The evidence regarding the need for cognitive resources for event-based intentions is mixed. It has been shown that if participants are carrying out some ongoing task, performance is negatively affected by having an additional event-based prospective memory task to perform (Smith, 2001). Smith argues that a prospective memory task usurps cognitive resources because participants are monitoring for cues that should indicate that the intended task be carried out. Other experiments have shown that dividing attention leads to worse prospective remembering: If participants in addition to some ongoing task and a prospective memory task are given an extra task, prospective memory suffers (McDaniel et al., 1998; Stone, Dismukes, & Remington, 2001). In addition, if the difficulty of some ongoing task is increased, prospective memory suffers as well (Kidder, Park, Hertzog, & Morrell, 1997; Marsh & Hicks, 1998; Stone et al., 2001). Even if the total number of tasks and the difficulty level of the ongoing task(s) remain unchanged but participants are required to switch between different ongoing tasks at unpredictable times, prospective memory is worse than when no switches are required (Marsh, Hancock, & Hicks, 2002).

In contrast, other studies did not find that a manipulation of cognitive resources disrupts prospective memory. D'Ydewalle, Luwel, and Brunfaut (1999) found that the addition of an extra ongoing task did not affect prospective memory performance. Otani, Landau, Libkuman, St Louis, Kazen, and Throne (1997), as well as Brandimonte, Ferrante, and Delbello (2001) varied the cognitive demands of the ongoing activity but found no effect. The mixed evidence regarding the effects of cognitive load manipulations are likely due to a large variation in experimental procedures, for example regarding the nature of the

ongoing tasks, the way that cognitive load is manipulated and the kind of prospective memory task.

In an attempt to explain the discrepant findings, Marsh and Hicks (1998) focused on the *kind* of cognitive load. Making use of the working memory framework (Baddeley, 1986), they tested whether an effect of cognitive load depends on the part of working memory that the ongoing task makes use of. Working memory consists of three systems: the central executive, responsible for executive functions like planning, monitoring, and inhibition, the phonological loop, for retaining verbal information, and the visuospatial sketchpad, for retaining visual and spatial information. It could well be that only one component of working memory plays a role in the remembering and carrying out of delayed intentions.

Marsh and Hicks (1998) manipulated the use of these three components in order to discover which manipulation affects prospective memory. Participants had to perform three concurrent tasks. First, during each separate trial, participants were presented with three words that had to be reproduced at the end of the trial. Second, whenever one of these words signified a fruit, they had to respond by pressing the f-key on the keyboard (the prospective memory task). Third, an extra task was added that differed only in degree of difficulty. This was the task that either required the use of the central executive, the phonological loop, or the visuospatial sketchpad. When the extra task required merely one of the latter systems, increasing the difficulty of this task did not result in worse performance on the prospective memory task. However, when the extra task demanded the use of the central executive, increasing its difficulty level did affect performance. In sum, the available literature suggests that executive processes play an indispensable role in prospective memory. However it is yet unclear what their exact role is, and this study will make a first attempt to answer this question.

Marsh and Hicks (1998) have argued that prospective memory relies on executive processes. Since in their experiments only a specific type of prospective memory task was used, it should be established to what extent this claim can be generalised. Marsh and Hicks used categorical instructions: ''Respond to words designating a type of fruit''. Others have argued that categorical instructions provide less environmental support than instructions that specifically mention the target word and therefore require more self-initiated processing (Einstein, McDaniel, Richardson, Guynn, & Cunfer, 1995). It has already been shown that categorisation processes are affected by cognitive load (Baddeley, Lewis, Eldridge, & Thomson, 1984). It is therefore hypothesised that the need for executive processes to some extent depends on whether a target word is described categorically (respond to types of fruit) or specifically (respond to *apple*). More generally, the question regards the exact role of the central executive: Is it mostly responsible for self-initiated categorisation or is it responsible for more general aspects of prospective memory as presupposed by the existing prospective memory models?

EXPERIMENT 1

The objective of the experiment was to test whether the availability of executive resources is more important when a target event in a prospective memory task is defined categorically than when it is fully specified. Marsh and Hicks (1998) showed effects of cognitive load on prospective memory performance when using the random number generation task (Exp. II). In this experiment, the same paradigm was used, now including a condition with a specific instruction. Based on the results of Cherry, Martin, Simmons-D'Gerolamo, Pinkston, Griffing, and Gouvier (2001), Einstein et al. (1995), and Ellis and Milne (1996), we expected better performance with a specific instruction than with a categorical instruction. We also expected to replicate the results of Marsh and Hicks in that with a categorical instruction, performance would be affected by executive load. In addition, since Baddeley et al. (1984) have shown that categorisation is sensitive to manipulations of cognitive load, it was expected that the load effect would be larger with a categorical instruction than with a specific instruction. Note that we are not suggesting that executive load only has an effect on prospective memory when categorisation is involved. Indeed, McDaniel et al. (1998, Exp. 4) found an effect of dividing attention on an event-based prospective memory task that did not require categorisation. We are merely hypothesising that the effect of load is larger with tasks that require categorisation than with tasks that do not.

Method

Participants and design. A total of 91 paid undergraduates, with a mean age of 21 years (SD = 2.1), were randomly assigned to four experimental conditions of a 2 (Instruction: specific, categorical) $\times$ 2 (Cognitive load: low, high) factorial between-subjects design.

Materials. We randomly selected 68 five-letter words from a word frequency list (Martin, 1971), avoiding words that are semantically related or orthographically similar to ''apple'' but with a similar frequency. Nine words were used for the three practice trials; the remaining words were presented in the experimental trials, together with the target word *apple*. The practice trials and the target trial were identical for each participant. Word presentation for the remaining trials was randomised.

Procedure. The procedure was almost identical to that of Marsh and Hicks' (1998) Experiment II. People were engaged in a short-term memory task. Each trial took 25 s. During each trial, three words were visually displayed in succession on a computer screen. Each word was visible for 1500 ms. At the end of each trial, participants had to report as many of these three words as possible, for which they had 5 s. The next trial started immediately after these 5 s. During each trial, participants in addition had to perform the random number generation

(RNG) task. This task involves calling out numbers between one and ten in an unpredictable order. Those in the high load condition had to call out a number every 1000 ms, those in the low load condition had to call out a number only every 1250 ms. The pace was indicated by short beeps that were presented throughout each trial.

At the beginning of the experiment, participants were told they would have to perform a short-term memory task. Meanwhile they would have to perform the RNG task. Participants then practised the RNG task without the short-term memory task. Next they received the prospective memory instruction: Those participants in the categorical instruction condition had to press the enter-key as soon as a word presented on the screen was a type of fruit, those in the specific instruction condition had to press the enter-key as soon as they saw the word *apple*. The three tasks, short-term memory, prospective memory, and RNG, were equally important. All participants were subsequently given three practice trials during which no fruit exemplar was presented. After these practice trials, 20 experimental trials started. The number of experimental trials was not mentioned, nor were the participants reminded of the prospective memory task at this point. The cue word *apple* appeared as the second word on the 20th trial, which was also the last trial.

The software recorded whether the participants responded to the target word and if so, how long after the onset of the target word. We counted all responses that occurred between the onset of the target word and the moment that the beeps stopped and the message appeared to recall the three words, which was 14 s later. Some participants gave the response after they had stopped generating random numbers and started recalling the words they had seen, but these were regarded as omissions.

The experimenter was seated behind the participant and recorded the generated numbers and the words that were recalled. After the last trial, participants were debriefed, paid, and dismissed.

Results and discussion

Random number generation. Regarding the performance on the RNG task, we computed a score for randomness based on Evans (1978; see also Marsh & Hicks, 1998). We computed this score for each participant based on the five trials preceding and including the target trial. A low score refers to a high degree of randomness (see Table 1). A factorial ANOVA revealed that participants in the low load condition were significantly more random ($M = 0.34$, $SD = 0.05$) than participants in the high load condition ($M = 0.37$, $SD = 0.06$), $F(1, 87) = 8.26$, $MSE = 0.003$, $p = .005$. There was no main effect of instruction, $F = 0.23$, nor an interaction, $F = 2.08$, $p = .15$. The significant load effect indicates that the high load condition was more demanding than the low load condition.

TABLE 1
Experiment 1: Proportion of prospective memory responses, proportion of words recalled on short-term memory task, and RNG score as functions of cognitive load and instruction

Instruction	*Cognitive load*	*Prospective memory*	*Short-term memory*	*RNG score*	*Group size*
Categorical	Low	.35	.63	.34	23
	High	.45	.59	.36	22
Specific	Low	.73	.69	.33	22
	High	.50	.65	.38	24

A low RNG score indicates good performance.

Short-term memory. Next, we counted the number of words that participants recalled correctly on the short-term memory (STM) task, divided the numbers by 60 and performed a factorial ANOVA on these proportions with load and instruction as independent variables (see Table 1). The main effect of load was not significant, $F(1, 87) = 1.10$, $MSE = 0.02$, $p = .30$. However there was a significant main effect of instruction: Participants with a categorical instruction recalled on average fewer words correctly (60%) than those with a specific instruction (67%), $F(1, 87) = 4.60$, $p = .04$. The load by instruction interaction effect was not significant, $F = 0.12$. These results suggest that participants with a categorical instruction paid less attention to the short-term memory task than participants with a specific instruction.

Eighty-five percent of the participants successfully recalled the target word *apple*. A logit analysis of this percentage was performed with effects coding (i.e., -1, 1) for main effects of cognitive load, instruction and their interaction. The main effect of cognitive load was not statistically reliable, $B = -0.26$, $p = .42$. There was also no significant main effect of instruction specificity, $B = 0.51$, $p = .12$, and no significant interaction, $B = 0.31$, $p = .34$.

Prospective memory. When asked during debriefing, all participants could reproduce the content of the prospective memory instruction. The proportions of participants that responded to the target word are displayed in Table 1. The proportions were analysed in a logit analysis with instruction, load, and their interaction as predictors (effects coding). A significant main effect of instruction was found: Response rates were higher in the specific instruction condition than in the categorical instruction condition, $B = 0.45$, $p = .04$. The main effect of load was not reliable, $B = -0.13$, $p = .54$, nor was the interaction effect, $B = -0.36$, $p = .10$.

In sum, responding to the target word in accordance with the prospective memory instruction was more likely with a specific instruction than with a

categorical instruction. Results did not confirm the hypothesis that load effects are larger with categorical instructions than with specific instructions.

The discrepancy between Marsh and Hicks' (1998) effect of load with categorical instructions and the null-finding with categorical instructions may be explained by differences in the strategy that participants applied. In this experiment, participants with a categorical instruction recalled on average 60% of the words presented, whereas Marsh and Hicks reported a percentage of 78. In contrast, our participants performed better on the RNG task (i.e., were more random) compared to those in the Marsh and Hicks study. Quite possibly, participants in this study paid more attention to the RNG task, thereby paying less attention to the words, which led to worse performance on both the STM and the prospective memory task. If no attention is paid to the words on the screen and thus to the prospective memory task, it is unlikely that participants are monitoring for a target word. Not finding an effect of taxing executive functions responsible for monitoring may then be not that strange.

EXPERIMENT 2

Experiment 1 did not replicate the effect of executive load on prospective remembering, that was reported by Marsh and Hicks (1998). The way in which participants distributed their attention over the different concurrent tasks might have contributed to this. In Experiment 2, therefore, a different experimental procedure was used. Similar to Experiment 1, participants were engaged in a verbal short-term memory task and they had to press a key as soon as one of the words that need to be memorised was a particular word. In addition, while participants were engaged in the short-term memory task, they had to perform an extra task that was used to manipulate the load that was placed on the central executive.

In order to make participants more attentive to the words on the screen, the number of words to be memorised was increased and participants had to construct sentences with the words after each trial. In addition, a manipulation of the central executive task was chosen that is less demanding than the RNG task. It was hoped that participants then would be more likely to monitor for a target word. It has been shown that tapping random intervals is less demanding than random number generation at a pace of 1 Hz (Vandierendonck, De Vooght, & Van der Goten, 1998, Exp. III). The Random Interval Generation (RIG) task (Vandierendonck, 2000; Vandierendonck et al., 1998) has the additional advantage that it does not tax the phonological loop. This way, it could be better established whether only the central executive system is responsible for prospective memory performance, and not any of the other systems or a combination of systems.

One other important alteration was that now both typical and less typical target words were used. In Experiment 1, a typical exemplar from the category of fruits was used (*apple*). Mäntylä (1994) has argued that responding to atypical

target words in a prospective memory task requires more self-initiated processing than responding to typical exemplars. Hence, it was expected that the effect of executive load would be largest in prospective memory situations in which a cue that is specified only categorically, is itself an atypical instance of that specified category.

Furthermore, cognitive load was manipulated while controlling for mental fatigue. In the paradigm of Experiment 1, as well as in many other paradigms, load was manipulated by increasing the difficulty of the ongoing task that people are performing between the time of instruction and the occurrence of the target event. This means that at the time of the target event, participants in the high load condition had been working harder than those in the low load condition for a longer period. It is therefore not clear whether any difference in performance should be attributed to general fatigue or to the availability of the central executive specifically. In order to test the hypothesis that prospective remembering critically depends on the executive functions *available* during the time that the intention needs to be retrieved, one should take care to keep the degree of exertion equal across experimental conditions. Cognitive load was therefore manipulated in such a way that groups differed only to the extent that the central executive was taxed during the time that the target event occurred and the response needed to be made.

Experiments 2 and 3 are highly similar and were carried out at the same time. Participants were randomly assigned to the experiments and conditions. Executive load was manipulated in both experiments, with an extra manipulation of target word typicality. Experiment 2 used categorical instructions and Experiment 3 specific instructions. After the experiments are reported and discussed separately, a complete three-way design will be analysed, and the implications for the general hypothesis regarding categorisation and cognitive load will be discussed. It will also be assessed what process (or processes) subserving prospective memory might be the responsibility of the central executive: Taxing the central executive might affect the level of processing of the cue, or hinder a controlled memory search.

Method

Participants. Eighty paid undergraduates participated in the experiment. Their mean age was 22 years (SD = 5.3).

Materials. We used 91 three-, four-, and five-letter words. Two of them, *owl* and *sparrow*, were used as target words in the experiment. In Dutch, both words consist of three letters. The target words were chosen based on a pilot study, in which 30 people named the first five birds that came to mind. Twenty-seven people named *sparrow* and this was the most frequently named bird, whereas only one person named *owl*. We chose to use these words since

they are identical in word length and varied in typicality. The remaining 89 distracter words were randomly selected from a frequency list (Martin, 1971). Half of them came from the list of frequently used words, in which *sparrow* was listed, and the other words were taken from the list of less frequently used words, of which *owl* was a member. Care was taken to ensure that none of the words was semantically related or orthographically similar to the target words. No other bird names were used. Fourteen words were used for the practice trials, whereas the remaining words were quasirandomly assigned to the experimental trials, ensuring that words of different length were present in any given trial.

Design. Participants were randomly assigned to either the low load or high load condition, with an equal number of participants per condition. There were 11 experimental trials. The target words appeared in the fifth and eleventh trial. In one target trial the typical target word (*sparrow*) appeared and in the other the less typical target word (*owl*) appeared, so that typicality was a within-subjects variable. Thus we had a 2 (Cognitive load: high, low) $\times$ 2 (Target word: sparrow, owl) design with a repeated measure on the second variable. The order in which the target words appeared was counterbalanced.

Procedure. Participants were tested individually. When they entered the lab, the experimenter told them that the experiment was about testing people's memory and their creativity. Participants sat down in a cubicle in front of a computer screen, a keyboard, a pen and a piece of paper. The experimenter briefly summarised the experimental procedure. There were several trials. During each trial, seven words appeared in succession on the screen. Participants had to try to memorise them, and at the end of the trial had to write down as many of these words as possible and construct one grammatically correct sentence with as many of these words as possible. In order to increase the difficulty of memorisation, the participants had to tap the b-key on the keyboard during the presentation of the words. The experimenter then demonstrated how to tap fixed intervals and how to tap randomly. Fixed interval tapping required tapping an isochronous rhythm: All intervals between two taps had to be equal in length (about half a second). Tapping random intervals required tapping a completely unpredictable rhythm. The prospective memory task and the number of trials were not mentioned at this point.

After the verbal instructions, the experimenter left the cubicle and participants read the complete set of instructions on the computer screen. This was self-paced, except for the part where the prospective memory task was mentioned. This task was presented as an extra task in order to test long-term memory and it was on screen for 7 s. Participants had to hit the enter-key as quickly as possible as soon as the name of a bird appeared among the words to be memorised during the experiment.

In the instructions random and fixed tapping were explained in further detail. Participants had to alternate between fixed tapping and random tapping; a switch had to be made after each trial. Whether participants had to tap regularly or randomly was indicated at the top-right part of the screen. For both tasks, participants had to tap at an average rate of two taps per second. The three tasks, RIG, short-term memory, and long-term memory, were equally important.

There were two practice trials, one with random tapping and one with fixed tapping. The software provided feedback that was identical for all participants. In order to ensure a maximum difference between the low and high load conditions, positive feedback was given on the way they tapped fixed intervals, and it was indicated that randomness could be improved. The experimental trials then started, without further feedback.

Before each trial, it was indicated whether participants had to tap fixed or random intervals; participants then started tapping. The first word appeared after 5 s and remained on screen for 1.5 s. The next word appeared 1.5 s after the removal of the first word. The same applied to the remaining five words. After the disappearance of the last word, the trial continued for another 5 s. A beep then sounded and a message appeared telling the participant to now write down as many words as possible and to construct a sentence. The next trial started 40 s later.

The target words appeared as the fourth word in the fifth and eleventh (the last) trial. Half of the participants started with random tapping and half started with regular tapping. In this way, those who started with random tapping were also tapping randomly when the first target word appeared during the fifth trial, and when the second target word appeared during the eleventh trial. The opposite applies to those who started with regular tapping. Thus, every participant tapped both random and fixed intervals; only the kind of tapping during the target trials was manipulated.

The software registered how participants tapped and whether and when participants responded to *owl* and *sparrow*. We only counted those prospective memory responses that occurred before the end of the trial when the words had to be written down. After the last trial, the participants were debriefed, paid, thanked, and dismissed. The whole procedure took between 20 and 25 minutes.

Results

Random and fixed interval generation. Participants had to alternate between tapping random and regular intervals. The average deviation was used as a measure for regularity. For each trial of each participant, we computed the average deviation from the mean length of the intervals in the sequence. However, we did not compute the measure for the trials during which the target words appeared since many participants interrupted the tapping task in order to give the prospective memory response. The average deviation in a sequence was

subsequently turned into a proportional measure by dividing it by the mean interval length of that sequence. A value of 0.10 for a given trial thus means that each interval deviated on average 10% from the mean interval length on that trial. A proportional measure was chosen as participants varied in their mean interval length (although participants had to tap, on average, in a rhythm of 2 Hz). Here we are only interested in regularity.

For each participant we averaged the measures for the random tapping trials and the measures for the fixed tapping trials separately. A paired-samples *t*-test on the regularity scores showed that participants were significantly more regular in the fixed tapping trials ($M = 0.11$, $SD = 0.06$) than in the random tapping trials ($M = 0.41$, $SD = 0.14$), $t(79) = 18.01$, $p < .001$.

Short-term memory. We counted the number of words that participants recalled correctly during the 11 experimental trials. Two mean scores were computed for each participant, one based on the random interval tapping trials and another based on the fixed interval tapping trials, and these were subjected to a paired-samples *t*-test. When tapping random intervals, the mean number of words recalled was significantly lower than when tapping fixed intervals (65% and 69%, respectively), $t(79) = 4.20$, $p < .001$.

Prospective memory. During debriefing, all participants could recall the contents of the prospective memory instruction. Response rates are displayed in Table 2. A McNemar change test (Siegel & Castellan, 1988) showed that response rates in the first and second trial were not statistically different, $p = 0.35$. Next, a logit analysis was performed on the response rates with effects of a within-subjects variable for typicality and a between-subjects variable for cognitive load, and their interaction (effects coding). Results showed a significant main effect of typicality, $B = .40$, $p = .005$. The main effect of load, $B = -.27$, $p = .24$, and the interaction effect, $B = -.02$, $p = .91$, were not significant.

Discussion

As the prospective memory task required categorisation, we expected a main effect of cognitive load that also would be larger for the less typical target word *owl*. The results did not confirm this hypothesis: The effect of the load

TABLE 2
Experiment 2: Proportion of prospective memory response rates as a function of cognitive load and target word

Target word	*Low load*	*High load*
Sparrow	.40	.28
Owl	.23	.15

manipulation was not different for the typical and the less typical target word, although there was a significant main effect of typicality. Response rates were higher for the typical target word than for the less typical target word, which replicates the findings of Mäntylä (1994; see also Cherry et al., 2001). The data therefore do not support Mäntylä's notion that typicality effects are attributable to self-initiated processing. However, care should be taken with this interpretation since there was no general effect of the cognitive load manipulation.

Though not on prospective memory, the load manipulation had a significant effect on general short-term memory performance: Participants could recall fewer words with little executive resources available than with more resources available. The disruptive effect of random interval generation on memory performance has already been demonstrated (Vandierendonck et al., 1998). The finding is in accordance with studies showing that memory encoding processes are affected by cognitive load (Naveh-Benjamin, Craik, Gavrilescu, & Anderson, 2000).

EXPERIMENT 3

As stated earlier, an experiment very similar to Experiment 2 was carried out at the same time, but now using specific instructions. As with specific instructions no categorisation of target event needs to take place, only a relatively small effect of the cognitive load manipulation was expected (cf. McDaniel et al., 1998, Exp. 4).

Method

Participants and design. Eighty undergraduates served as paid participants, with a mean age of 21 years (SD = 2.2). They were randomly assigned to four conditions, determined by a 2 (Target word: sparrow, owl) × 2 (Cognitive load: low, high) factorial between-subjects design. Participants in the sparrow condition only saw *sparrow* and those in the owl condition only saw *owl*.

Procedure. The exact same procedure was used as in Experiment 2, except that now the prospective memory instruction was specific: ''Hit the enter-key as soon as you see the word *sparrow*'' (alternatively, *owl*). The target word appeared during both the fifth and the eleventh trial.

Results

Random and fixed interval generation. The regularity measures for the trials were computed as described in Experiment 2. A paired-samples t-test showed that participants' tapping was significantly more regular during the fixed trials (M = 0.11, SD = 0.05) than during the random trials (M = 0.40, SD = 0.15), $t(79) = 18.73$, $p < .001$, demonstrating that participants were tapping fixed intervals and random intervals during the correct trials.

Short-term memory. In a similar way as in Experiment 2, we computed two STM scores for each participant—one based on random tapping trials and one based on fixed tapping trials—and subjected these to a related samples *t*-test. Short-term memory recall was significantly worse for the random trials than for the fixed trials (68 and 72%, respectively), $t(79) = 3.90$, $p < .001$.

Prospective memory. All participants could repeat the prospective memory instruction during debriefing. The proportions displayed in Table 3 show that response rates for *owl* were higher than for *sparrow*. Indeed, a logit analysis of response rates with the between-variables target word and cognitive load and the within-variable trial and all first and second order interactions revealed a significant main effect of the target word, $B = -.56$, $p = .03$. In addition, there was a main effect of the trial, $B = .22$, $p = .01$: 65% of the participants responded during the first target trial and 75% responded during the second target trial. The main effect of cognitive load, $B = -.10$, $p = .69$, and the target word by cognitive load effect, $B = .14$, $p = .57$, were not significant, nor was any other effect.

Discussion

As soon as typicality was no longer an issue (to the extent that no categorisation had to take place), the finding of Experiment 2 that *sparrow* was easier to respond to than *owl* disappeared. With specific instructions, *owl* was even easier to respond to than *sparrow*. Therefore, we may conclude that only typicality differences within one particular category can explain the different response rates for the two target words in Experiment 2.

Similar to the results from Experiment 2, we found no significant main effect of executive load on prospective memory. As expected, the observed difference in response rates was even smaller than with a categorical instruction. Similar to Experiment 2, taxing the central executive did have a significant effect on short-term memory performance: When participants had to tap random sequences they afterwards recalled fewer words than when they had to tap regular sequences.

TABLE 3
Experiment 3: Proportion of prospective memory response rates as a function of cognitive load and target word (standard deviations in parentheses)

Target word	*Low load*	*High load*
Sparrow	.60 (.45)	.58 (.44)
Owl	.78 (.41)	.85 (.37)

COMBINED ANALYSIS OF EXPERIMENTS 2 AND 3

Since this study addresses the role of the central executive in prospective memory and its central aim is to test whether an effect of manipulating its availability depends on the type of prospective memory instruction, the results from Experiment 3 (specific instructions) were compared with the results from Experiment 2 (categorical instructions).

Except for the type of instruction, the materials and procedures of Experiments 2 and 3 were identical. In addition, the experiments were run concurrently, with random assignment of participants to experiments and conditions. Therefore, the response rates under high and low load can be analysed with type of instruction as an additional independent variable. Note however that in Experiment 3 the same target word appeared in both target trials, whereas in Experiment 2, a different word appeared during the second trial so that only the response rates for the first target word can be compared (see Table 4, all participants).

In a similar way as in Experiment 1, it was expected that cognitive load would have a larger effect on prospective memory with a categorical instruction than with a specific instruction. A logit analysis was performed with instruction, cognitive load, target word, and all two- and three-way interactions as predictors of a prospective memory response to the first target word (effects coding). Parameters are presented in Table 5 (all participants). The analysis revealed a significant effect of instruction and a significant instruction by target word interaction effect.

Here, we have replicated the instruction effect that others found earlier (Cherry et al., 2001; Einstein et al., 1995; Ellis & Milne, 1996): An instruction that specifically mentions the target word results in better prospective memory than a more general instruction that only mentions the category that the target word belongs to. The significant interaction effect reflects the finding that in

TABLE 4
Experiments 2 and 3: Proportion of prospective memory responses (for first target word only) as a function of cognitive load and type of instruction

	All participants (N = 160)		*Given first target word recalled* (N = 133)	
Instruction	*Low load*	*High load*	*Low load*	*High load*
Categorical	.35	.20	.40	.28
Specific	.65	.65	.72	.79

The last two columns show the proportions when only analysing those participants that reported the target word on the short-term memory task.

TABLE 5
Parameter estimates (effects coded) based on logit analyses of prospective memory rates for first target words of Experiments 2 and 3

Effect	*All participants* ($N = 160$) *B*	*First target word recalled* ($N = 133$) *B*
Specificity	0.86*	1.00*
Cognitive load	−0.16	0.01
Target word	−0.30	−0.32
Specificity × Load	0.22	0.28
Specificity × Word	−0.41*	−0.58*
Load × Word	−0.19	−0.17
Specificity × Load × Word	−0.07	−0.15

One analysis is based on all participants ($N = 160$; column 2); another is based on only those participants that recalled the first target word on the short-term memory task ($N = 133$; column 3). Asterisks indicate statistical significance ($p < .05$).

Experiment 2 a typicality effect was found, showing that *sparrow* was responded to more often than *owl*, and that in Experiment 3, with a specific instruction, this effect was reversed.

Ongoing task performance

A mixed model ANOVA was carried out on short-term memory performance with cognitive load as a within-subjects variable and instruction as a between-subjects variable. Cognitive load had a significant effect on short-term memory performance: When tapping random intervals, participants recalled fewer words (66%) than when tapping fixed intervals (71%), $F(1, 158) = 32.80$, $MSE = 0.23$, $p < .001$. This effect was independent of type of instruction, interaction $F(1, 158) = 0.08$. There was also a significant main effect of instruction on the general percentage of words recalled: Participants with a specific instruction recalled more words (70%) than participants with a categorical instruction (67%), $F(1, 158) = 4.21$, $MSE = 0.02$, $p = .04$. This finding suggests that participants with a categorical instruction paid less attention to the short-term memory tasks, perhaps because they devoted more resources to the prospective memory task. The absolute size of the observed effect, however, is rather small.

As both cognitive load and instruction had a general effect on the number of words recalled, it might also have affected recall rates for the target words. Therefore, the number of times the first target word was recalled during the short-term memory task was analysed. A logit analysis with effects of cognitive load, instruction and their interaction (effects coding) revealed no main effect of instruction, $B = .21$, $p = .35$, but a marginally significant effect of cognitive load, $B = -.41$, $p = .07$: In the low load condition, 89% of the participants recalled

having seen the target word, whereas in the high load condition this percentage was only 78. The interaction effect was not significant, $B = .08$, $p = .71$.

When participants did not recall a target word during the short-term memory task, it is possible that this occurred because the target word was not seen due to distraction. As people cannot be expected to respond to a cue that they do not perceive, we analysed prospective memory performance again but only for those participants of whom one can be sure that they saw the target word. That is, the same logit analysis on the prospective memory response rates was performed again but now including only those participants that reported the target word for the short-term memory task (proportions are displayed in Table 4). Results are presented in Table 5 (first target word recalled). Again, there was a significant main effect of instruction and a significant word by instruction interaction effect.

Table 5 shows that the main effect of cognitive load was smaller than in the earlier analysis. This suggests that any effect that the manipulation might have had on prospective memory can be entirely attributed to an effect on processing of the prospective memory cue, as reflected by the marginally significant effect of load on recall rates of the target word. Manipulating cognitive load had no effect on prospective memory given that participants perceived the target word and could report them at the end of the trial.

GENERAL DISCUSSION

The purpose of the experiments was to determine the generality of the claim that prospective memory tasks require executive processes (Marsh & Hicks, 1998). Based on the assumption that specific instructions require less self-initiated processing than categorical instructions (Einstein et al., 1995) and the finding that categorisation processes are affected by cognitive load (Baddeley et al., 1984), the hypothesis was tested that effects of manipulations of executive load are dependent on the type of instruction: Effects were expected to be larger with categorical than with specific instructions. In the experiments the availability of executive resources and instruction specificity were manipulated, as well as the typicality of the target word in relation to the category mentioned in the categorical instruction. Assuming that in case of a categorical instruction responding to atypical exemplars requires more self-initiated processing than responding to typical exemplars (Mäntylä, 1994), the largest effect of cognitive load was expected in a situation with a categorical instruction and a less typical exemplar as target word.

No significant effect of the executive load manipulations on prospective memory was obtained, not even with a categorical instruction and a less typical exemplar as target word. In the research presented here, cognitive load manipulations aimed at influencing the availability of executive resources at the time that a stimulus was present that needed to cue an action. Although there is some evidence that this availability had an effect on the processing of stimuli

that might serve as cues for a postponed action, this effect was rather small. Importantly, the significant effect on general prospective memory performance reported by Marsh and Hicks (1998) could not be replicated.

It could be argued that no effect was found due to a lack of statistical power. In Experiment 1, there was only one occurrence of the target event, and in Experiments 2 and 3, there were only two. Many prospective memory researchers argue for multiple target events for a more sensitive performance measure. One reason for using only one or two target events was that we tried to mimic a real-life situation in which target events do not occur repeatedly. Increasing the number of target events per time unit can lead to a different strategy in handling the task and the use of different cognitive processes, so that the experiment measures vigilance instead of prospective memory in its traditional sense (see, for example, Brandimonte, Ferrante, Feresin, & Delbello, 2001; Van den Berg, Aarts, Midden, & Verplanken, 2002). Moreover, using more than one target for an estimate of general prospective memory performance assumes that observations are independent. This assumption, however, is likely to be untrue since the first target event provides information on how often participants may expect target events to occur. This knowledge influences the way that the prospective memory is handled after the first target event so that response rates later in the experiment may measure other processes than response rates early in the experiment. In fact, Experiment 3 showed a significant improvement over time. Other research has also shown changes in prospective memory performance over time (Brandimonte et al., 2001; Ellis, Kvavilashvili, & Milne, 1999; Van den Berg et al., 2002).

In sum, using more target events can have important implications for the external validity of experimental findings: Increasing the number of events per time unit, and including more target events by extending the duration of the experiment, can both result in a different way of handling the prospective memory task, making use of different cognitive processes. Although the present data may suffer from limited statistical power, the finding that the absolute size of the cognitive load effects on prospective memory were much smaller than the one observed by Marsh and Hicks (1998) suggests that something other than a lack of power lies behind the nonsignificant results.

Marsh and Hicks (1998, Exp. II) used the RNG task, which involves monitoring (Miyake, Friedman, Emerson, Witzki, & Howerter, 2000). Note that monitoring is a matter of strategy: One can choose to monitor for a specific target event or choose not to and hope that when the event occurs the intention is automatically remembered. If generating numbers at a high pace makes it impossible to monitor for a target event, this does not mean that people are monitoring when they are generating numbers at a slower pace. The fact that, compared to the Marsh and Hicks experiment, participants performed better on the RNG task but worse on the short-term memory task suggests that participants deemed performance on the RNG more important than performance on the

two memory tasks (relative to Marsh and Hicks' participants). It is important to note here that in Experiment 1 and the one by Marsh and Hicks the way in which the instructions were given were similar: It was stressed that all three tasks were equally important. Seemingly, an experimenter has only limited influence on the way that participants handle the tasks. Participants may have their own interpretation of what is equal regarding the use of cognitive resources.

In Experiments 2 and 3 the availability of executive resources was manipulated in a different way, using the random interval generation task. The experimental procedure was also altered in other ways, aimed at making strategic monitoring for the prospective memory target event more likely. The load manipulation was based on the assumption that this task requires executive processes supported by the central executive (Vandierendonck, 2000; Vandierendonck et al., 1998) and regular interval generation does not or to a much lesser degree. There is evidence that random interval generation negatively affects the inhibition of prepotent responses such as saccadic eye movements (Stuyven, Van der Goten, Vandierendonck, Claeys, & Crevits, 2000) and disrupts monitoring for repetitiveness (Vandierendonck, 2000). Although now the effect of load was in the hypothesised direction, there was still no significant effect on general prospective memory performance. This might indicate that the manipulation was too subtle, perhaps because in the low load condition executive resources were also taxed due to task uncertainty (alternating fixed and random tapping; cf., Marsh et al., 2002). But again, it might be related to strategy: If participants chose not to monitor, no or only little executive resources were deployed even in the low load condition. Participants may have relied more on bottom-up processes, which are not well supported in case of a categorical instruction.

The results from Experiments 1, 2, and 3 showed that participants with a categorical instruction performed worse on the ongoing short-term memory task than participants with a specific instruction. Although this suggests that participants used a different strategy in handling all simultaneous tasks, the absolute size of this difference was rather small (around 5%); probably so small that any (extra) amount of resources devoted to the prospective memory task in the categorical instruction condition was not sufficient for a significant effect of the executive load manipulation. In other words, we believe that one will find effects of executive load in situations in which participants are devoting a significant amount of executive resources to the prospective memory task and are actively monitoring for a relevant cue (see, e.g., Van den Berg et al., 2002).

Thus, the *availability* of executive resources is important only if people *engage* in monitoring. If this interpretation is correct, it can be concluded that Marsh and Hicks (1998) did not establish that in general, prospective memory depends on executive functions, but rather that their participants tried to monitor in order to comply with the prospective memory instruction and that they failed under high executive load conditions.

Instruction specificity also had a large effect on prospective memory response rates. Prospective memory performance was significantly better with specific instructions than with categorical instructions. This replicates earlier findings by Cherry et al. (2001), Ellis and Milne (1996), and Einstein et al. (1995). Einstein and his colleagues (1995) ascribed the specificity effect to a greater need for self-initiated processing (Craik, 1986): With categorical instructions, there is less environmental support, requiring strategic monitoring. This view is not supported by our results, as there was no significant interaction between instruction specificity and cognitive load. However, this hypothesis deserves further scrutiny, as there was no main effect of cognitive load.

Furthermore, the specificity effect cannot be attributed to recognition processes as a result of having seen or heard the target word in the instructions, creating some internal response such as, for example, a feeling of familiarity (Einstein & McDaniel, 1996). If this were true, this internal response would have made the participant more aware of the stimulus, which would probably have resulted in better recall rates for that word on the short-term memory task. In other words, we would have seen an effect of specificity on the recall rates for the target word of about the same magnitude as on prospective memory performance. This was not the case.

The specificity effect is better explained by some bottom-up effect by activation spreading through an associative memory system. Upon processing of the target word, activation spreads to everything that is related to that word. In case of a specific instruction, there is a more direct link between the target word and the intention than with a categorical instruction.

Such a bottom-up effect also explains the typicality effect observed in Experiment 2, replicating earlier findings (e.g., Cherry et al., 2001; Mäntylä, 1994). Typicality effects did not interact with effects of cognitive load, providing no support for the assumption that typicality effects arise because of a difference in need for self-initiated processing (Mäntylä, 1994). It is more likely that typicality effects occur because of a difference in associative strengths between target words and the particular category that in turn is associated with an intention. The finding that the typicality effect in Experiment 3 was in the opposite direction can be attributed to a general effect of the frequency with which the target words occur in everyday language and the number of preexisting associated concepts, and thus can be related to the so-called fan effect (Anderson, 1974).

Although the cognitive load manipulation had no significant effect on the prospective memory measure in Experiments 2 and 3, it affected the recall rates for the target words on the short-term memory task. In the high load condition, participants recalled fewer words than in the low load condition, and this was also true for the target words. It seems that load has an effect on the processing of events that need to cue an intended action. As the effect of load was obtained both with relevant and irrelevant words in respect to the prospective memory

task, the central executive seems to be responsible for processing that stimuli generally receive. The central executive therefore seems to play a role in the early stages of remembering and acting on an intention: The perception of stimuli that need to cue an intended action. Another possibility is that it is not the central executive *per se* that is involved in processing environmental stimuli, but that this effect occurs with any manipulation of cognitive load. It has been shown by other researchers that dividing attention during encoding results in worse subsequent recall (Craik, Govoni, Naveh-Benjamin, & Anderson, 1996; Naveh-Benjamin et al., 2000; Naveh-Benjamin & Guez, 2000) or that under high cognitive load conditions some stimuli are not even reportable (Rees, Russell, Frith, & Driver, 1999). The point is that manipulations of cognitive load may have an effect on prospective memory that has nothing to do with memory retrieval or disengagement from the ongoing task. Note, however, that the effects observed here were rather small, so small in fact that they could not be traced on the prospective memory measure. This suggests that effects of cognitive load on prospective memory found in earlier studies may be a combination of on the one hand a relatively small general effect of cognitive load on processing of environmental stimuli and on the other hand an effect on strategic monitoring in case people attempt to engage in such monitoring, but only when the cognitive load manipulation involves the central executive.

The results are in agreement with the automatic associative memory system model. Note however, that this does not mean that the Noticing+Search model is incorrect. The existence of a controlled memory search once a target event is noticed cannot be tested by manipulating the availability of cognitive resources. While controlled it may still be initiated and completed obligatorily. The same reasoning can be applied to the Norman and Shallice (1986) model of action control. It is highly likely that the claim that departing from custom always requires executive processes is true. It is possible that executive resources are needed for additional processing once the intention is retrieved from memory: The intention needs to be held in working memory while the ongoing task needs to be interrupted, after which the intended behaviour needs to be initiated (Guynn et al., 2001). Not finding an effect of an executive load manipulation does not disprove this claim as executive processes could be called upon obligatorily. Therefore, as long as one does not make a more precise analysis of performance on concurrent tasks, the discussion about the need for cognitive resources is not advantageous when dealing with cognitive load manipulations.

The findings are in line with the observation made by McDaniel and Einstein (2000) that whether prospective memory relies on strategic processes depends on many different factors. According to them, one should not ask whether executive load affects prospective memory but instead which types of prospective memory tasks are particularly sensitive to executive load. Most likely, tasks that *seem* to be difficult are more likely to be affected by

executive load than tasks that seem to be easy and well supported by the environment.

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