The Role of Attention in Nonspecific Preparation

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Abstract
We examined the attentional demands of the preparation process that intervenes a warning stimulus (S1) and a subsequent reaction stimulus (S2). Twelve participants performed a reaction task with a variable S1–S2 interval both with and without concurrent memory load that served to deplete attentional resources. We found that memory load did not modify the effect of the S1-S2 interval on reaction time. We argue that this finding casts doubt on the common notion that the preparation process is under direct attentional control.

Keywords: Attention, Preparation, Timing, Dual-task

Introduction
In daily life, we perform many actions automatically. Those actions are typically over learned to such an extent that they are triggered by appropriate conditions in the environment. For instance, we open our hand toward an object that is thrown to us, and in handwriting we perform the individual strokes of a letter as an automated chunk. However, our daily actions cannot be understood as exclusively relying on automatic response tendencies. We are usually quite capable of performing adequate actions in new situations, and of resisting automatic tendencies in inappropriate situations (e.g., we can resist answering a ringing phone that is not ours). To account for these abilities, Norman and Shallice (1986) have proposed that a supervisory attentional system (SAS) may bias an otherwise automatic action toward a superordinate goal. This view is consistent with neurological evidence showing that patients with prefrontal brain damage have difficulty performing actions beyond the routine level (Shallice, 1988). Supported by such observations, the Norman and Shallice model has encouraged cognitive scientists to describe behavior in terms of an interaction between automatic and attentional processes.

Recently there has been discussion on the role of attention in the timing of actions in warned reaction tasks (e.g., Nobre, 2007). In those tasks, participants are presented with a neutral warning stimulus (S1) followed, after some variable foreperiod (FP), by an imperative stimulus (S2) to which they respond in accordance with some task rule. When the levels of FP are presented randomly and equiprobable across the trials of a block (i.e. the variable-foreperiod design), it has invariably been observed that the response time (RT) with respect to S2 decreases as FP increases (e.g., Vallesi & Shallice, 2007; Woodrow, 1914; Zahn, Rosenthal & Shakow, 1963). To account for this FP effect a preparatory process has been postulated that develops over time (see Niemi & Näätänen, 1981 for a review). This process has been characterized as nonspecific because S1 provides no information about the content of S2 or about the response that is required but only about the fact that S2 is impending.

So far, the literature has not provided clear evidence for a role of attention in nonspecific preparation, although most accounts assume such a role. Attentional involvement is particularly prominent in the classical account of the FP effect, stating that people prepare in accordance with the conditional probability of S2 occurrence. This results in a higher state of preparation (and a shorter RT) as FP lengthens, because the conditional probability of S2 occurrence increases during FP as time elapses without earlier occurrence of S2. People presumably adopt such a strategy because it is effortful to maintain a high state of preparation throughout the entire trial (Gottsdanker, 1975), and it is possibly for this reason that nonspecific preparation has been conceived as an attention demanding process. Recent work has extended this view by linking nonspecific preparation to prefrontal functioning. Thus, studies comparing prefrontal patients to normal controls (Stuss et al., 2005; Vallesi et al., 2007) and an experimental study involving transcranial magnetic stimulation (Vallesi, Shallice, & Walsh, 2007) suggest that the dorsolateral prefrontal cortex (DLPFC) subserves the preparation process based on the conditional probability of S2 occurrence.

Los and colleagues (e.g., Los & Heslenfeld, 2005; Los, Knol, and Boers, 2001; Los & Van den Heuvel, 2001) questioned the classical account. They noted that the FP effect does not exist on its own, but mainly derives from more elementary sequential effects stemming from the FP that occurred on the preceding trial (FPn-1). It has frequently been found that RT on a given trial n increases as a function of the duration of FPn-1. As shown in Figure 1, these sequential effects are typically asymmetrical: When the FP of the current trial (FPn) increases sequential effects become less pronounced and disappear for the longest FP (e.g., Elliot, 1970; Woodrow, 1914, Zahn et al., 1963). It is important to note that the FP effect, which is obtained by averaging across FPn-1,
results from this asymmetry of sequential effects. Therefore, an adequate account of the FP effect should first and foremost account for the asymmetry of sequential effects.

Figure 1: Reaction time as a function of the foreperiod (FP) on trial n and trial n-1 (data after Zahn et al., 1963).

Note the typical asymmetry of sequential effects.

Considering the fact that the classical account of the FP effect (i.e., in terms of conditional probability of S2 occurrence) does not account for sequential effects, Los and colleagues (e.g., Los et al., 2001) suggested an alternative explanation based on the principles of trace conditioning. Their model assumes that as participants perform the task, they develop a representation of critical moments, that is of the possible moments of S2 occurrence relative to the offset of S1. Furthermore, each critical moment, is associated with a conditioned strength, which directly determines the level of preparation at any moment during FP. In addition, the state of conditioning is dynamically adjusted during FP on a trial-by-trial basis in accordance with a simple set of rules. Specifically, the conditioned strength of any critical moment is (a) lowered as that moment is being bypassed during FP (extinction), (b) enhanced when that moment is used for the presentation of S2 (reinforcement) and (c) left unchanged when that moment is neither bypassed during FP nor used for the presentation of S2 (i.e., persistence of the conditioned strength for moments beyond the imperative moment). Because the influence of extinction is limited to critical moments prior to the imperative moment, this model readily accounts for both the asymmetry of sequential effects and the FP effect (for formalized versions of this model, see Bosse et al., 2006; Los et al., 2001).

Within the context of the conditioning model, attention is assumed to play a global role of keeping focused on the task demands to respond as fast as possible to S2. However, all processes needed to comply with these demands, including the preparatory process, are assumed to be outside the attentional window of the participant. In effect, attention for the task goal (i.e., to respond as fast as possible to S2) triggers the conditioning mechanism specified above (Los & Heslenfeld, 2005; Los & Van den Heuvel, 2001).

Recently Vallesi, Shallice and colleagues (Vallesi et al., 2007; Vallesi & Shallice, 2007; Vallesi, Shallice & Walsh, 2007) reinstated a key role for conditional probability of S2 occurrence, and thereby for attentional processing during FP. In their “hybrid” model, the state of nonspecific preparation at any moment in time is a combination of an attentional contribution (driven by the conditional probability of S2 occurrence) and an automatic (“refractory”) contribution, driven by the length of FPn-1. The automatic component, by itself, gives rise to symmetrical sequential effects. In particular, preparation becomes more refractory as it has been maintained during a longer FP on trial n-1, resulting in a lower preparatory state on trial n (Vallesi & Shallice, 2007). The attentional component may compensate a low preparatory state as the conditional probability of S2 occurrence increases during FPn. Thus, the attentional component increasingly dominates the preparation state as FP lengthens and is therefore responsible for the asymmetry of sequential effects, and for the downward slope of the FP-RT function. In effect, according to the hybrid account, the FP effect reflects the attentional contribution.

To summarize, both the conditioning model and the hybrid model provide a coherent account of the FP effect and the more elemental sequential effects. According to the conditioning model attention plays a role in these effects only by maintaining the task goal, which in turn triggers an autonomous conditioning mechanism. By contrast, according to the hybrid account, both the FP effect and the asymmetry of sequential effects reflect the attentional component. Given this state of affairs, it is pertinent to investigate the attentional basis of the FP effect.

**Experimental Approach.** In this paper, we used a dual-task approach to examine the role of attention in nonspecific preparation. Within this approach, the primary task was a RT task with a variable FP, which was combined with a secondary memory task in the dual-task condition. The idea is that the secondary task withdraws attention from the primary task. Thus, performance on the primary task will be modified by the presence of the secondary task insofar as it is dependent on attention (e.g., Logan, 1980; Pashler, 1994).

In the present application, we used a 1-back task as a secondary task. Participants saw a central stream of random digits, and they had to count the number of immediate repetitions, which they had to report at the end of a block of trials. The 1-back task is particularly appropriate for present purposes in view of the evidence that it taxes the DLPFC (Jonides et al., 1997; Mitchell, Macrea, & Gilchrist, 2002). Thus, given that according to the hybrid model the FP effect reveals the involvement of the DLPFC, taxing this brain site by a concurrent 1-back task should lead to a flattening of the FP-RT function (see also Vallesi & Shallice, 2007). By contrast, according to the conditioning model, the FP-RT function does not reflect attentional processing, so a concurrent 1-back task should leave the shape of the FP-RT function unaffected.
More generally, the first question of this paper is whether the FP effect is influenced by the presence of a secondary memory task. If the shape of the FP-RT function is dependent on attention, the secondary task will modify its shape. A second, related question is to what extent the memory task influences the (asymmetry of) sequential effects. Again, we expected that insofar as these effects are dependent on attention, they will be modified by the presence of a secondary task.

**Method**

**Participants** Twelve participants (7 females) took part in this experiment. Age varied between 19 and 36, with a mean age of 22. Each participant served in a single session of approximately 1h and 20 minutes, and received €10.

![Figure 2: An example trial with a FP of 800 ms.](image)

**Reaction Time Task** Participants sat at a distance of about 80 cm from the computer screen. During each block of trials, a continuous sequence of digits was presented in the middle of the screen. The digits were randomly drawn with replacement from the complete 10-digit set. Each digit was on for 500 ms and off for 300 ms. Figure 2 shows a timeline of the events on a single trial. On each trial, simultaneously with the onset of one of the digits, a 50 dBA tone (S1) was presented through the speakers for 40 ms, which marked the start of the FP. Dependent on the length of the FP, S2 was presented simultaneously with the onset of the first (800 ms), the second (1600 ms), or the third (2400 ms) digit after the tone. S2 was a square that appeared for 100 ms with equal probability to the left or to the right of the digit. Participants were instructed to react to the square as quickly as possible, with either the z key (when it appeared left) or the m key (when it appeared right) of a standard QWERTY key board. They could react until 1800 ms after the onset of the imperative stimulus. The tone that marked the start of FP on the next trial was presented simultaneously with the third digit after the digit that appeared together with the imperative stimulus.

**Memory Load task.** In the memory load condition, participants performed a 1-back task concurrently with the RT task. In the 1-back task, participants had to count the number of digit repetitions that occurred within a block of trials. At the end of the block they were asked to enter the number of digits they had counted, using the digit pad of the key board. For example, if a sequence of digits was 3-4-5-4-4-6-5-2-2-3-1-8-8-8-9, the correct response would have been 4.

**Procedure** We used a 2 by 3 by 3 within subjects design: memory load * FPn * FPn-1. Memory load (load or no load) was varied between blocks; FP (800, 1600, or 2400 ms) was varied randomly within blocks. This meant that both FPn and FPn-1 had three possible values.

Participants received written task instruction which emphasized speed for the RT task and accuracy for both the RT task and the memory load task. After reading the instruction participants performed 4 blocks of practice trials. The first and the second practice block both consisted of 42 trials. In the first block participants performed the RT task only; in the second block they performed the memory load task only. Blocks 3 and 4 consisted of 30 and 48 trials respectively; here participants practiced the RT task and the memory load task simultaneously.

After practice, the experiment started. In each block of the experiment participants had to perform the RT task. The blocks with and without memory load were presented in alternation; the order of block type counterbalanced across participants. Before the start of each block a message appeared onscreen, which told the participants whether to perform the memory load task or not.

A block consisted of 30, 36, 42 or 48 trials. Block length was varied to ensure that participants counted rather than guessed the number of digit repetitions in the memory load condition. There were 4 blocks of each length making a total of 16 blocks. The order of block length was randomly varied. After each block participants got feedback on their performance in the RT task (mean RT and percentage of correct responses). In dual task blocks, participants also got feedback on their performance in the memory task (the specified number of digit repetitions along with the number of digit repetitions that had actually occurred in that block). Participants were instructed to write down this information on a score sheet to allow inspection of the results by the experimenter.

**Data Analysis** Practice blocks and the first trial of each subsequent block (warm-up trial) were discarded from the analysis. Trials with an RT shorter than 150 ms and longer than 1000 ms were also discarded. The remaining trials were analyzed using a repeated measures Analysis of Variance (ANOVA), using the Huyn-Feldt correction for violations of the sphericity assumption of the variance-covariance matrix. In all tests, the significance level was .05.
Table 1. Results of the ANOVA on mean RT and mean Error data.

<table>
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<tr>
<th>Factor</th>
<th>df</th>
<th>MSE</th>
<th>F</th>
<th>P</th>
<th>partial η²</th>
<th>MSE</th>
<th>F</th>
<th>p</th>
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<td>Load</td>
<td>1, 11</td>
<td>210063.41</td>
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<td>&lt;0.01</td>
<td>0.71</td>
<td>13.57</td>
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<tr>
<td>FPn</td>
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<td>75.07</td>
<td>&lt;0.01</td>
<td>0.87</td>
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<td>0.13</td>
<td>0.17</td>
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<tr>
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<td>942.05</td>
<td>4.13</td>
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<td>8.88</td>
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<td>0.5</td>
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<td>4, 44</td>
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Results

Memory Load Task. We first analyzed performance on the memory load task. We calculated the percentage of deviation from the correct number of digit repetitions. Participants showed an overall error percentage of 9.56. The mean error percentage of individual participants ranged from 4.1 to 16.9.

Reaction Time Task. Table 1 shows the results of the ANOVA, with the Huyn-Feld correction applied to the values of MSE and p. The overall error percentage was 1.70% (SD=0.452). There were no significant effects on the error rate, except for the effect of memory load. Performance without load was faster, but more erroneous (M=2.75, SD=0.84) than performance with load (M=0.66, SD=0.16).

Figure 3 shows RT (based on correct trials only) as a function of Memory load, FPn and FPn-1. The ANOVA of these data revealed highly significant main effects of memory load, FPn and FP (see Table 1). On trials with memory load, RT was longer than on trials without memory load. FPn and FP showed opposite effects on RT: when FPn-1 increased, RT increased and when FPn increased, RT decreased.

As Table 1 shows, the interaction between FPn and Memory load was far from significant. This indicates that the downward slope of the FP-RT function was of nearly the same magnitude in the No load condition (mean RTs of 361, 332, and 319 ms for FPs of 800, 1600, and 2400, respectively) as in the load condition (mean RTs of 422, 394, and 383 ms, for FPs of 800, 1600, and 2400 ms, respectively). The interaction between FPn and FPn-1 reflects the typical pattern of asymmetrical sequential effects. When FPn was short, RT increased as FPn-1 increased (M=371ms SD=14.48, M=399ms SD=14.73 M=405ms SD=13.57, for a short, middle and long FPn-1, respectively). This sequential effect was smaller for the middle FPn (M = 359 ms, SD = 13.92; M = 360 ms, SD = 13.50; M = 370 ms, SD = 13.50, for a short, middle, and long FPn-1, respectively) and nearly absent for the longest FPn (M = 349 ms, SD = 13.72; M = 349 ms, SD = 10.91; M = 356 ms, SD = 12.49 for the short, middle, and long FPn-1, respectively). The significant interaction between FPn-1 and memory load reflects a larger effect of FPn-1 in the no-load condition than in the load condition. The two significant two-way interactions were qualified by the significant three-way interaction among load, FPn-1, and FPn.

Figure 3 shows that the typical asymmetry of sequential effects was more pronounced in the condition without load than in the condition with load. Post-hoc analysis revealed that for the shortest FP (FP=800 ms) the difference between FPn-1 = 800 ms and FPn-1 2400 ms was smaller in the load condition than in the no-load condition (F(1, 11) = 6.198, p<0.02); the difference between FPn-1 = 800 ms and FPn-1 = 1600 ms was not significantly modified by memory load (F(1,11)=0.423, p=0.529). The interaction between FPn-1 and Load for the middle FP (FP = 1600 ms) approached significance (F(1,11)=4.679, p=0.053). For the longest FP (FP=2400) the effect of FPn-1 was not significantly modified by memory load.

Figure 3. Mean RT as a function of Foreperiod on trial n, Foreperiod on trial n-1 and memory load.
**Discussion**

In this study we adopted a dual-task approach to investigate the role of attention in nonspecific preparation. This approach allows conclusions about the attentional needs of the primary RT task on the assumption that the secondary task depletes attentional resources. In its present application, we used a secondary memory task to withdraw attention from the RT task, which involved a variable FP design. This allowed us to examine the modifying influence of memory load on the shape of the FP-RT function and on sequential effects of FP. Our main finding was that memory load did not alter the shape of the FP-RT function, which indicates that the shape of this function does not reflect attentional processing. Given that the downward slope of the FP-RT function is generally taken to reflect nonspecific preparation, we conclude that nonspecific preparation does not operate under direct attentional control.

It is important to note that memory load was a very potent variable in our experiment, in that it exhibited both a strong main effect and a modifying influence of sequential effects. These powerful effects stand in strong contrast with the far from significant interaction between memory load and FPn. This suggests that the absence of the latter interaction should be regarded as genuine rather than as reflecting insufficient statistical power.

Considering that memory load did not modify the preparation process, its main effect suggests that attention affects the reaction process elsewhere. One possibility in this respect is that attention is needed to consolidate the contents of working memory. Thus, Logan (1978, 1979, 1980) observed interactions of memory load only with task variables that influence the complexity of the set of S-R mapping rules, which participants presumably kept in working memory to enable adequate task performance.

Given that effects of memory load are mediated by working memory, the presently observed interactions between memory load and FPn-1 and among memory load, FPn, and FPn-1, are somewhat puzzling. Indeed, sequential effects are generally considered to contain all hallmarks of automatic processing, and so, it is not immediately obvious why they would interact with memory load. Yet, both the hybrid model and the conditioning model provide some clues about how such interactions may come about.

According to the hybrid model (Vallesi et. al., 2007; Vallesi & Shallice, 2007), sequential effects are taken to reflect refractoriness stemming from the maintenance of preparation on the preceding trial. Specifically, the longer a participant has to maintain a prepared state on trial n, the greater the refractoriness on trial n+1, and the longer RT. The asymmetry of sequential effects is assumed to reflect an increasing compensating contribution of the attentional component. Thus, for the shortest FPn the contribution of the attentional component is minimal, giving rise to large sequential effects. As FPn increases, the increasing influence of the attentional component comes to dominate the preparatory state, thereby gradually quenching sequential effects.

Assuming that memory load reduces the contribution of the attentional component to the preparatory state, the hybrid model would predict that memory load modifies sequential influences. In particular, by reducing the compensating attentional influence for longer FPns, memory load should have the effect of making sequential effects more pronounced for longer FPns (Vallesi & Shallice, 2007). The data are clearly inconsistent with this prediction. The significant interaction between memory load and FPn-1 indicated that memory load decreased sequential effects across FPns, rather than increasing them for the longer FPns.

According to the conditioning model (Los & Heslenfeld, 2005; Los et. al., 2001; Los & Van den Heuvel, 2001), sequential effects are caused by the operation of extinction. This process is assumed to reduce the conditioned strength associated with critical moments that are bypassed during FP. Thus, if a bypassed critical moment turns out to become the imperative moment on the next trial, RT is predicted to be relatively long. The asymmetry of this effect reflects that extinction does not influence the conditioned strength of critical moments that are not bypassed during FP on trial n-1.

The rationale for this extinction mechanism is that a high preparatory state must be kept in check by an inhibitory process to avoid premature responding. Accordingly, if one assumes that in the memory load condition participants engage in a lower preparatory state for the RT task, less extinction is needed while bypassing a critical moment, which in turn should result in reduced sequential effects. The present data are generally consistent with this prediction: Sequential effects were smaller in the memory load condition than in the no-load condition.

Referring back to the notion that the 1-back task influences the DLPFC, this interpretation suggests a different role of the DLPFC than assumed by the hybrid model (Stuss et al., 2005; Vallesi, Shallice, & Walsh, 2007). Instead of supporting preparation in keeping with the conditional probability of S2 occurrence, our data suggest that the DLPFC is involved in the inhibitory control of a prepared response during FP (see also Narayanan, Horst, & Laubach, 2006 and Narayanan & Laubach, 2006 for evidence of this function in the dorsomedial PFC; see Mitchell et al., 2002 for a similar role of the DLPFC in the control of eye movements).

Although generally consistent with an inhibitory basis of sequential effects, the present data do not provide unequivocal support for the rules specified under the conditioning model. According to this model, the reduction of sequential effects in the memory load condition should have been particularly strong for the shortest FP. Despite the fact that the accompanying three-way interaction was significant, it failed to reveal the regular pattern predicted by the conditioning model.
Indeed, if it did, the reduction of sequential effects should have propagated to the FP-RT function, which, as we have seen, was unaffected by memory load.

In conclusion, the present findings provide evidence against direct attentional guidance of nonspecific preparation during FP. In particular, withdrawing attention from the primary RT task did not result in any modification of the FP-RT function. Instead, it resulted in an intriguing modification of sequential effects of FP. This modifying influence appears most consistent with elemental learning rules of trace conditioning although its processing basis remains to be clarified.

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