PERGAMON

Neuropsychologia 37 (1999) 661–670

NEUROPSYCHOLOGIA

The absent mind: further investigations of sustained attention to response

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Received 8 January 1998; accepted 8 October 1998

Abstract

We have previously demonstrated that performance on a brief and conceptually simple laboratory task (the Sustained Attention to Response Test: SART) was predictive of everyday attentional failures and action slips in brain injured patients and normal control participants. The SART is a go-no-go paradigm in which the no-go target appears rarely and unpredictably. Performance on this measure was previously interpreted as requiring sustained attention to response rather than a putative 'response inhibition' capacity. Three further studies are presented which support this claim. They demonstrate that performance is crucially determined by the duration of time over which attention must be maintained on one's own actions that this demand underpins the task's relationship to everyday attentional lapses. In keeping with a number of recent studies it suggests that inefficiencies in the maintenance of attentional control may be apparent over much briefer periods than is traditionally considered using vigilance measures and analysis.
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Keywords: Supervisory attention; Frontal lobes; Executive function; Inhibition

1. Introduction

In the 1983 British Football Association Cup Final, a defender for Brighton and Hove Albion failed to prevent a Manchester United player from passing him and scoring a goal. Together with the scorer and the Manchester supporters, the Brighton player raised his arms in an unmistakable gesture of celebration. It was only when his arms were fully raised in triumph that he and several thousand supporters became aware of his error and he returned his arms slowly to his side.

To be absentminded is to be inattentive to ongoing activity, to lose track of current aims and to become distracted from intended thought or action by salient but (currently) irrelevant stimuli. An absent mind may be something of a blessing when one is performing routine actions in predictable environments. Becoming engrossed in thought rather than attending to each and every stroke of the toothbrush rarely has a negative outcome. Quite apart from the considerable tedium that constant attention to current activity would surely entail, it is often posited that subjective control may impair the efficiency of routine skilled performance [e.g., 14, 19]. The subjective sense that one's mind has been absent from the activity in which one is engaged is probably most often occasioned when an error occurs. Such errors, well documented by Reason [19], may happen when an action is triggered inappropriately (the goal celebration for the other team), is targeted at the wrong stimulus (inhaling from a pencil rather than a cigarette) or when an initial plan becomes derailed by distraction (the search for the scissors is never resumed after the unexpected telephone call).

The distinction between sequences of behavior which can be performed in an automatic manner given appropriate environmental contingencies and actions which are subjectively experienced as involving mental effort and control has long been drawn within psychology and other fields [6, 7, 14, 22]. Cognitive neuropsychological accounts of this distinction have emerged particularly in the study of patients with anterior brain lesions. For patients with Parkinson's Disease, for example, the automatic control of motor action may be particularly impaired and previously routine actions may require considerable conscious attention in order to be achieved [8, 21]. Patients with elements of a dysexecutive syndrome following damage to the prefrontal cortex can show a greater tendency for their behavior to be captured by irrelevant stimuli in the environment [12]. Such failure to

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PII: S0028-3932(98)00127-4

modulate the most automatic response to a given stimulus can be seen in distractibility and in extreme forms in utilization behavior where the actions afforded by objects (e.g., to inject with a syringe) led to their use despite an inappropriate context and being irrelevant to any obvious current aim [10].

One account of such dysexecutive impairments views them as arising from damage to a Supervisory Attentional System [14, 22]. In this conceptualization, the enactment of well-learned, routine responses (represented as schema) are governed by their level of activation relative to possible competitors for control of perceptual and output systems. The level of activation is determined by the strength of environmental (or internal) cues and the strength of their association with particular patterns of behavior. Via such a system, apparently complex activities such as those involved in driving a car can be performed appropriately but in a rather automatic, 'stimulus-driven' fashion [14, 22]. Supervisory Attentional modulation of this process is required to construct novel responses and to modify or suppress schema expression when the most activated schema is inappropriate to an overall goal. Such control is also experienced subjectively as non-automatic and self-conscious attention to action [14, 22].

Stuss, Shallice and colleagues have applied the concepts of Supervisory Attentional control to the process of sustaining attention [24]. They argued that in a sustained attention task—where events are repetitive, the discrimination required is relatively undemanding or targets are separated by long intervals—the schema mediating the appropriate response to a stimulus is deprived of externally driven activation for much of the time. At low levels of activation it will become increasingly vulnerable to competition from other task-irrelevant schema which may be triggered by environmental or internal events. Overcoming this decay requires that an internal supervisor is able to intercede to bias the competition in its favor. As such, the more a sustained attention task succeeds in minimizing the environmental support offered to the relevant schema, the better it will measure people's capacity to maintain subjectively willed supervisory control (their 'mind') on the task.

The frequency with which people fail to maintain attention to ongoing activity, become derailed in the execution of tasks and have problems in maintaining the representation of a current goal was considered by Donald Broadbent and colleagues in developing the Cognitive Failures Questionnaire (CFQ) [1]. Respondents are offered examples such as 'Do you find you accidentally throw away the thing you want and keep what you meant to throw away, as in the example of throwing away the matchbox and putting the used match in your pocket?'; 'Do you daydream when you ought to be listening to something?'; 'Do you start doing one thing at home and get distracted into doing something else (unintentionally)?'. Self-reports of these periodic detachments between intention and action showed little relationship to general ability as reflected in IQ measures and appeared to reflect something more than just the self-esteem of the respondent [1, 2, 9, 18]. The validity of underlying individual differences in a tendency to lapse from intention received support from the CFQ's relationship to composite mishaps, accident citations, hospitalizations and injuries [9].

The search for behavioral correlates of CFQ ratings in laboratory tasks, however, proved rather disappointing [1, 2, 9, 18]. Absentmindedness, it appeared, was a rather difficult phenomenon to capture in settings where the strangeness of the testing situation, the novelty of the tasks and the experimental control over extraneous factors would tend to act against this kind of drift. Recently, however, we described a computer-administered paradigm—the Sustained Attention to Response Test (SART)—which was successful in eliciting such a state in participants [20]. The task presented repetitive and temporally predictable visual stimuli (digits between 1 and 9) to which participants were required to respond with a key press, with the exception of the digit 3. In classic 'vigilance' paradigms, where responses are required for rare target presentations, the automation of the simple target-response relationship may rapidly reduce the need for active attention to task. In Stuss et al.'s terms [24], if it had been sufficiently learned, the presentation of a target could activate a fairly dormant response schema sufficiently to determine action without much necessity for endogenous, supervisory help. In the SART, such an automatic response tendency is encouraged but it is re-directed at the frequent non-targets. A 'mindless', 'stimulus—press, stimulus—press' style works very efficiently for 91% of stimuli presented at temporally predictable intervals. Good performance requires that the participant remain sufficiently attentive to their responses such that, at the appearance of a target, they can substitute the directly antagonistic 'response' of not pressing. Within a Supervisory Attention framework, while the non-target response is frequently exogenously activated and elicited by the task, the activation level of the target response must be endogenously maintained close to threshold if it is to successfully compete when appropriate.

There is good evidence that the ability to self-sustain attention is reliant on prefrontal lobe function, particularly of the right hemisphere [5, 16, 17, 29]. The sensitivity of the SART to people in whom frontal damage is prevalent, namely the survivors of traumatic brain injury, has previously been reported [20]. In accounting for this sensitivity, and for the reasons outlined above, it was proposed that poor performance on the SART was principally attributable to inefficient endogenous maintenance of attention rather than a notional ability to withhold a response per se. In the first of the studies presented here, we further tested this position by comparing performance on the SART with a version of the task in which the sustained attention component was diminished but the central competition between response and no-response was maintained. Two aspects of the SART which ostensibly place particular demands on a capacity to maintain active attention are the long and unpredictable intervals *between* targets and the requirement for continuous performance over the 225 trial/4.3 min duration of the task. We hypothesized that if these two aspects were reduced, then participants would more easily be able to withhold their responses to target digits. In particular we hypothesized that if the SART's sensitivity to self-reports of everyday absentmindedness is mediated by the sustained attention demands of the task, and not by the requirement for response inhibition per se, then the standard version of the SART would distinguish between groups defined by high and low CFQ scores but that the modification of the task would not.

2. Experiment 1

2.1. Method

2.1.1. Participants

Sixty participants were recruited from the MRC Cognition and Brain Sciences Unit Subject Panel. The 17 male and 43 female participants were of mean age 34.40 (S.D. 10.73) ranging from 18 to 65 years with a mean estimated full scale IQ of 115.40 (S.D. 5.42) based on National Adult Reading Scale errors [12]. From the group of 60 participants, CFQ self-report scorers within the upper and lower quartile of this population range were selected. The two groups of 15 participants comprised 23 females and 7 males, with a mean age of 35.33 (S.D. 10.91) ranging from 19 to 65 years, and an estimated full scale IQ mean of 117 (S.D. 6.51).

Characteristics of the two groups are presented in Table 1. There were no significant differences in sex distribution [$\chi^2 = 0.17$, $P = 0.680$], age [$t(28) = 1.14$, $P = 0.263$] or estimated full scale IQ [$t(20) = 0.07$, $P = 0.943$]. As a consequence of the subgroup selection, CFQ scores differed [$t(28) = 11.53$, $P < 0.001$] with the low CFQ group obtaining a mean CFQ self-report score of 27.6 (S.D. 6.51) and the high CFQ self-report mean reaching 62.13 (S.D. 9.88).

2.2. Apparatus

The following tests were given:

2.2.1. Sustained attention to response test (SART)

Over 4.3 min, 225 single digits (25 of each digit between 1 and 9) were presented centrally on a computer screen. The digits were displayed in one of five randomly-assigned fonts (48, 72, 94, 100 and 120 point) representing digit heights between 12 and 29 mm. Each digit was displayed for 250 ms and then replaced by a 900-ms duration mask, composed of an *X* presented within a 29-mm ring with a diagonal cross in the middle. Presentation was regularly paced at an onset-to-onset interval of 1150 ms. Both digits and mask were white against a black background.

Participants were required to respond to the digits with a key press with the exception of the number 3 which required no response. The 25 target digits were distributed throughout the 225 trials in a pre-fixed quasi-random fashion. The 225 trials were presented in a single continuous block. Reaction times of all key presses relative to digit onset were collected.

All presentations were made using a Macintosh 170 PowerBook running PsyScope™ software [4]. The screen was of 215 mm × 135 mm and positioned approximately 40 cm from the participants' eyes although no restrictions were placed on the participants' movements. Participants made responses using their preferred hand on the mouse key.

Participants were asked to give equal weight to responding as quickly as possible and to minimizing errors of commission. Each session was preceded by a practice trial of 18 digits, two of which were targets.

2.2.2. Modified response withholding task

The procedure for this task was almost identical to that of the SART. The exceptions were that target probability was set at 0.5 (compared with the 0.11 target probability of SART) and block duration was set at 10

Table 1
Characteristics of two groups formed on the basis of self-rated CFQ scores

Group	*n*	Age	Sex (m : f)	Estimated Full Scale IQ	Self-rated CFQ Score
High self-rated CFQ group	15	33.06 (S.D. 9.16)	3 : 12	116.8 (S.D. 5.17)	62.13 (S.D. 0.876)
Low self-rated CFQ group	15	37.6 (S.D. 12.32)	5 : 10	117.0 (S.D. 6.51)	27.6 (S.D. 6.09)

trials. Ten blocks were run in total, each being followed by a brief rest period. Onset of the next block was determined by the participant who recommenced the test when they felt ready. The 100 trials of the task comprised 50 non-target digits between 1 and 9 and 50 target digits (6) randomly intermixed.

Of the 50 target digits presented, 25 were nominated in advance and at random as scored targets for compatible analysis with the 25 targets of the SART. As with the SART the task was preceded by a practice session of 18 digits and participants were asked to give equal weight to speed and accuracy in making responses with their preferred hand.

2.2.3. National Adult Reading Test [13]

This test requires correct pronunciation of 50 irregularly spelled English words from which an estimation of full scale IQ can be derived.

2.2.4. Cognitive Failures Questionnaire: Self-report [1]

This 25-item checklist asks people to rate the frequency with which they make everyday cognitive errors.

2.3. Procedure

The above measures, including the rating scales, were randomly assigned an order of presentation for each participant. Assessments occurred over an hour-long session for which they were paid an honorarium of £4.00.

2.4. Results

2.4.1. Errors of commission (responding to targets)

In line with a previous report, a between-groups ANOVA (high versus low CFQ) indicated that self-rating scores on the Cognitive Failures Questionnaire formed a significant predictor of SART errors of commission, that is mistakenly pressing for a target digit [$F(1,28) = 7.267$, $P < 0.05$]. Participants who rated themselves as making more slips of action in everyday life made a mean of 8.27 (S.D. 4.03) errors of commission relative to 4.60 (S.D. 3.40) for participants who rated themselves as making fewer such everyday mistakes (see Fig. 1).

It was hypothesized that the performance of the high self-rating CFQ group would no longer be distinguishable from low-CFQ subjects when the sustained attention demands of the withholding task were reduced. Low CFQ scorers made a mean of 1.73 (S.D. 1.75) errors of commission on the modified task. High CFQ scorers made a mean of 2.0 (S.D. 2.01) such errors. A repeated measures ANOVA with group (high vs low CFQ) as the between-subjects factor, condition (SART vs modified response withholding task) as the within-subjects factor and errors of commission as the dependent variable revealed a significant effect of group [$F(1,28) = 5.54$, $P < 0.05$] and of condition [$F(1,28) = 44.16$, $P < 0.01$]

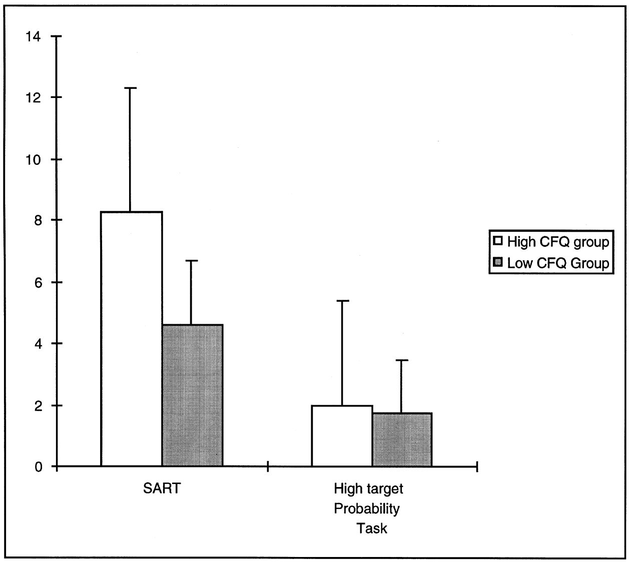

Fig. 1. Experiment 1: Errors of commission on the SART and on a modification of the task for high and low CFQ scorers.

and a significant interaction between group and condition [$F(1,28) = 6.12$, $P < 0.05$]. Tukey's HSD post-hoc tests showed that both high and low CFQ groups made significantly fewer errors in the modified response withholding task ($P < 0.01$ and $P < 0.05$ respectively) and that while the groups were significantly different in their SART error scores ($P < 0.01$) there was no statistically significant difference between them on the modified task. In essence both high and low scoring CFQ groups showed improved performance on the high target probability task and the absolute difference between them, apparent on the SART, disappeared (see Fig. 1).

2.4.2. Reaction times

It was previously reported that variations in the speed with which individual participants responded to non-targets formed a significant predictor of subsequent errors of commission [20]. In considering the reasons for the improved performance of the groups, in particular the high CFQ scorers, reaction times (RT) were again examined. In line with the previous finding, speeding of responses was predictive of subsequent errors in the SART (mean RT in the four trials preceding an error 348.38 ms (S.D. 74.04), mean RT in the 4 trials preceding a correct response 366.1 ms (S.D. 53.82), repeated measures ANOVA [$F(1,28) = 6.06$, $P < 0.05$]). For both groups, RTs were significantly slower in the high target probability condition [$F = 19.69$, $P < 0.001$]. However, in neither condition did the groups significantly differ in RT to non-targets [$F = 1.872$, $P = 0.182$].

2.5. Discussion of Experiment 1

The frequency with which participants rated themselves as making absentminded errors in everyday life formed a significant predictor of performance on the Sustained Attention to Response Test. In line with the hypothesis, when the task was changed to reduce the demands for self-sustained attention while maintaining the necessity to withhold responses, performance was enhanced and the group difference disappeared. This result is consistent with the position that the relationship between the SART and everyday absentmindedness is mediated by its particular demands upon self-sustained attention to task and not simply by a requirement for response inhibition. Although floor effects for errors on the modified task prevent the determination of whether high CFQ scorers were *disproportionately* assisted by these modifications, the result indicates that the sensitivity of the SART does not simply emerge from the need to switch between responding and not responding per se but from either the rarity of targets, the duration of the task or both.

In line with a previous finding [20] where the mean speed of response to non-targets did not differentiate head injured participants from healthy controls, no differences in mean speed were found between high and low CFQ groups on either the SART or the modified task. This sensitivity of the SART cannot therefore be simply attributed to a group tendency to make faster responses. Within groups SART errors of commission were preceded by faster responses than targets which attracted the correct non-response. We will return to the question of response speed in the main discussion below.

Experiment 1, therefore, supports the relationship between performance on a conceptually simple and brief laboratory task and self-reported absentmindedness in everyday life. It also demonstrates that modifying two characteristics of the SART which would place particular demands on a system for willfully maintaining attention to activity improves performance. Experiment 1 does not, however, allow the relative contributions of these characteristics, reduced inter-target intervals and shorter runs of continuous performance, to be established. These factors are considered separately in Experiments 2 and 3.

We have argued that the major determinant of performance on the SART lies in the efficiency with which endogenous attention can be maintained on task and that the demands on this capacity can be modulated by the frequency of target presentation. When target presentation occurs frequently, appropriate response selection is externally driven and has a reduced requirement for endogenous attentional allocation. When target presentation is infrequent, attentional resources must be directed to maintaining the target response sufficiently active to intervene when appropriate. Given that attentional lapses on this repetitive and conceptually simple task are likely for all but a few participants, it is therefore a clear prediction that the ratio of targets to non-targets will be a significant determinant of performance with shorter mean inter-target intervals leading to better performance. In Experiment 2, therefore, the performance of participants on a response withholding task were compared across three levels of target probability. It was predicted that performance would decline with decreasing probability—which in the SART is synonymous with increasing mean inter-target interval. The 14 participants for this study were recruited from the larger group of high and low CFQ scorers who took part in study 1. As the testing for Experiment 2 took place almost 24 months after that of Experiment 1, this study also provides an opportunity to examine the robustness of the relationship between self-reported absentmindedness and SART performance over time.

3. Experiment 2

3.1. Method

3.1.1. Participants

Fourteen participants were recruited from the Cognition and Brain Sciences Unit subject panel. The participants were selected on the basis of their high or low Cognitive Failures Questionnaire self-report scores collected during the previous study (see Experiment 1). As the current study took place some two years after the study described in Experiment 1, not all subjects who had previously participated were available. Within each group, availability was the only criteria used in the selection. This newly formed low CFQ group was of mean age 44.43 (S.D. 6.43) and consisted of five women and two men while the high CFQ group were of mean age 44.43 (S.D. 6.43) and comprised six women and one man. The groups did not differ significantly on age [$t(12) = 0.64$, $P = 0.537$] or sex distribution [$\chi^2 = 0.42$, $P = 0.515$]. As would be expected given the selection criteria, these sub groups significantly differed on their previously collected CFQ scores (Low CFQ group 24.86 (S.D. 7.93); High CFQ group 63.57 (S.D. 13.43); $F(1,12) = 43.16$, $P < 0.001$).

3.2. Apparatus

3.2.1. Experimental manipulation of SART inter-target interval

In this computer-administered procedure the probability of target occurrence in the response withholding task was varied. Across all conditions, each trial was identical to that of the SART, that is a randomly selected digit between 1 and 9 was presented for 250 ms followed by a 900-ms mask with participants asked to press for all digits with the exception of 3. The experiment was programmed using PsyScope software [4] and administered on a Macintosh laptop computer (see Experiment 1 for details).

Performance in withholding responses to targets was examined within blocks under three conditions of target probability, 0.11 (as with the SART), 0.25 and 0.5, with target probability being determined by weighting the random selection process of the experimental program. Each block consisted of 135 trials. Blocks at each target probability were presented twice within each session. Order of block presentation was balanced for participants (i.e. ABCCBA) with the conditions presented in the positions A, B and C varying systematically in a Latin square fashion between participants and matched between groups. The two 135 trial blocks allowed for the presentation of 30 targets within the lowest probability condition. In order to equate higher target probability conditions for scoring purposes, 30 targets in each were nominated at random as targets to be scored.

3.3. Procedure

Testing took place in a quiet office. Participants, tested individually, were instructed to press the mouse key with their preferred hand as quickly as possible for each digit while making as few errors (pressing for the 3) as possible.

3.4. Results

3.4.1. Errors of commission (responding to targets)

A repeated measures analysis of variance with condition (low, medium and high target probability) as the within-subject factor, group (high vs low self-reported CFQ) and the between-subject factor and errors of commission as the dependent variable revealed a significant main effect of condition [$F(2,24) = 15.97$, $P < 0.001$] and of group [$F(1,12) = 6.80$, $P < 0.05$]. The interaction also reached significance [$F(2,24) = 5.69$, $P < 0.05$]. Participants selected on the basis of their reported high frequency of everyday attentional lapses on the CFQ questionnaire made a mean of 9.43 errors of commission in the low target probability condition (S.D. 6.92). Their performance improved slightly on the medium probability condition to 8.43 (S.D. 4.65) with very few errors being made at the highest probability level (0.43 (S.D. 0.53)). Participants selected for low everyday absent-mindedness performed approximately twice as well in the low probability condition, making a mean of 3.71 (S.D. 2.43) errors of commission. This decreased to 2.14 (S.D. 1.77) in the medium condition and 0.86 (S.D. 1.07) in the high probability condition. Post hoc analysis using Tukey's HSD test revealed that group differences in low and medium probability conditions were statistically significant at the $P < 0.001$ level. There was no significant difference at the highest probability level. As predicted, therefore, self-reported CFQ scores significantly predict performance on this measure at low target probabilities with this distinction disappearing as the frequency of targets increases. Errors of omission, that is, failing to respond to a non-target, were again rare and did not significantly vary with condition.

3.4.2. Reaction times

A repeated measures analysis of variance with condition (low, medium and high target probability) as the within-subject factor, group (high vs low self-reported CFQ) the between-subject factor and mean reaction time to non-targets as the dependent variable revealed a significant main effect of condition [$F(2,24) = 17.81$, $P < 0.001$] but no effect of group [$F(1,12) = 0.38$, $P = 0.551$]. The Low CFQ group responded to non-targets at a mean of 379.1 ms following non-target onset (S.D. 65.21) in the low probability condition. This increased to 400.47 ms (S.D. 92.67) and 418.67 (S.D. 86.46) in the medium and high probability conditions respectively. A similar pattern was apparent in the High CFQ group who's reaction times across the low, medium and high target probability conditions were 356.18 (S.D. 53.68), 371.11(S.D. 58.83) and 403.62 (S.D. 58.83) msec. Post-hoc analysis using Tukey's HSD revealed that differences at the $P < 0.05$ level existed between the highest and lowest probability conditions for the Low and High CFQ groups and between the high and medium probability conditions for the high CFQ group only. In short, the groups did not significantly differ in their reaction times and for both groups response times slowed as the frequency of targets in the task increased.

3.5. Discussion of Experiment 2

The results of Experiment 2 show that the capacity of the Sustained Attention to Response Test to discriminate between healthy subjects who differ in their self-reported frequency of everyday attentional and cognitive lapses is robust even two years after initial testing. In Experiment 1 it was demonstrated that removing two factors which could contribute to the 'sustained attention' demands of the task significantly improved performance and abolished the sensitivity of the measure to everyday absent-mindedness. Experiment 2 demonstrates that manipulating only target probability while keeping overall task duration constant produces a very similar pattern of results. Participants selected on the basis of high CFQ scores make approximately twice as many errors as their Low CFQ counterparts on the low target probability, standard SART, version of the task. When the interval over which attention is to be maintained was diminished, however, this discriminative power evaporated. The reaction time data again demonstrates that while simple speed of response cannot account for the group differences, increasing the frequency of targets produces a systematic slowing of responses to non-targets.

In Experiment 1 we considered the effects of reducing both inter-target interval and duration of continuous performance. In Experiment 2 we considered the manipulation of target frequency in isolation. In Experiment 3, the effect of inter-target interval is directly compared with that of task duration.

Based on the theoretical position outlined in the introduction and the supporting results of Experiment 2 it is a clear prediction that inter-target interval will form a powerful determinant of performance in this withholding task. The case is much less clear for duration of continuous performance. It appears likely that a certain number of trials are required to encourage an 'automatic' style of responding to non-targets. It is also probable that over long periods of continuous performance factors such as fatigue and motivation would begin to erode efficiency. Between these extremes, however, the central argument of this paper informs no clear prediction and, therefore, it must be hypothesized that continuous performance duration does not significantly contribute to task difficulty.

4. Experiment 3

4.1. Method

4.1.1. Participants

Fifteen participants, none of whom had been involved in Experiments 1 and 2, were recruited from the Cognition and Brain Sciences Unit subject Panel. The mean age of this group, comprising eight men and six women, was 40.8 (S.D. 20.82).

4.2. Apparatus

4.2.1. Experimental manipulation of SART target probability and requirement for continuous performance

Across all conditions, each trial was identical to that of the SART, that is a randomly selected digit between 1 and 9 was presented for 250 ms followed by a 900-ms mask with participants asked to press for all digits with the exception of 3.

The task was blocked into four conditions with each condition occurring twice within the testing session in a fixed ABCDDCBA order. In the first (and also, therefore, last) condition 225 trials were presented in a continuous block with the probability of a target digit being presented set at 0.11. This was selected as the upper limit for continuous performance as it is identical to that of the standard SART, which is of known sensitivity to attentional lapses in everyday life. In the three subsequent conditions, termed 'low', 'medium', and 'high' probability, 225 trials were again presented but in adjacent sub-blocks of 45 trials, with each sub-block being followed by an opportunity for the participant to briefly rest from the task. The probability of target digit occurrence in each of these conditions were set at 0.11, 0.22 and 0.5 respectively by varying the weighting in the program's random selection. The 450 trials of the lowest target probability conditions allowed for the presentation of 50 target digits in each. To equate conditions for scoring purposes, 50 target digit presentations were selected randomly as scored targets.

4.3. Procedure

Testing took place on an individual basis in a quiet office. Participants were instructed to press the mouse key with their preferred hand as quickly as possible for each digit while making as few errors (pressing for the 3) as possible. A brief reminder of this instruction was presented at each break. The session lasted for between 50 and 60 min, depending on the length of the breaks.

4.4. Results

4.4.1. Target probability and errors of commission

As predicted and seen in Experiment 2, participants made incrementally fewer errors in withholding a response to target as the probability of a target's occurrence increased. Of the 50 scored targets in each condition, participants failed to withhold a response for a mean of 16.73 (S.D. 9.83) in the low-probability condition, 12.87 (S.D. 8.68) in the medium-probability condition and 6.60 (S.D. 6.17) in the high-probability condition (see Fig. 2). A repeated measures ANOVA with condition as the within-subject factor (high-, medium- and low-probability conditions) and errors of commission as the dependent measure reveals a significant effect of condition [$F(2,28) = 18.76$, *d.f.* 28:2, $P < 0.001$]. Tukey's HSD post-hoc analysis indicated that the differences between errors of commission on the high and medium and high and low probability conditions were

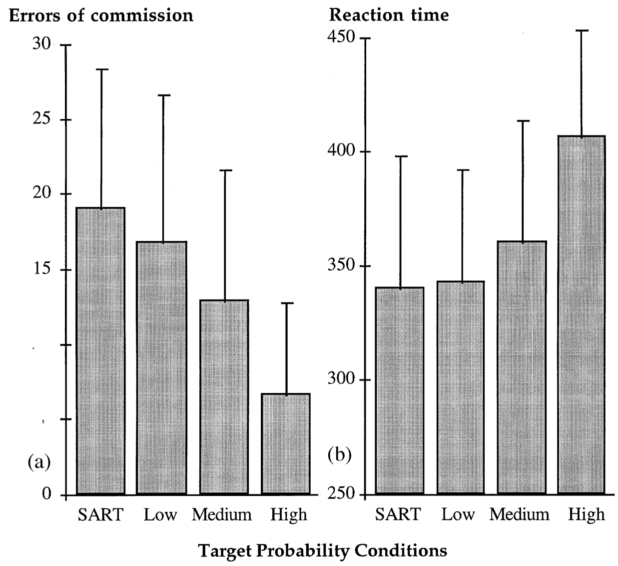

Fig. 2. Experiment 3: (a) Performance of participants in withholding responses to targets under three levels of inter-target interval and two levels of continuous performance duration (error bars: 1 S.D); (b) Reaction times to non-targets under three levels of inter-target interval and two levels of continuous performance duration (error bars: 1 S.D).

significant at the $P < 0.01$ level, while the low vs medium comparison failed to reach statistical significance (see Fig. 2). Errors of omission, that is failing to respond to non-targets, were few and did not significantly differ with condition (mean errors of omission in the low, medium and high probability conditions were 2.60 (S.D. 3.96), 1.47 (S.D. 2.47) and 3.00 (S.D. 3.76) respectively).

4.4.2. Target probability and reaction times

Consideration of reaction times indicates that, as with Experiment 1, RT for responses to non-target digits slowed with increasing target probability. A repeated measures ANOVA with condition as the within-subject factor and RT to non-targets as the dependent variable indicated an overall effect of condition [$F(2,28) = 93.11$, $P < 0.001$]. Tukey's HSD post-hoc analysis indicated all comparisons were statistically significant at the $P < 0.01$ level (see Fig 3).

4.4.3. Continuous block duration and errors of commission

The mean number of errors of commission were slightly higher over the 225 trial blocks of the long duration condition (19.00, S.D. 9.33) than over the five, 45 trial blocks of the short duration condition (16.73, S.D. 9.83). This difference did not reach statistical significance on a repeated measures ANOVA [$F(1,14) = 2.72$, $P = 0.121$] (see Fig. 2).

4.4.4. Continuous block duration and reaction times

No statistically significant difference in reaction time to non-targets emerged between the two conditions [$F(1,14) = 0.34$, $P = 0.570$) (see Fig. 2).

4.5. Discussion of Experiment 3

In Experiment 3, the effects of two factors simultaneously manipulated in Experiment 1 were considered separately in the same population. The result of manipulating target probability replicate those seen in Experiment 2. Increasing the frequency with which a target digit is presented significantly assists participants in withholding to 50 nominated targets. This improved performance is accompanied by a slowing in reaction time to non-targets.

Comparison of errors of commission made when performing the task over two continuous blocks of 225 trials and over 10 sub-blocks of 45 trials with opportunities for rest revealed no statistically significant difference. Similarly, reaction times to non-targets did not differ between these two versions of the task. While it is possible that continuous performance provides a moderate additional challenge to a capacity to endogenously maintain attention, it is clear that any effect is minor relative to the effect of inter-target interval length, at least within these parameters.

5. General discussion

The results from Experiment 1 indicate that a conceptually simple laboratory procedure is sensitive to self-reported frequency of everyday lapses of attention in the normal population. It also shows that modifying two task parameters to reduce the need for self-sustained attention while maintaining the requirement to withhold responses enhances performance and erodes this sensitivity. Experiment 2 demonstrates that the predictive relationship between the SART and day-to-day cognitive failures evaporates as the gap between targets decreases. At the longest inter-target interval, participants with high scores on the Cognitive Failures Questionnaire made approximately twice as many errors as their low scoring counterparts. At the shortest interval the groups did not differ. In Experiment 3, the effect of inter-target interval was compared directly with a factor more conventionally held to place demand on sustained attention, namely duration of continuous performance. The results demonstrate a significant effect of varying the interval *between* targets—a manipulation at the level of seconds, while a manipulation at the level of minutes in terms of continuous performance duration had no effect.

In accounting for these findings, it is argued that the high frequency of targets acts as external (exogenous) support to performance and hence *reduces* the need for internal (endogenous) attentional allocation to response selection. If one difference between high and low CFQ raters is the efficiency with which the 'mind' is willfully maintained on current activity and goals, then, as observed in Experiments 1 and 2, this type of external facilitation would maximally assist those who have more difficulty in this respect.

In other measures of 'sustained attention' such as vigilance tasks or event-counting paradigms, the information available on performance is limited to accuracy of detection and/or reaction times to rare targets. One advantage of the SART for the experimental investigation of sustained attention is that participants are responding very frequently between targets. If attentional allocation to response selection is an element determining response speed, then these continuous recordings offer an 'on-line' window into task performance. Over these and previous studies a consistent picture of reaction times within these withholding tasks has emerged. In the SART errors of commission (pressing for a target) is preceded by faster responses than targets for which a participant correctly withholds a response. Modifications of the task with higher target probabilities attract slower reaction times and more correct responses. One plausible view of these characteristics of the SART is that, in line with the instructions to respond as quickly as possible while making as few mistakes as possible, participants are strategically, attentively titrating their speed of response against their observed efficacy in withholding at the appropriate moments. An error indicates that one has been going too fast and a correct non-response carries with it the possibility that one might be going too slowly. People who perform poorly at the SART may, therefore, simply be relatively inefficient or reckless in applying this strategy. Increasing the frequency of target presentations, however, acts in some way to apply a sufficient break on this tendency for performance to improve.

An alternative view is that rather than being strategic, speeding is occasioned by the development of an 'absent-minded', inattentive approach to the task. Compliance with the instruction to respond as quickly as possible in the SART is attentionally undemanding, as the onsets of stimuli are temporally predictable. Simply tapping along in time with the stimuli would produce very short RTs indeed. Keeping oneself ready to withhold a response is attentionally demanding. Subjective reports of SART performance, together with the tendency of participants to spontaneously utter 'Oops!' or similar exclamations following errors, suggests that targets are detected but this detection is insufficient to interfere with an already-initiated response. At least for non-head injured participants [20], the detection of an error tends to re-trigger attentional allocation to task and this acts to slow responses to a level where the alternative 'response' of withholding can intervene when necessary. When the frequency of targets is increased, environmental input to the alternative response is increased and the necessity for endogenous maintenance is reciprocally decreased. Exogenous activation of the alternative response therefore also acts to slow non-target responses.

Experiment 3 also indicates that, at least within the limits assessed, time-on-task contributes relatively little to the variance in performance, certainly relative to inter-target interval. This raises an important point when considering the clinical assessment of attentional functions. Within the literature on attentional dysfunction following traumatic brain injury (TBI), for example, emphasis has been placed on looking for time-on-task decrements over long periods of performance on vigilance tests. Although there have been exceptions [11, 27], such studies have generally not found good evidence of a *disproportionate decline* in performance [3, 15, 23]. Reports of *initially* impaired levels of performance, particularly in the amount of time required for a target to receive a response, have been, however, ubiquitous [e.g., 25, 26, 28]. As discussed, the simplest forms of such tasks may actually make rather minimal demands on an ability to willfully sustain attention, at least in terms of producing the appropriate response for a target. A component in making a rapid response to a target, on the other hand, is likely to require that its activation is in receipt of endogenous support during the periods between targets. In such terms both slowness in responding and increased variability in response times are likely consequences of inefficient endogenous attentional maintenance while an increased rate of decay in performance across the task is not so clearly predicted. In placing emphasis on the competition for response and in providing much greater exogenous input to one side of the competition, the SART acts to convert insufficient attention to ongoing behavior into a briefly obtained but reliable error score [20]. This emphasis on attention to action/response selection rather than the more traditional perceptual discrimination may also underlie the relationship with the reports of TBI survivors' relatives and normal participants of poor concentration and absentmindedness in everyday life. Many putative 'signal detection' failures will tend to be, by definition, unnoticed by the experiencer and hidden from others. Errors through poor attention to action/response (dialing familiar but unintended numbers, coming to a halt at a green traffic light) provide markers of absentmindedness for both the experiencer and observer.

In summary, these experiments support the position that performance on the SART, a conceptually simple and brief laboratory task, is primarily determined by a capacity to endogenously sustain attention. They demonstrate that reducing the demands for sustained attention while maintaining the central competition for response abolishes the sensitivity of the test to reported action lapses in everyday life. The results suggest that increasing the exogenous support to alternative response selection improves performance by reducing the need for endogenous attentional modulation of behavior.

Acknowledgments

We would like to thank Julia Darling for her careful preparation of this manuscript and Mark Darling for sharing his encyclopedic knowledge of football matches. We are grateful to two anonymous reviewers for their time, comments and suggestions.

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