

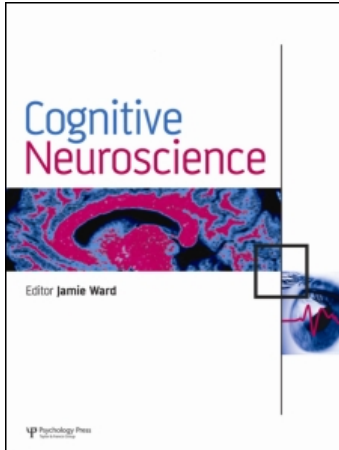
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### The footprints of a wandering mind: Further examination of the time course of an attentional lapse

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# The footprints of a wandering mind: Further examination of the time course of an attentional lapse

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Recently, understanding the sequence of events that precedes an attentional lapse has become an important question in cognitive neuroscience. To examine the processes which lead to such errors, participants performed a simple go/no-go task used for measuring attentional failure. To study the role of internal distraction, the participants' tendency to daydreaming was assessed via a questionnaire. Principal components analysis (PCA) was used to decompose the response time (RT) course into the underlying components. Analysis identified three components that made up 54% of the data collected. One factor indicated the overall magnitude of the RT in a given block. This factor showed a significant negative weighting prior to an error. A second factor indicating that RT shifted from slow to fast was also identified. The parity of this factor was predictive of error for individuals high on daydreaming, indicating that errors in individuals with a rich, imaginative mental life showed a shift from slow to fast responding prior to an attentional lapse. This analysis provides further evidence that attentional lapses can result from events that took place many seconds before the mistake and that the elements of the default mode may be involved in these lapses.

**Keywords:** Attentional lapses; Task-unrelated thought; Stimulus-independent thought; Default mode network; Mind-wandering.

Certain everyday tasks, such as brushing our teeth, involve few attentional resources; others, such as playing chess, require our undivided attention. In circumstances requiring concentration, lapses in attention frequently lead to error, and understanding how these mistakes occur is a key aim of cognitive neuroscience research. Some neural systems are involved in reducing distraction, either excelling at maintaining task-relevant information in the face of conflict (Egner & Hirsch, 2005) or detecting when it is necessary to reinstate control (Botvinick, Braver, Barch, Carter, & Cohen, 2001). Evidence suggests that these systems often become less active prior to task failure. Performance lapses are preceded by a reduction in the activation of cognitive control systems (Weissman, Roberts, Visscher, & Woldorff, 2006), coupled with suppression of the processing of task-related information derived from perception (Kam et al., 2010; Smallwood, Beach,

Schooler, & Handy, 2008; Weissman, Roberts, Visscher, & Woldorff, 2006).

Studies have also identified neural structures which are more active prior to an error, often focusing on the role of the "default mode network" (DMN; Buckner, Andrews-Hanna, & Schacter, 2008). The DMN is a constellation of brain areas including the medial prefrontal cortex (mPFC), posterior cingulate, retrosplenial cortex, and inferior lobule that show *both* intrinsic activity at rest (Raichle et al., 2001) and evidence of functional interconnectedness (Greicius, Krasnow, Reiss, & Menon, 2003). One reason why this system could be associated with attentional lapses is that the DMN has been linked to the generation of task-unrelated thoughts (Mason et al., 2007; McKiernan, D'Angelo, Kaufman, & Binder, 2006), which are known to disrupt task performance (Smallwood & Schooler, 2006). Consistent with the idea that the

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DMN represents information unrelated to the current task, several recent studies have revealed that aspects of this network are unusually active in the period prior to a lapse in attention (Christoff, Gordon, Smallwood, Smith, & Schooler, 2009; Eichele et al., 2008; Li, Yan, Bergquist, & Sinha, 2007; Weissman et al., 2006). Lapses, therefore, are influenced by a process of internally generated distraction which is in part due to processes associated with the DMN.

Given the evolving knowledge of the systems that implement task-relevant processes and those that lead to internal distraction, an important question is how to relate these processes to the series of events that precedes an error. Neuroimaging evidence suggests that structures in the DMN (including the posterior cingulate cortex/precuneus) show a systematic increase in activation over approximately 20–30 s prior to an error (Eichele et al., 2008). Behavioral studies also confirm that lapses in attention can be related to changes that took place many seconds before the error. Applying principal components analysis (PCA) to response time (RT), Smallwood and colleagues (McSpadden, Luus, & Schooler, 2008) demonstrated that lapses on a simple go/no-go sustained attention task were preceded by a slow shift in responding from slow (e.g., careful) to fast (e.g., careless) responding. This shift evolved over a period of approximately 20 s. Further corroboration that this temporal pattern was linked to internal distractions was provided by experience-sampling evidence that this pattern was generally more prevalent prior to reports of task-unrelated thoughts. Finally, reports of task unrelated thought (TUT) and the fluctuating RT were both most prevalent under conditions of slow stimulus presentation. Taken together, these different lines of evidence support a growing consensus that attentional lapses do not solely result from “momentary fluctuations in brain activity” (Eichele et al., 2008, p. 6176) but instead are the result of processes that begin many seconds before the error occurred.

## CURRENT STUDY

The current study aimed to provide further analysis of whether lapses can be linked to events that took place many seconds prior to a mistake. To this end, participants performed the same simple go/no-go task frequently used in the study of attentional lapses (Carriere, Cheyne, & Smilek, 2008; Manly, Robertson, Galloway, & Hawkins, 1999; Robertson, Manly, Andrade, Baddeley, & Yiend, 1997; Smallwood et al., 2004) and that was used for the initial investigation (Smallwood et al., 2008). The first aim of the study was

to replicate the association between errors on this task and relatively long-term changes in responding (Smallwood, McSpadden, et al., 2008). The second aim was to explore whether the transient lapses in attention are linked to internal distraction. To this end, we also measured daydreaming frequency (DDF), a personality trait which shows an individual’s tendency to engage in rich and absorbing internal thought, and which is known to be associated with increased activity in the DMN (Mason et al., 2007). If a significant proportion of the variance associating the gradual transitions from fast to slow with error was accounted for by DDF, this would provide supplementary evidence that this behavior is associated with a state of internal distraction.

## METHODS

### Participants

There were 36 participants (22 females, age range 22–34 years). Ethical approval was granted by the University of Aberdeen.

### Materials

For the sustained attention to response task (SART), participants were presented with sequential stimuli at a rate of one every 2,500 ms, and they responded by pressing the space bar. Stimuli were presented for 1000 milliseconds and a 1500 millisecond fixation cross. The slow rate of stimulus presentation was selected because previous studies have documented that this stimulus presentation rate yields greater off-task thought (Smallwood et al., 2004). Stimuli were the numeric digits, 0–9, and the target no-go stimulus was nominated as the digit ‘3.’ Stimuli were presented in 18-point font in the center of the screen.

Stimulus order was varied by a quasi-random procedure. Targets occurred at the end of randomized blocks of nontargets with a variable length (block lengths in seconds: 3, 11, 17, and 23). Each block length occurred five times, yielding a total of 20 blocks. This procedure ensured that the majority of blocks (15) shared a minimum duration in which no targets occurred (11 events). Shorter blocks (three stimuli in length, five blocks per participant) were included as controls to ensure that participants sustained their attention throughout the task.

Individual differences in predisposition to daydreaming were measured with the DDF component of the Imaginal Process Inventory (Singer & Antrobus, 1972) containing 11 items which refer to daytime

experience (e.g., “I would characterize myself as a frequent daydreamer”). Questions were measured on a scale from 1 to 5. Cronbach’s alpha was high (.85), indicating satisfactory internal reliability.

## Procedure

Upon arrival, participants were greeted by a research assistant and seated in a comfortable chair in front of a computer screen. The experimenter outlined the experimental procedure and invited each participant to read and sign an informed consent sheet. Participants completed the sustained attention task and then the DDF, using a counterbalanced design. In total, testing lasted no more than 30 min.

## RESULTS

### Descriptive statistics

Mean accuracy in the task was 73% ( $SD = 11$ ) and was uncorrelated with DDF score ( $r = -.02$ ,  $p = .9$ ). Consistent with previous research on the SART (e.g., Robertson et al., 1997), RT was faster over the four stimuli prior to an error ( $M = 490$ ,  $SE = 22$ ) than with a correctly withheld response,  $M = 538$ ,  $SE = 27$ ,  $t(30) = 2.88$ ,  $p < .01$ .

### PCA

PCA was conducted on the RT series data in the periods prior to a target. Analysis considered only blocks

that were reasonably long (in this case 11 events in length), providing a consistent window of 27.5 s free from targets, in which temporal changes in RT could evolve. By the same approach as Smallwood, McSpadden, et al. (2008), the RT courses for different individuals were appended to create a large matrix with 540 rows and 11 columns. Factors were selected by PCA on the basis of eigenvalues greater than 1. No factor rotation was employed, to ensure that the components retained the time course of the raw data as far as possible. After blocks with missing RT were excluded, a total of 505 blocks was included in the analysis. The PCA procedure was “blind” to the nature of the response at the subsequent target.

PCA identified three factors that accounted for 54% of the total variance present in the data. The exact proportion explained by each of these factors is presented in Table 1, while the factor loadings on the RT series for each of the components is represented graphically in Figure 1. Factor 1 (blue diamonds) describes the magnitude of RT maintained throughout a block, positive values indicating slow RT and negative weightings fast RT. Factor 2<sup>1</sup> (red triangles) describes a pattern of behavior in which positive weightings indicate that RT gradually shifts from a slow to a faster rate as the block proceeds (negative weightings indicate fast to slow). Finally, factor 3 (green circles) also shows evidence of fluctuations between rapid and slow RT, although in this case RT appears to have reached a local minimum early in the

<sup>1</sup>The factor profile for factor 2 was reversed for compatibility with previous work (Smallwood, Beach, et al., 2008; Smallwood, McSpadden, et al., 2008).

**TABLE 1**  
Proportion of variance explained by the three factors, or behavior states, identified by principal component analysis (PCA)

Component	Total variance explained			Extraction sums of squared loadings		
	Total	% of variance	Cumulative %	Total	% of variance	Cumulative %
1	4.23	35.29	35.29	4.23	35.29	35.29
2	1.29	10.71	46.00	1.29	10.71	46.00
3	1.02	8.51	54.51	1.02	8.51	54.51
4	0.87	7.27	61.78			
5	0.71	5.92	67.70			
6	0.67	5.56	73.27			
7	0.65	5.39	78.66			
8	0.60	5.01	83.67			
9	0.57	4.75	88.42			
10	0.52	4.37	92.79			
11	0.47	3.96	96.74			
12	0.39	3.26	100.00			

Notes: Extraction method: principal components analysis.

block and so has been decelerating for approximately half of the block.

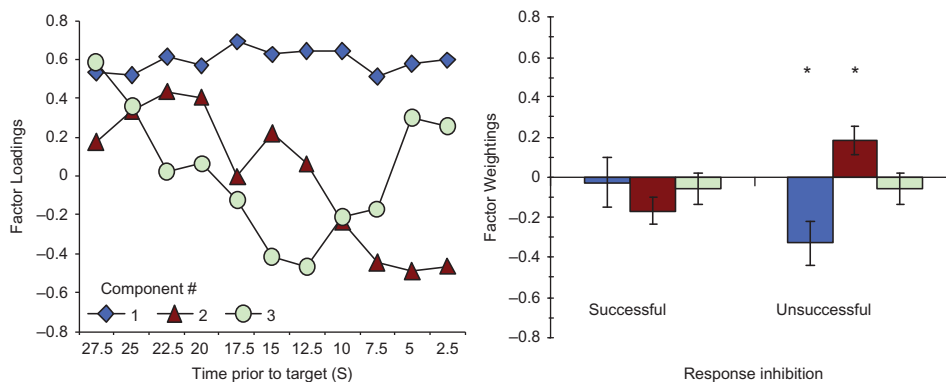
For the purpose of analysis, the data were collapsed to the group level. Factor weightings were averaged for each individual in the period prior to errors and correct responses. Following this reshaping, the mean weighting for each component was as follows: factor 1 ( $M = -0.12$ ,  $SE = 0.12$ ), factor 2 ( $M = -0.05$ ,  $SE = 0.07$ ), and factor 3 ( $M = -0.04$ ,  $SE = 0.06$ ). In no case did these reshaped values have a significant intercept (all  $p > .29$ ). Correlations indicated that after reshaping, factors 1 and 2 were negatively correlated ( $r = -.33$ ,  $p < .05$ ), factors 2 and 3 were negatively correlated ( $r = -.42$ ,  $p < .01$ ), and factors 1 and 3 showed a trend toward a positive correlation ( $r = .29$ ,  $p = .09$ ).

The general linear model (GLM) was used to analyze the relationship between each of the PCA components of RT, target accuracy, and DDF. Five individuals did not make any mistakes, and their data were dropped from all future analysis. The data from the remaining 31 cases were contrasted with a mixed GLM with repeated measures on target accuracy (correct/incorrect) and factor type (components 1–3). DDF was entered as a continuous, between-participants measure. This revealed two significant effects. First, we observed a DDF  $\times$  component interaction,  $F(1, 29) = 6.17$ ,  $p < .05$ ,  $\eta^2 = .15$ . Subsequent analysis indicated that, in general, daydreamers weighted heavily on component 1 ( $r = .36$ ,  $p < .05$ ) but not components 2 ( $r = .179$ ,  $p = .29$ ) or 3 ( $r = -.06$ ,  $p = .69$ ). Daydreamers in general had slow RT throughout the task. In addition, a Component  $\times$  Accuracy  $\times$  DDF quadratic contrast was observed,  $F(1, 29) = 8.5$ ,  $p < .01$ ,  $\eta^2 = .23$ . To follow up this interaction, paired  $t$ -tests were used to determine whether any components

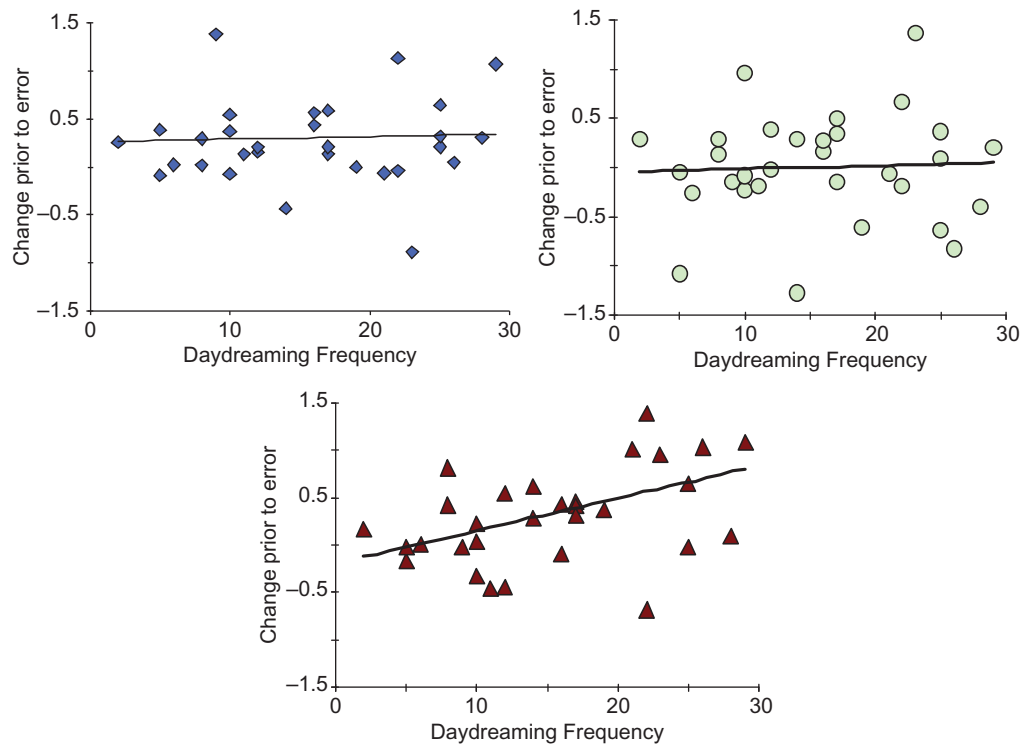
varied with accuracy. This analysis indicated that component 1 was generally more negative prior to a lapse,  $t(30) = -3.41$ ,  $p < .005$ , and component 2 was more positive,  $t(30) = 3.56$ ,  $p < .005$ . Component 3 did not vary,  $t(30) = -0.004$ ,  $p = .99$ . Next, correlations were used to explore which component(s) interacted with both accuracy and DDF by comparing the association with the difference in the component weighting between epochs prior to an incorrect response relative to those prior to a correctly withheld response (error – correct). These correlations indicated that the DDF was associated with increases in component 2 prior to an error ( $r = .47$ ,  $p < .01$ ). No association with DDF was observed for either components 1 ( $r = .04$ ,  $p = .83$ ) or 3 ( $r = .04$ ,  $p = .82$ ). Figure 2 presents scatter plots illustrating the relationship between DDF and the difference in weighting of each component in blocks that ended in an error and those that ended with a response that was correctly withheld.

## DISCUSSION

This study provides further evidence that at least some variance in attentional lapses can be traced back to events that took place many seconds before the mistake occurred. PCA successfully identified the presence of three components within the time series of a go/no-go sustained attention task. Component 1 (indicated by blue diamonds) reflected the overall mean RT for a given epoch, with negative weights indicating fast RT and positive weights indicating slow responding. Prior to a lapse, this component showed a strong negative weighting, indicating that short RT preceded a lapse, a pattern consistent with



**Figure 1.** (Left-hand panel) Time series of the three components identified in response time using Principal Components Analysis (PCA). The time prior to the target is plotted on the x-axis and the RT loadings for each component is plotted on the y-axis. (Right-hand panel) Analysis of the presence of each behavior state in the period prior to targets to which a response was successfully or unsuccessfully withheld. Both Components One and Two varied with accuracy. Component Three did not. The accuracy of response inhibition is plotted on the x-axis. The y-axis presents the average weighting for each component in the period prior to each type of event. Error bars indicate one standard error of the mean. \* indicate significant differences at the  $p < .05$  level.



**Figure 2.** Scatter plots demonstrating the relationship between individual differences in the tendency to daydream and the relative presence of each PCA component associated with error. The x-axis describes the DDQ score for each individual. The y-axis reflects individuals differences in the relative presence of each PCA component associated with accuracy (Error trials - Correct trials). Only the second PCA component varied with a tendency to daydream ( $r = .47, p < .01$ ).

previous investigations (e.g., Robertson et al., 1997). Component 2 reflected a sinusoidal pattern, positive weighting indicating a transition from slow to fast responding over approximately 20 s, and negative weighting indicating the reverse (represented by red triangles). Component 2 generally showed a positive weighting prior to an error, replicating previous work (Smallwood, McSpadden, et al., 2008). Component 3 showed evidence of a transition from a state of acceleration to deceleration (represented by green circles). This component did not vary prior to a lapse. The strong consistency of these behavior states with previous research (Smallwood, McSpadden, et al., 2008) attests to the stability of the underlying phenomena.

Our analysis indicated that attentional lapses which seem to evolve over a significant period of time were most obvious in individuals reporting a rich and absorbing mental life. Specifically, individuals who reported greater levels of daydreaming demonstrated slower RT during task performance and made errors that were preceded by a shift from slow to fast responding over the 20 s prior to target presentation. Previous observations (Smallwood, McSpadden, et al., 2008) indicated that a similar temporal pattern was apparent in the periods prior to errors and off-task

reports and in tasks with a slow stimulus presentation rate and a greater engagement in task-unrelated thought. Taken together, these results suggest that the gradual shift from slow to fast responding on the SART could reflect those mistakes for which the process of internal distraction are especially important.

The characteristics of component 2 make it possible to deduce a number of the features associated with the state. First, while measures that index stochastic features of performance (such as RT variability) are related to measures of attentional lapses (e.g., Ode, Robinson, & Hanson, 2010; Cheyne, Solman, Carriere, & Smilek, 2009), the current data suggest that certain features of such lapses have a systematic evolution. Rather than simply being a stochastic process that influences the efficiency with which a target is processed, the current data suggest that some errors are the result of events that took place sometime before the target was presented. Understanding those processes which govern the systematic temporal changes and those which influence the stochastic elements of error is an important question for future research.

Second, while other phenomena indicate brief temporal lapses in attention (e.g., hundreds of milliseconds),

the characteristics of the errors observed in these data evolved over a substantially longer period. A good example of a brief lapse in attention is the *attentional blink* (Shapiro, Raymond, & Arnell, 1997), in which the detection of a first target (known as T1) in a stream of rapidly presented items can cause attention to blink and so miss a second target (known as T2) if it occurs within about 400 ms. Intriguingly, both the attentional blink (Vogel, Luck, & Shapiro, 1998) and attentional lapses in the SART (Datta et al., 2007; Smallwood, McSpadden, et al., 2008) are associated with a reduction in the extent to which the attention is coupled to the task, as indexed by reductions in the amplitude of a positive deflection in the event related potential known as the P3. The fact that attentional lapses with quite different temporal characteristics exhibit similar “perceptual decoupling” implies that both attentional phenomena may involve shared neural processes. It is important for future research to explore the similarities and differences that underpin lapses in attentional focus of both shorter and longer durations.

Third, while generalizations from behavioral studies of neuroimaging should be made cautiously, there are several reasons to suspect that aspects of the DMN could be particularly associated with errors which stem from events in the relatively distant past. For example, in the current data, these lapses were observed in a population for whom aspects of the DMN (the precuneus/the mPFC) are especially active during periods of cognitive tasks which allow TUT (Mason et al., 2007). Furthermore, neuroimaging studies have shown that the intrusion of aspects of the DMN has been observed prior to errors in tasks of sustained attention (Weissman et al., 2006) and, in particular, on the same go/no-go task as employed here (Christoff et al., 2009). Functional connectivity analysis also indicated that activity in the DMN shows fluctuations at a rate of 0.01 Hz (e.g., Fox et al., 2008), a rate consistent with the time scale of changes in attention observed in the current data. Finally, the gradual increase in activity in the precuneus over approximately 30 s prior to a lapse (Eichele et al., 2008) clearly resembles the temporal evolution observed in RT in these data. All in all, this convergence in subjective, behavioral, and neurocognitive evidence supports the assumption that those errors which evolve over long durations are most likely due to processes associated with elements of the DMN.

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