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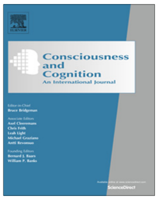

Fluctuations in pre-trial attentional state and their influence on goal neglect

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ABSTRACT

Fluctuations in attentional state and their relation to goal neglect were examined in the current study. Participants performed a variant of the Stroop task in which attentional state ratings were given prior to each trial. It was found that pre-trial attentional state ratings predicted subsequent trial performance, such that when participants rated their current attentional state as highly focused on the current task, performance tended to be high compared to when participants reported their current attentional state as being unfocused on the current task. This effect was larger for incongruent than congruent trials leading to differences in the magnitude of the Stroop effect as a function of pre-trial attentional state. Furthermore, variability in attentional state was correlated with overall levels of performance, and when attentional state was covaried out, the Stroop effect was greatly reduced. These results suggest a link between fluctuations in pre-trial attentional state and goal neglect.

1. Introduction

Our ability to focus and sustain attention on important task-relevant information is a critically important skill that is needed in a host of everyday activities. Despite the importance of focusing and sustaining attention on goal-relevant information, sometimes the attention system falters leading to lapses of attention. Understanding these lapses of attention, whereby attention is disengaged from the current task and focused on other external distracting stimuli or internal thoughts (daydreaming), is important for understanding how and when attentional processes falter in both the laboratory and in real world situations (Kane et al., 2007; Reason, 1984; Reason & Mycielska, 1982; Smallwood & Schooler, 2006; Unsworth, McMillan, Brewer, & Spillers, 2012). Theoretically, cognitive control processes are needed to ensure active goal-maintenance leading to task appropriate behaviors. Prominent theories of cognitive control suggest that cognitive control is implemented by the prefrontal cortex in situations where task goals need to be actively maintained and dynamically updated (Miller & Cohen, 2001). Accordingly, top-down attention control processes are needed to maintain task goals and bias responding so that the appropriate behavior is executed. In many situations, participants will have to actively maintain a novel task goal that is in direct opposition to prepotent response tendencies (Roberts & Pennington, 1996). If there is a failure of active goal maintenance, then it is likely that prepotent response tendencies will guide behavior, leading to goal neglect and the execution of the incorrect response (Duncan, 1995). In situations when attention is tightly focused on the task goal, performance will be both fast and accurate. However, if attention is not tightly focused on the task goal, goal neglect can occur, which will

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lead to overall slower responses or to fast errors that are guided by prepotent tendencies. For example, consider the Stroop task in which participants are required to name the color in which color names are printed. When the color and the word match ("RED" presented in red ink), the task is quite easy. When the color and the word conflict ("RED" presented in blue ink), however, both reaction time and error rates increase. According to views of cognitive control, because the prepotent response conflicts with the task goal ("Say the color not the word"), a loss of goal maintenance should result in the prepotent response guiding behavior and hence the occurrence of fast word-naming errors or slower overall response times (Kane & Engle, 2003).

De Jong, Berendsen, and Cools (1999) presented evidence in support of this general argument in a study in which participants performed congruent and incongruent Stroop trials with either a long or a short response-stimulus interval (RSI). De Jong et al. reasoned that the fast pace of the short RSI would keep attention tightly focused on the task goal, thereby preventing losses of goal-maintenance. The long RSI, however, should induce more lapses of attention (and goal neglect) as participants would have ample time between trials for their minds to wander. This suggests that the Stroop effect should be much larger in the long RSI condition than the short RSI condition. This is precisely what was found. In the long RSI condition there was a significant Stroop effect, but in the short RSI condition the Stroop effect was no longer significant. Furthermore, examining the reaction time distributions in each condition, De Jong et al. found that the difference in the magnitude of the Stroop effect was localized primarily in the slowest RTs. De Jong et al. suggested that these results provide evidence for fluctuations in attention that occur on a trial-by-trial basis and lead to goal neglect (see also Kane & Engle, 2003; West, 1999).

The above work suggests the importance of maintaining goal-relevant information in an active state to ensure accurate responding and further suggest that periodic lapses in attention can lead to goal neglect problems. Indeed, it is a common assumption that attention waxes and wanes during a task in which attention is initially focused on the task, but slowly wanes as our minds wander or we become distracted, then attention once again focuses back on the task at hand (Gilden, 2001). These trial-to-trial fluctuations of attention have been found to occur in a number of prolonged tasks and research suggests that participants' self-reports of their attentional state are reliable and valid indicators of variations in attention (Smallwood & Schooler, 2006). Specifically, a number of studies have utilized thought-probe techniques in which periodically during a prolonged attention task participants are probed and are required to report whether their attention was currently focused on-task or whether they were mind-wandering. This research has consistently found that not only do participants report extensive mind-wandering during attentional tasks, but also these self-reports of mind-wandering are correlated with actual performance, such that self-reports of mind-wandering are associated with lower levels of performance (McVay & Kane, 2012; Schooler, Reichle, & Halpern, 2004).

More recently Macdonald, Mathan, and Yeung (2011) examined trial-to-trial fluctuations in attentional state in a rapid serial presentation detection task by probing participants after each trial (rather than randomly throughout the task) and found that fluctuations in subjective attentional state strongly predicted performance such that when attentional state ratings were high, performance was relatively good, and when attentional state ratings were low, performance was worse. Furthermore, Macdonald et al. found that subjective attentional state ratings were negatively related with pre-stimulus EEG alpha power suggesting that fluctuations in attention are reflected in not only subjective ratings, but also in EEG alpha power.

The goal of the present study was to examine the extent to which fluctuations in pre-trial attentional state would predict performance on the subsequent trial and the extent to which pre-trial attentional state would predict levels of goal neglect. In particular, prior work has suggested that fluctuations in attentional state are one of the main contributors to goal neglect such that when attention is sharply focused and the current goal state is actively maintained performance will be good. However, when attention is loosely focused the goal will not be maintained as well (or at all) leading to worse performance (De Jong et al., 1999). Despite these initial claims, no study has actually attempted to measure pre-trial subjective attentional state on a trial-by-trial basis to see if trial-to-trial differences in attentional state influence the amount of goal neglect observed on a task. Therefore, to directly examine the notion that pre-trial attentional state is an important predictor of subsequent performance, participants performed a version of the Stroop task that promoted goal neglect. Specifically, in this task participants were presented with both congruent and incongruent trials, but critically there were far more congruent trials than incongruent trials. Prior research has suggested that proportion congruence manipulations in the Stroop and other tasks place high demands on goal maintenance (Kane & Engle, 2003). In one condition participants performed the Stroop task under normal conditions. In the other condition, participants performed the same Stroop task, with the exception that prior to each trial participants were instructed to provide a numerical rating (1–10) on their current attentional state. Specifically, in the attentional state condition, participants rated how focused they were on the current task prior to each trial. This was done because we were primarily interested in determining if pre-trial attentional state would predict subsequent performance on a trial-by-trial basis. Prior research has primarily examined changes in attentional state by probing participants periodically after some trials, and thus it is not known how pre-trial attentional state (i.e., how focused one is) relates to performance and how this changes on a trial-by-trial basis. Furthermore, most prior research has participants indicate if they are on- or off-task and we wanted to see if a more continuous measure of attentional state would predict performance. The reason for including a condition where participants did not provide attentional state ratings was to examine possible reactivity effects whereby providing attentional state ratings could lead to changes in performance compared to more standard versions of the Stroop task. If there are no differences between the two conditions, we can assume that the attentional ratings provide a window into normally ongoing processes in the Stroop task. If pre-trial attentional state is an important determinant of performance, we should see that pre-trial attentional state not only predicts trial-to-trial variability in performance, but critically pre-trial attentional state should predict the amount of Stroop interference that is observed.

Table 1
Descriptive statistics for the control and attentional state conditions.

Measure	Control	AttnState
Con RT	739.71 (98.58)	745.87 (160.99)
Incon RT	920.47 (193.65)	927.21 (228.17)
Con Acc	.97 (.03)	.96 (.04)
Incon Acc	.90 (.10)	.89 (.15)
Stroop RT	180.77 (133.02)	181.34 (135.24)
Stroop Acc	.06 (.10)	.08 (.13)

Note: Standard deviations are in parentheses. Con RT = correct mean reaction time for congruent trials; Incon RT = correct mean reaction time for incongruent trials; Con acc = accuracy for congruent trials; Incon acc = accuracy for incongruent trials; Stroop RT = magnitude of the Stroop effect for reaction time; Stroop Acc = magnitude of the Stroop effect for accuracy.

When participants rate their current attentional state as high, overall levels of performance should be high and the magnitude of the Stroop effect should be small. Conversely, when participants rate their current attentional state as low, overall levels of performance should be low and the magnitude of the Stroop effect should be large.

2. Method

Participants were 109 undergraduate students recruited from the subject pool at the University of Oregon. Participants were randomly assigned to one of the two conditions (control condition, $n = 55$; attentional state condition, $n = 54$). We tested participants over one full academic quarter, using the end of the quarter as our stopping rule for data collection. Participants were between the ages of 18 and 35 and received course credit for their participation. Each participant was tested individually in a laboratory session lasting approximately one hour. Participants first performed the Stroop task and then following a short break they performed an unrelated delayed free recall task. All participants performed the same computerized version of the Stroop task. Participants were presented with a color word (red, green, or blue) presented in one of three different font colors (red, green, or blue). All words were presented in Courier New with an 18 point font. The participants' task was to indicate the font color via key press as quickly and accurately as possible. Prior to the real trials participants received 18 trials of response mapping practice where they saw one of three colored squares and were required to press the corresponding colored key. For the real trials, participants received 100 trials in total. Of these trials 80% were congruent (red printed in red) and the other 20% were incongruent (red printed in green). Congruent and incongruent trials were mixed throughout the task. Combinations of colors and color words were randomly distributed across participants. In the attentional state condition, prior to performing the task participants were informed that we were also interested in their overall attentional state in the task. Before each trial participants were asked to indicate their attentional state for the current trial only by rating how focused they were on the current task on a 1–10 scale with a 1 indicating that they were not at all focused on the current task, a 5 indicating that they were somewhat focused on the current task, and a 10 indicating that they were totally focused on the current task. While making the ratings they were told to incorporate the amount of mind wandering and distraction into a single value similar to Macdonald et al. (2011). Thus, we were primarily interested in participants ratings of how focused they were rather than what might have been derailing their focus (i.e., mind-wandering or external distraction). Participants provided their attentional state ratings by typing in a number from 1 to 10 and pressing enter to record their response. Immediately after giving their attentional state rating the next trial began.

We report how we determined our sample size, all data exclusions, all manipulations, and all measures in our study.

3. Results

First, we examined overall differences in performance between the two conditions to examine any reactivity effects due to providing attentional state ratings. As seen in Table 1, there were no differences between the two conditions in performance in terms of reaction time or accuracy. Specifically, overall levels of performance were similar for the control and attentional state conditions on all measures of performance, all t's < 1.6, all p's > .12, all η^2's < .02.

Given that there did not seem to be any reactivity effects associated with providing attentional state ratings, we next focused only on the attentional state condition to better examine whether pre-trial attentional state ratings predict performance. First, we examined whether there was a relation between pre-trial attentional state and reaction time. Because not all participants utilized the entire rating scale we used linear mixed models to analyze the data given their ability to deal with unbalanced designs and missing data. In the model attentional state and trial congruency (congruent vs. incongruent) were entered as a fixed factor and subjects were entered as random factors. As shown in Fig. 1a there was an effect of attentional state on reaction time, $t = -4.10$, $p < .001$ ($b = -16.33$, $SE = .04$). This suggests that when attentional state was high participants performed much better than when attentional state was low.[1] Importantly, as shown in Fig. 1b, there was a significant interaction between trial congruency and attentional state, $t = -2.04$, $p < .05$ ($b = -9.11$, $SE = .04$), suggesting that atten-

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[1] Each data point in Fig. 1a is composed of a minimum of 53 ratings (10 = 482, 9 = 771, 8 = 885, 7 = 616, 6 = 303, 5 = 521, 4 = 133, 3 = 194, 2 = 80, 1 = 53).

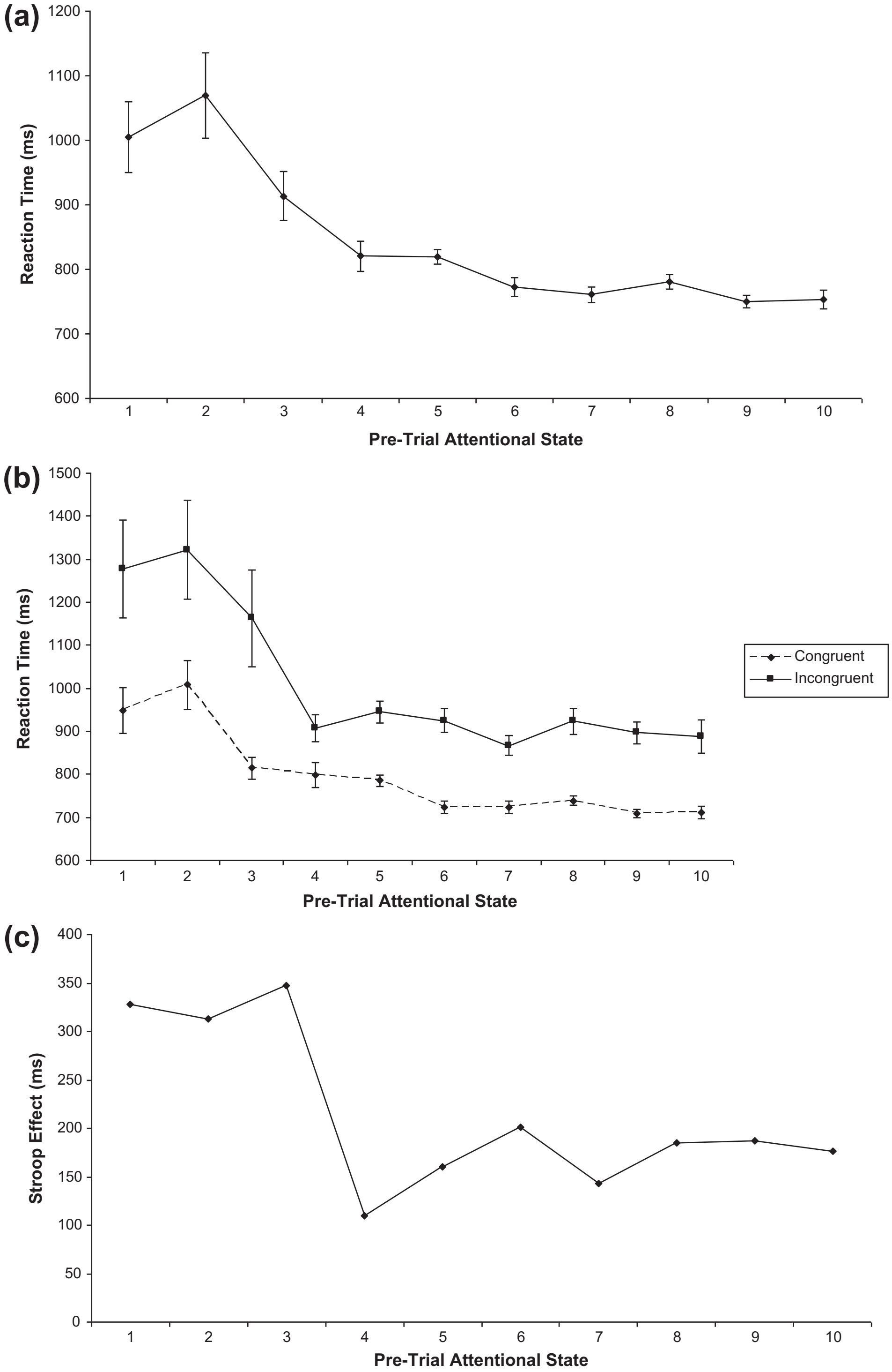

Fig. 1. (a) Reaction time as a function of pre-trial attentional state, (b) Reaction time as a function of pre-trial attentional state and trial congruency, (c) Magnitude of the Stroop effect as a function of pre-trial attentional state. Error bars reflect one standard error of the mean.

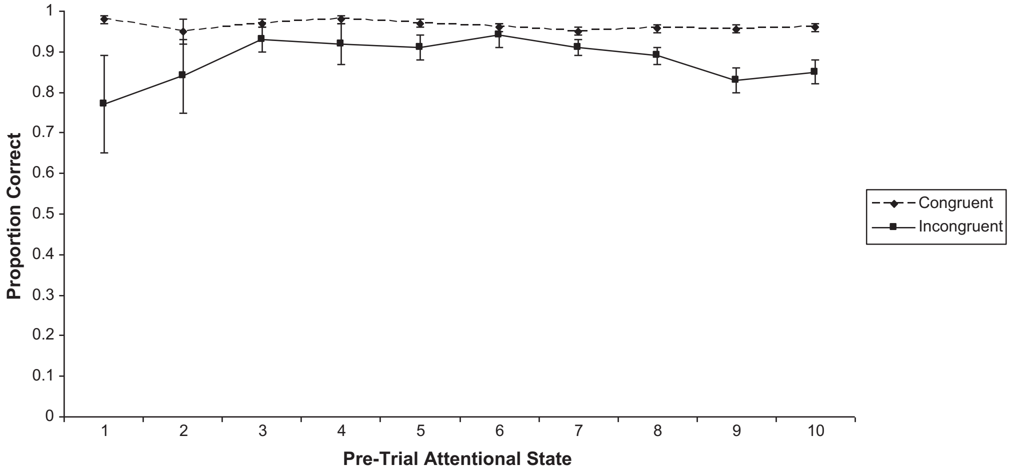

Fig. 2. Proportion correct as a function of pre-trial attentional state and trial congruency. Error bars reflect one standard error of the mean.

tional state influenced reaction times more on incongruent trials than on congruent trials.[2] That is, when participants rated their pre-trial attentional state as being more focused on the task, the Stroop effect was small. However, when participants rated their pre-trial attentional state as being less focused the Stroop effect was much larger (see Fig. 1c). As can be seen, most of the effect was driven by responses at the low end suggesting that being highly unfocused and off-task is particularly detrimental to performance.[3] As shown in Fig. 2, examining accuracy suggested no significant effect of attentional state, $t = .46$, $p > .64$, and no significant interaction between attentional state and trial congruency, $t = -1.27$, $p > .20$. This is likely due, in part, to the fact that accuracy was quite high on both congruent and incongruent trials.

Next we examined whether individual differences in attentional state would predict performance on the Stroop task. We computed each individual's mean attentional state throughout the task and examined the correlation between mean attentional state and performance. We also examined whether variability in attentional state would predict performance, assuming that individuals who demonstrate more fluctuations in attentional state would likely perform more poorly than individuals who can sustain their attention throughout the task (Unsworth, Redick, Lakey, & Young, 2010). Therefore, we computed each individual's standard deviation for their attentional state ratings and correlated these values with performance. Shown in Table 2 are the descriptive statistics for the various indicators of performance. Shown in Table 3 are the correlations between the mean and standard deviation of attentional state ratings with the measures of performance. As can be seen, mean attentional state ratings were weakly related with reaction time, but not with any of the other measures. Importantly, the standard deviation of attentional state ratings were significantly related to all measures of performance. Specifically, each individual's standard deviation of their attentional state ratings was significantly correlated with reaction time for both congruent and incongruent conditions, with variability in reaction time, with overall accuracy in each condition, and importantly with the overall magnitude of the Stroop effect in both reaction time and accuracy. Thus, those individuals who reported more fluctuations in their pre-trial attentional state demonstrated slower, more variable, and less accurate performance overall on the task and demonstrated the largest Stroop effects. The mean and standard deviation of the attentional state ratings were not significantly related ($r = -.11$, $p > .41$).

Given the strong link between attentional state ratings (particularly variability in attentional state) and performance, we next examined whether the Stroop effect would be reduced or eliminated once individual differences in attentional state were covaried out. Therefore, we first examined the strength of the overall Stroop effect by examining the difference between incongruent and congruent reaction times. As expected, there was a strong Stroop effect, $F(1,53) = 97.09$, $MSE = 9145$, $p < .01$, partial $\eta^2 = .65$, (see Table 1). However, once the standard deviation of the attentional state ratings was covaried out the Stroop effect was **greatly reduced**, $F(1,52) = 9.36$, $MSE = 8031$, $p < .01$, partial $\eta^2 = .15$. In particular, note that partial η^2 dropped from .65 to .15. Similar results occurred when examining the Stroop effect for accuracy. Specifically, as shown in Table 1 there was a strong Stroop effect on accuracy, $F(1,53) = 18.47$, $MSE = .008$, $p < .01$, partial $\eta^2 = .26$. However, once the standard deviation of the attentional state ratings was covaried out the Stroop effect for accuracy was no longer significant, $F(1,52) = .39$, $MSE = .008$, $p > .90$, partial $\eta^2 = .00$. Thus, once individual differences in variability in pre-trial attentional state were accounted for, the Stroop effect was greatly reduced. These results provide strong support for the no-

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[2] Note we reran the analysis after normalizing each participants data (i.e., subtracting each participant's mean RT from their RT for each attentional state rating) to ensure that the results were not only due to differences across participants. The results were virtually identical to those of the non-normalized data, with a significant interaction between trial congruency and attentional state, $t = -2.02$, $p < .05$ ($b = -9.10$, $SE = .05$).

[3] Note we reran the analysis excluding responses 1–3 and although the main effect of attentional state was still significant, $t = -2.52$, $p < .05$ ($b = -11.59$, $SE = .05$), the interaction was not, $t = -1.23$, $p > .21$, suggesting that differences between congruent and incongruent trials was largely driven by low attentional state ratings.

Table 2
Descriptive statistics and reliability estimates for all measures.

Measure	*M*	SD	Skew	Kurtosis	Reliability
M AttnState	7.18	1.92	−.93	.26	.98
AttnState *SD*	.92	.57	1.49	2.23	.84
M Con RT	745.87	160.99	.89	.93	.94
M Incon RT	927.21	228.17	.95	1.77	.85
Con RT *SD*	214.43	100.09	1.35	1.64	.59
Incon RT *SD*	298.28	212.42	2.63	4.19	.56
Con Acc	.96	.04	−1.91	4.06	.74
Incon Acc	.89	.15	−2.47	5.82	.75
Stroop RT	181.34	135.24	1.34	1.71	.79
Stroop Acc	.08	.13	2.05	4.48	.70

Note: M AttnState = mean attentional state; AttnState *SD* = standard deviation of attentional state; *M* Con RT = correct mean reaction time for congruent trials; *M* Incon RT = correct mean reaction time for incongruent trials; Con RT *SD* = standard deviation for correct congruent trials; Incon RT *SD* = standard deviation for correct incongruent trials; Con acc = accuracy for congruent trials; Incon acc = accuracy for incongruent trials; Stroop RT = magnitude of the Stroop effect for reaction time; Stroop Acc = magnitude of the Stroop effect for accuracy. Reliabilities are Cronbach alphas for all measures except the Stroop effect difference scores which are split-half reliabilities.

Table 3
Correlations between the mean and standard deviation of attentional state with measures of performance on the Stroop task.

Measure	*M* AttnState	AttnState *SD*
M Con RT	−.27*	.35*
M Incon RT	−.23	.47*
Con RT *SD*	−.18	.41*
Incon RT *SD*	−.07	.44*
Con Acc	−.15	−.38*
Incon Acc	−.07	−.34*
Stroop RT	−.07	.37*
Stroop Acc	.03	.27*

Note: M AttnState = mean attentional state; AttnState *SD* = standard deviation of attentional state; *M* Con RT = correct mean reaction time for congruent trials; *M* Incon RT = correct mean reaction time for incongruent trials; Con RT *SD* = standard deviation for correct congruent trials; Incon RT *SD* = standard deviation for correct incongruent trials; Con acc = accuracy for congruent trials; Incon acc = accuracy for incongruent trials; Stroop RT = magnitude of the Stroop effect for reaction time; Stroop Acc = magnitude of the Stroop effect for accuracy.

* Significant at the $p < .05$ level.

tion that the Stroop effect (and variation in the Stroop effect) are influenced by trial-to-trial variations in attentional state which can lead to goal neglect.

4. Conclusions

In the current study we examined whether trial-to-trial fluctuations in attentional state would predict performance and goal neglect on the Stroop task. Using a novel attentional probing technique in which participants provided subjective attentional state ratings prior to each trial (c.f. Macdonald et al., 2011); we provide direct evidence for the role of pre-trial attentional state and fluctuations in attentional state in determining performance. Specifically, the results suggest that pre-trial attentional state ratings strongly predicted subsequent trial performance. When participants rated their current attentional state as focused on the current task, performance tended to be good compared to when participants reported their current attentional state as being low and unfocused on the current task. In particular, when participants reported their current attentional state as being moderately to highly focused on the task, the Stroop effect was much smaller compared to when participants reported that they were less focused on the current task. Thus, being highly unfocused and off-task is particularly harmful to performance. Furthermore, variability in attentional state ratings (fluctuations) was moderately correlated with various measures of performance including the magnitude of the Stroop effect for both reaction time and accuracy at an individual level suggesting that individual differences in susceptibility to goal neglect partially account for variation in the Stroop effect. Indeed, when variability in attentional state ratings were covaried out, the Stroop effect was greatly reduced suggesting that trial-to-trial fluctuations in attentional focus are a major contributor to the Stroop effect. This result is important, because it suggests that the Stroop effect is not entirely driven by stimulus characteristics, but rather is determined, in part, by attentional fluctuations that occur even before the stimulus is present (De Jong et al., 1999). Overall, these results extend prior research which has examined changes in attentional state by probing individuals periodically after some trials, by suggesting that similar changes in attentional state can be assessed prior to trials, can be examined on a trial-by-trial basis rather than after only some trials, and can be examined at a more fine-grained level (i.e., using a broader range of ratings).

A potential alternative explanation that needs to be addressed is the possibility that participants used the ratings as an opportunity to decide at the start of a trial how hard they felt like working and that performance is a reflection of participants intentionally changing how hard they would work on each trial to match their ratings. That is, when participants rated their focus as low they intentionally decided not to try hard on the next trial, whereas when participant rated their focus as high, they tried harder. Although this effort or motivation idea is consistent with fluctuations in focus, we do not think participants were intentionally changing their performance to match the ratings for two reasons. First, if participants were simply deciding to blow off the task when they rated their focus as low, one would expect differences to arise in errors across all trials. However, accuracy did not change much as a function of attention state ratings. Second, if participants were intentionally deciding to respond more slowly on trials where they rated their focus as low one would expect overall differences in reaction time with little to no differences between congruent and incongruent trials given that participants did not know in advance whether the next trial would be an incongruent or congruent trial. Thus, one would expect the magnitude of the Stroop effect to be constant across levels of attentional state, but overall differences in reaction time as function of attentional state. Given that attentional state ratings had more of an effect on incongruent than congruent trials (leading to differences in the magnitude of the Stroop effect) we do not see this as a likely explanation of the results. However, future work is needed to better examine potential similarities and differences between changes in motivation/effort and changes in attentional state and how these influence performance.

Collectively the current results suggest that the ability to focus and sustain attention on task (as revealed by attentional state ratings) is an important contributor to goal neglect and to performance on cognitive control measures. Future work is needed to better examine how fluctuations in attention are related across tasks and similarly predict performance when attention control is required. By measuring subjective attentional state on a trial-to-trial basis the current results provide a promising means for examining fluctuations in attention and their role in complex cognitive operations.

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