Mind-wandering impedes response inhibition by affecting the triggering of the inhibitory process

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Abstract

Mind-wandering is a state where our mental focus shifts towards task-unrelated thoughts. While it is known that mind-wandering has a detrimental effect on concurrent task performance, e.g., decreased accuracy, its effect on executive functions is poorly studied. Yet, the latter question is relevant to many real-world situations, e.g., rapid stopping during driving. Here we studied how mind-wandering would affect the requirement to subsequently stop an incipient motor response. We tested, first, whether mind-wandering affected stopping, and second, which component of stopping was affected: the triggering of the inhibitory brake or the implementation of the brake following triggering. We observed that during mind-wandering, stopping-latency increased as did the proportion of trials with failed triggering. Indeed, 67% of the variance of the increase in stopping-latency was explained by the increased trigger failures. Thus, mind-wandering affects stopping, primarily by affecting the triggering of the brake.

Statement of Relevance

The ability to rapidly stop contextually inappropriate actions is a key feature of everyday life. But how is that ability affected when our minds wander to task-unrelated thoughts? This has not been studied much, and what studies exist provide conflicting answers. In two experiments, we addressed the limitations of the previous studies with a better design. We observed that mind-wandering made stopping-latency slower and more variable. This deficit seemed to be primarily related to the triggering of the stopping process itself. This might imply that mind wandering affected the ability to attend to the stop signal and initiate the processes that mediate stopping. Our experimental method to model how mind-wandering affects stopping could be extended to real-world situations such as driving or handling machinery which often demand rapid stopping.

Introduction

As we go about our jobs and responsibilities in our daily lives, our minds are not always focused on the task at hand. Sometimes they wander to task-unrelated thoughts (mind-wandering, MW) such as what to cook for dinner, worries about health and finances, etc., and sometimes our minds may be blank and unfocused (Off-focus) (Mittner et al., 2016). While research is still required to determine the differences between Off-focus and MW, both these mental-states reflect general task disengagement, and the brain activity during these periods is different compared to On-task periods (reviewed in Christoff et al., 2016; Mittner et al., 2016). MW has been well studied in recent years and it is thought to occur up to half of our waking hours (Killingsworth and Gilbert, 2010). Unsurprisingly, studies have reported that MW is associated with poorer sustained attention on concurrent tasks resulting in worse performance, e.g., increased variability in reaction times (RT) and decreased accuracy (Arnau et al., 2020; Bastian and Sackur, 2013; Compton et al., 2019; Mittner et al., 2014). However, the effect of MW might be quite consequential if during the MW episode there is a subsequent need for rapid executive control, i.e. the high-level processes that regulate other cognitive subprocesses and behavior (Miyake et al., 2000). Many daily activities such as driving and handling machinery require active engagement of executive control especially perhaps response inhibition, i.e. the cognitive process that controls rapid behavioral action-stopping. For example, when one is driving and the traffic light suddenly turns red, one must quickly stop pressing the accelerator and switch to pressing the brake instead. How does MW affect that executive requirement to rapidly stop an incipient action? Here we specifically examine this.

Although the literature has often suggested that MW has a detrimental effect on response inhibition (Mooneyham and Schooler, 2013; Smallwood et al., 2008, 2007), the evidence supporting this is weak. Several MW studies have used the Go/No-Go task (sometimes called the Sustained Attention to Response Task) to demonstrate that No-Go errors increase during MW, which may reflect the failure to inhibit the prepotent response (Christoff et al., 2009; Groot et al., 2021; Smallwood et al., 2008, 2007; Stawarczyk et al., 2014). However, in this task, prepotent motor activity occurs only if the task is fast-paced and the probability of No-Go trials is low (Wessel, 2018). It is unclear if the aforementioned studies satisfied both these criteria. When these criteria are not satisfied, No-Go performance might instead reflect the decision to not respond rather than action-stopping (Bari and Robbins, 2013; Wessel, 2018). Thus, it is unclear whether

these MW studies actually tested the effect of MW on response inhibition. The picture from other tasks is also unclear. For Stroop tasks, two studies reported no effect of MW on incongruent trials (Compton et al., 2019; Thomson et al., 2013), while one did (Kam and Handy, 2014); for Switching tasks, three studies reported no effect of MW on the switch trials (Arnau et al., 2020; Kam and Handy, 2014; Thomson et al., 2014); for Flanker tasks, two studies reported no effect of MW on incongruent trials (Gonçalves et al., 2018; Thomson et al., 2014); and finally, for the Stop Signal Task, one study suggested that response inhibition is unaffected by MW (Mittner et al., 2014). Thus, taken together, it remains unclear whether MW affects response inhibition. Other factors that might explain such mixed results are that, many studies were not specifically set-up to test whether MW affects response inhibition, many did not perform within-subject comparison of MW and On-Task episodes, and also, many did not exclude participants who reported no or few MW episodes.

Learning from these issues, our study had three key elements, 1) We used a Stop Signal Task which gives an unequivocal measure of response inhibition (Bari and Robbins, 2013), 2) For each participant, we selected trials that require response inhibition during self-reported episodes of MW and On-Task. We then performed within-subject comparison of these two episodes, 3) We excluded participants from analysis who did not contribute enough data to the MW condition, i.e. had no or few MW episodes.

In the Stop Signal Task, participants are cued to make a response in every trial, however, in a minority of trials when a stop signal is presented, they must try to ‘brake’ and stop the incipient response (Verbruggen et al., 2019). Behaviorally, the stopping-latency is measured as Stop Signal Reaction Time (SSRT) and this is thought to indicate the time when the inhibitory brake is applied to stop the incipient response. As mentioned above, while a previous MW study used this task and also had a within-subject design, their results are difficult to interpret as they did not report the typical SSRT metric (Mittner et al., 2014).

Using the Stop Signal Task instead of the other response inhibition tasks mentioned above, has two advantages. First, this taps into extensive research that has used this task to map out a prefrontal-basal-ganglia network which is critical for action-stopping (reviewed in Aron et al., 2016; Bari and Robbins, 2013) (also see Jana et al., 2020). Second, this task provides a way to parcellate the response inhibition process into two distinct stages- trigger and brake, and then investigate which stage is affected by MW. It has been argued that successful action-stopping not

only depends on a quick implementation of the ‘brake’ to stop the response, but also depends on how consistently the brake is ‘triggered’ (Band et al., 2003; Matzke et al., 2017a; Schachar and Logan, 1990; Sebastian et al., 2018). In other words, the application of the brake depends on how consistently it is triggered- if triggering is slow or inconsistent then so will be the braking. This will result in poorer stopping as measured by SSRT. Triggering has recently been operationalized in a modeling framework for behavioral data by Matzke et al. (2017b). This model estimates a parameter called trigger failures – the proportion of trials where there was a failure to trigger the brake. Subsequently, studies have demonstrated that trigger failures (TF) are well correlated with real-world measures of impulsivity (Skippen et al., 2019), and that some clinical populations who have response inhibition deficits also have greater TF (Matzke et al., 2017a; Swick and Ashley, 2020), suggesting that TF index a core component of response inhibition. However, TF remain controversial as it seems unlikely that the salient stop signal would *not* trigger the brake in some trials. One possibility is that TF reflect periods of goal neglect or attentional failures where the stop signal *is* processed by the sensory system, but this encoded signal is not utilized to select the appropriate action i.e. initiate the brake (Matzke et al., 2017a; Skippen et al., 2019). Given that MW is a mental-state associated with attentional lapses (Mooneyham and Schooler, 2013; Smallwood and Schooler, 2015), an auxiliary aim of our study is to validate the attentional account of TF by testing whether MW episodes are associated with greater TF.

In two studies, participants performed the Stop Signal Task while they were intermittently probed to report their mental-state. Based on the probe responses, we classified trials just prior to the probe as either On-Task or MW episodes. We then performed within-subject comparison of the stopping performance between On-Task and MW episodes. We envisioned a number of possible outcomes. Since during MW, attention is directed away from the task, one likely outcome was that MW would increase TF, and thus increase in SSRT also. Alternatively, MW might not change TF and SSRT at all, which would indicate that MW does not affect response inhibition (see *Fig. 1* for all the possible outcomes). Thus, this investigation will inform whether and how MW affects response inhibition: by directly affecting the braking mechanism or by affecting triggering mechanism. Further, at the end of the task, participants completed the Mind Wandering Questionnaire (Mrazek et al., 2013). This allowed us to test whether trait level MW is related to state level MW as demonstrated by Mrazek et al. (2013), and thus, whether probe responses could be trusted.

Fig. 1 | The possible effects of mind-wandering (MW) on the trigger and brake stages and how that might change the behavioral metrics, trigger failures (TF) and stop signal reaction time (SSRT).

Methods

Participants

Healthy adult participants were recruited using the online recruitment platform, Prolific. They were monetarily compensated for their time. The study was covered by a protocol from the Institutional Review Board of the University of California San Diego.

Study 1. 32 participants performed the study. 2 participants were rejected because of poor behavior (1 subject failed to stop in all trials, and another had bimodal Go RT distribution). Thus, 30 participants were included (Sex: 6/30 females; Handedness: 24/29 right-handed, one did not report; Age: 34±2 years, min = 18 years, max = 64 years). 11/30 participants reported sufficient number of MW episodes (see below).

Study 2. Based on the results of study 1, we conducted a power analysis and preregistered the sample size (<https://osf.io/n24m9/>; data and scripts also provided at that link). 207 participants performed the study. 62 were rejected because they did not satisfy the behavioral criteria (mean go RT > mean failed stop RT by 10 ms, accuracy in go trials > 90%, unimodal go RT, probability of stopping between 0.3-0.7). Thus, 145 participants were included (Sex: 68/132 females, 13 participants did not report; Handedness: 122/145 right-handed; Age: 34±1 years, min = 19 years, max = 68 years). 40/145 participants reported sufficient number of MW episodes (see below).

Study design

Overview

Participants performed a browser-based Stop Signal Task with an auditory tone as the stop signal (*Fig. 2A*). In each trial a left/right arrow was presented, and participants had to respond quickly with the corresponding left/right key press with their right hand. In 25% of trials, after a delay, called Stop Signal Delay (SSD), a tone was presented and, in these trials, they had to try to stop their response. The SSDs were tracked such that it reduced by 50 ms after a failed stop response, and increased by 50 ms after a successful stop response, so as to achieve successful stopping in roughly 50% of trials. Intermittently, after 16-22 trials (40-55 s), they received a mental-state probe: “In the previous trial, was your mind: 1. Focused on the task, 2. Wandering or thinking of something else, 3. Blank or unfocused”, where they responded by pressing the 1, 2, or 3 keys with their left hand (*Fig. 2B*). At the end of the study they completed the Mind-wandering questionnaire (MWQ) (Mrazek et al., 2013) (see Supplemental Materials for details).

Fig. 2 | Task design. **A.** Schematic of the auditory Stop Signal Task. In 75% trials, participants made a left/right key press when the left/right arrow was presented. In 25% trials, a tone was presented after a stop signal delay, and in these trials, participants had to try to stop their response. **B.** Mental-state probe which was presented after every 16-22 trials. Participants responded by pressing the 1/2/3 number keys. The first, second, and third response indicates an on-task, mind-wandering, and off-focus mental-state, respectively.

Analyses

On-Task vs MW episodes

Most of our analyses were focused on the 6-trial period (15 s) prior to the mental-state probe. Each 6-trial period always included at least one stop trial (but when the probe appeared and when the stop signal was presented was not predictable). This duration is similar to that used by previous studies (Bastian and Sackur, 2013; Christoff et al., 2009; Kam et al., 2012, 2011). Based on the probe response, the 6-trial period was classified as an On-Task, MW, or Off-focus episode. For each participant, analyses were performed on the data pooled across all episodes of a particular type. We also performed supplementary analyses with a 10 s (4-trial) period and confirmed that the main results still held up (*Fig. S3* in Supplemental Material).

Stop Signal Reaction Time (SSRT)

SSRT was computed using the integration method (with replacement of go failures) as described in Verbruggen et al. (2019).

Estimation of trigger failures

The percentage of trigger failures, mean and standard deviation (SD) of SSRT was estimated using the Bayesian Estimation of Ex-Gaussian STop-Signal (BEESTS) model developed by Matzke and colleagues (2017b). This model assumes a race between independent go- and stop-processes. It estimates the SSRT distribution by using the go RT distribution, and by considering the failed stop RT as a censored go RT distribution. Additionally, the model also determines the probability of trigger failures for each participant (see Supplemental Materials for more details).

Statistical analysis

For pairwise comparisons, the data were first checked for normality using Lilliefors test, and if normally distributed a two-tailed paired *t*-test (*t*-statistic) was performed, else a two-tailed Wilcoxon signed rank test (*z*-statistic). For unpaired comparisons, for normally distributed data a two-tailed unpaired *t*-test (*t*-statistic) was performed, else a two-tailed Wilcoxon rank sum test (*z*-statistic). For parametric tests, the effect size was computed as Cohen's *d* and Bayes' factor in favor of the alternate hypothesis, BF_{10} , while for non-parametric tests, effect size was calculated as $r = z/\sqrt{N}$ where *N* is the number of observations. We interpret the effect sizes as small (*d*: 0.2-0.5; BF_{10} : 1-3; *r*: 0.2-0.5), medium (*d*: 0.5-0.8; BF_{10} : 3-10; *r*: 0.5-0.8), large (*d* > 0.8; BF_{10} > 10; *r* > 0.8). For comparisons across multiple levels, repeated-measures ANOVA or Friedman's

test (for non-parametric data) was used. This was followed by pairwise comparisons using Bonferroni-Holm corrected t -tests or Wilcoxon signed rank test (Bonferroni-Holm corrected p -value: p_{BH}). The Greenhouse-Geisser correction was applied where the assumption of sphericity in ANOVA was violated (corrected F -statistic: F_{GG}). Effect sizes for ANOVAs were interpreted as small (partial eta-squared, η_p^2 : 0.01-0.06), medium (η_p^2 : 0.06-0.14), and large ($\eta_p^2 > 0.14$). For all correlational analyses, if the data were normally distributed then Pearson's correlation coefficient (r_p) was used, else Spearman's correlation coefficient (r_s). All data are presented as mean $\pm$ s.e.m.

Results

Study 1: Behavior

30 participants performed the Stop Signal Task. They made left/right keypress when the go cue (left/right arrow) was presented. Depending on the stop signal delay, SSD, participants successfully stopped or failed to stop, roughly half the time. After every 16-22 trials (40-55 s) they were asked to report their mental-state (On-Task, MW, Off-focus). Overall, the behavioral performance was typical (*Table 1*; column titled 'All' under study 1). SSRT was 289 $\pm$ 11 ms and successful stopping of 50 $\pm$ 1 %. Our core hypothesis was that the 6-trial period (15 s) preceding MW reports would have greater SSRT and Trigger Failures (TF), compared to On-Task reports. Thus, based on the probe response, we classified 6-trials prior to all mental-state reports (32 probes in total) as On-Task, MW, or Off-focus episodes. However, not all participants reported having MW episodes, and still fewer reported having Off-focus episodes (*Table 2*). So, for the following analyses we considered only the 11 participants who had >5 instances of MW. This cutoff of using >5 instances of MW was arbitrary, but, 1) successful stop % was within 25-75% range for this cutoff (*Table S1* in Supplemental Material) suggesting that SSRT could be properly estimated (Verbruggen et al., 2019), and 2) the results also held up for other cutoffs (*Fig. S4* in Supplemental Material). As there were few Off-focus reports, we focused on the MW episodes (see Supplemental Material for Off-focus results and discussion).

Table 1: Behavioral responses across all trials (Values represent mean $\pm$ s.e.m.)

Parameters	Study 1		Study 2	
Group	MW (N = 11)	All (N = 30)	MW (N = 40)	All (N = 145)

Mean Correct go RT	505±18 ms	514±12 ms	517±12 ms	530±6 ms
Mean Failed Stop RT	464±16 ms	474±11 ms	478±10 ms	489±5 ms
Correct Go	99±0 %	99±0 %	98±0 %	98±0 %
Error Go	1±0 %	1±0 %	2±0 %	1±0 %
Successful Stop	49±1 %	50±1 %	48±1 %	49±0 %
SSRT	300±16 ms	289±11 ms	307±8 ms	311±5 ms
Mean SSD	190±17 ms	209±14 ms	197±13 ms	207±7 ms

Table 2: Mental-state reports (Values represent mean±s.e.m.). MW group had >5 MW episodes.

Parameters	Study 1		Study 2	
Group	MW (N = 11)	Non-MW (N = 19)	MW (N = 40)	Non-MW (N = 105)
On-Task reports	63±3 %	95±2 %	57±3 %	92±1 %
MW reports	31±3 %	5±1 %	35±2 %	5±1 %
Off-focus reports	5±2 %	1±0 %	8±1 %	3±1 %

Fig. 3 | Behavioral responses in study 1. A. Comparison between SSRT during the On-Task (blue) and MW (green) episodes. Each dot represents a participant while the bar and cross-hairs represent the mean±s.e.m. **B.** Same as A but for mean go RT. $p > 0.1$: ns, $p \leq 0.01$ & $p > 0.001$: **.

We started by comparing SSRT between MW and On-Task episodes. The main result of interest was that SSRT in MW episodes (335 ± 19 ms; called $SSRT_{MW}$ henceforth) was significantly greater than in On-Task episodes (290 ± 18 ms; called $SSRT_{ON}$ henceforth) ($t(10) = 4.4$, $p = 0.001$,

$d = 1.3$, $BF_{10} = 32.3$; *Fig. 3A*). This occurred in the context of no significant change in mean go RT between MW (502 ± 21 ms) and On-Task episodes (514 ± 21 ms) ($t(10) = 0.9$, $p = 0.400$, $d = 0.3$, $BF_{10} = 0.4$; *Fig. 3B*). Thus, MW affected the executive function of stopping an incipient response without affecting general task performance.

Study 1: BEESTS

Next, we estimated trigger failures (TF) using the BEESTS model to test whether it increased during MW compared to On-Task episodes (see *Fig. S5* in the Supplemental Material for the correlation between estimated and behavioral measures). Since there were fewer MW than On-Task episodes, we wanted to ensure that any observed difference could be not attributed to just the different number of trials used to estimate the parameters. Thus, we trial-matched the On-Task episodes (called On-matched henceforth). For each participant, from all On-Task episodes, we randomly selected the same number of episodes as there were MW episodes, and estimated the BEESTS parameters. For each participant, we did this 10 times and averaged the estimates.

During mind-wandering, the reliability of triggering (TF) decreased and the mean stopping-latency (mean SSRT) increased, i.e. response inhibition became worse. A 1-way repeated measures ANOVA with episode (On-Task, MW, On-matched) as the independent variable and mean SSRT as the dependent variable revealed that there was a significant effect of episode ($F_{GG}(1.3, 12.9) = 21.4$, $p < 0.001$, $\eta_p^2 = 0.7$; *Fig. 4A*). Further, post-hoc multiple comparisons revealed that mean $SSRT_{MW}$ (351 ± 22 ms) was significantly greater than both $SSRT_{ON}$ (248 ± 20 ms; $t(10) = 6.4$, $p_{BH} < 0.001$, $d = 1.9$, $BF_{10} > 100$) and $SSRT_{On-matched}$ (279 ± 18 ms; $t(10) = 3.5$, $p_{BH} = 0.012$, $d = 1.0$, $BF_{10} = 9.0$). Similarly, a Friedman test with episode (On-Task, MW, On-matched) as the independent variable and TF as the dependent variable revealed a significant effect of episode ($\chi^2(2, 20) = 12.2$, $p = 0.002$; *Fig. 4B*). Further, post-hoc multiple comparisons revealed that TF_{MW} (22 ± 2 %) was significantly greater than both TF_{ON} (12 ± 2 %; $z(11) = 2.8$, $p_{BH} = 0.013$, $r = 0.9$) and $TF_{On-matched}$ (17 ± 2 %; $z(11) = 2.0$, $p_{BH} = 0.041$, $r = 0.6$). However, there was no significant effect of episode on the estimated mean go RT (On-Task = 508 ± 22 ms; MW = 492 ± 21 ms; On-matched = 508 ± 20 ms; $F(2, 20) = 1.8$, $p = 0.190$, $\eta_p^2 = 0.2$; *Fig. 4C*).

Fig. 4 | BEESTS estimates in study 1. **A.** Comparison of the mean SSRT among On-Task (dark blue), MW (green), and On-matched (light blue). Rest of the details same as Fig. 2B. **B.** Same as A but for TF. **C.** Same as A but for mean go RT. **D.** Same as A but for the SD of the SSRT distribution. **E.** Correlation between the change in SSRT between MW and On-matched episodes and the change in TF between MW and On-matched episodes. Rest of the details same as Fig. 2A. **F.** Correlation between the change in TF between MW and On-matched episodes and the change in the SD of the SSRT distribution between MW and On-matched episodes. Rest of the details same as Fig. 3E. $p > 0.1$: ns, $p \leq 0.05$ & $p > 0.01$: *, $p \leq 0.01$ & $p > 0.001$: **, $p \leq 0.001$: ***.

Besides the change in mean stopping-latency, increased variability of stopping-latency can also impact one's ability to effectively stop responses (Band et al., 2003; Matzke et al., 2018; Swick and Ashley, 2020; Weigard et al., 2019). Hence, we tested if MW increased the estimated standard deviation (SD) of the SSRT distribution. A Friedman test revealed that the factor episode had a marginally significant effect ($\chi^2(2,20) = 4.9$, $p = 0.086$; Fig. 4D), with the highest SD in MW episodes (MW = 247 ± 19 ms; On-Task = 182 ± 21 ms; On-matched = 225 ± 21 ms).

Now note that SSRT is the total time taken to stop the response which includes the trigger and brake stages, thus any changes in trigger should be reflect in SSRT. However, our measure of the trigger stage, TF, reflect the percentage of trials where the brake was not triggered and not the

duration of that stage. So, why should the change in TF relate to the change in SSRT? Perhaps triggering is graded (i.e. worse and longer in some trials) rather than absolute (Bissett et al., 2019) where TF reflect the weakly triggered trials (i.e. longer trigger process). This interpretation would mean that TF captures some aspect of the duration of the trigger stage, and that the change in TF would correlate with the change in SSRT. We reasoned that if MW affects only the trigger then a majority of the variance of the change in SSRT should be explained by the change in TF, while if MW affects both the trigger and brake then a minority of the variance of the change in SSRT should be explained by the change in TF. We tested these ideas in our data.

The change in TF between the MW and On-matched episodes was highly correlated to the change in SSRT ($r_s = 0.82, p = 0.004$; *Fig. 4E*). This correlation is unlikely to be simulation artifact as we also observed a positive correlation between TF and behavioral estimate of SSRT (*Fig. S6*). This is consistent with the interpretation that triggering is graded and that TF captures some aspect of the duration of the trigger stage. Similarly, there was a strong positive correlation between the change in TF and the change in SD of the SSRT distribution ($r_s = 0.75, p = 0.011$; *Fig. 4F*). Thus, across participants, the change in TF during mind-wandering could explain 67% and 56% of the variance of the change in the mean and variability of the SSRT distribution, respectively.

Taken together, we observed that, consistent with our predictions, TF and SSRT increased specifically during MW compared to On-Task episodes, i.e. response inhibition became worse. Further, the change in TF explained a large proportion of the variance of the change in the mean and variability of the SSRT distribution, suggesting that the detrimental effect of MW on response inhibition is largely due to the hit on the trigger stage. Given that MW is associated with increased attentional lapses (Mooneyham and Schooler, 2013; Smallwood and Schooler, 2015), this supports the attentional account of TF, i.e. TF reflect attentional failures where the stop signal is not utilized to select the appropriate action of initiating the brake.

We noticed that many participants reported no or few instances of MW. This is consistent with other studies where some subjects did not report MW episodes (Arnau et al., 2020; Compton et al., 2019). Perhaps these participants had episodes of MW when they were not probed or were low trait-MW individuals. Indeed, there was a moderate but significant correlation between the percentage of MW reports (i.e. state-level MW) and the trait MW assessed based on the MWQ filled at the end of the experiment ($r_s = 0.38, p = 0.037$; *Fig. S7A* in Supplemental Material), consistent with Mrazek et al. (2013). This suggests that participants reported their mental-state

accurately and that the probe reports could be trusted. Since using a cutoff of >5 episodes of MW to select participants provided results consistent with our predictions, we continued with the same criterion in our replication study.

Study 2 – Participant size determination

Based on the results of study 1: the behavioral difference between $SSRT_{MW}$ and $SSRT_{ON}$, and the difference between TF_{MW} and $TF_{On-matched}$, we calculated the sample size and preregistered our replication study (<https://osf.io/n24m9/>). As noted above, we anticipated that many participants would report no or few episodes of MW. Hence, we decided to run the study until there were $N = 40$ participants who had >5 episodes of MW [see Fig. S8 in Supplemental Material to see how effect sizes changed with number of participants].

Study 2 - Behavior

Similar to study 1, roughly 1/3rd of participants (40/145) reported >5 episodes of MW (Table 2). Behavioral performance was typical with SSRT of 311 ± 5 ms and successful stopping of 49 ± 0 %. Replicating study 1, $SSRT_{MW}$ (332 ± 10 ms) was significantly greater than $SSRT_{ON}$ (309 ± 9 ms) ($t(39) = 3.2$, $p = 0.003$, $d = 0.5$, $BF_{10} = 12.7$) (Fig. 5A). This time, mean go RT for MW episodes (531 ± 14 ms) was now longer than On-Task (522 ± 13 ms) ($W(40) = 247$, $z(40) = 2.2$, $p = 0.029$; $r = 0.3$; Fig. 5B) suggesting a decline in general task performance during MW.

Figure 5 | Behavioral responses in study 2. A. Comparison between SSRT during the On-Task (blue) and MW (green) episodes in study 2. Rest of the details same as Fig 2A. **B.** Same as A but for mean go RT. $p < 0.01$ & $p > 0.001$: **, $p < 0.001$: ***.

Study 2: BEESTS

Next, we estimated the BEESTS parameters. A Friedman test with episode (On-Task, MW, On-matched) as the independent variable and mean SSRT as the dependent variable showed that the effect of episode was marginally significant ($\chi^2(2,20) = 4.9$, $p = 0.089$; *Fig. 6A*). Further, post-hoc multiple comparisons revealed that mean $SSRT_{MW}$ (339 ± 15 ms) was significantly greater than both $SSRT_{ON}$ (293 ± 12 ms; $z(40) = 2.5$, $p_{BH} = 0.035$, $r = 0.4$) and $SSRT_{On-matched}$ (300 ± 12 ms; $z(40) = 2.3$, $p_{BH} = 0.043$, $r = 0.4$). Next, a Friedman test with episode (On-Task, MW, On-matched) as the independent variable and TF as the dependent variable revealed that there was a significant effect of episode ($\chi^2(2,20) = 18.7$, $p < 0.001$; *Fig. 6B*). Further, post-hoc multiple comparisons revealed that TF_{MW} (21 ± 1 %) was significantly greater than both TF_{ON} (15 ± 1 %; $z(40) = 2.9$, $p_{BH} = 0.001$, $r = 0.5$) and $TF_{On-matched}$ (17 ± 1 %; $z(40) = 3.6$, $p_{BH} = 0.008$, $r = 0.6$). Thus, the main results of the increase in TF and SSRT during MW, as seen in study 1, held up in the larger sample.

Figure 6 | BEESTS estimates in study 2. **A.** Comparison of the BEESTS estimate of the mean SSRT among On-Task (dark blue), MW (green), and On-matched (light blue). Rest of the details same as Fig. 4A. **B.** Same as A but for Trigger Failures. **C.** Same as A but for mean go RT. **D.** Same as A but for the SD of the SSRT distribution. **E.** Correlation between the change in %TF between MW and On-matched epochs and

the change in mean SSRT between MW and On-matched episodes. Rest of the details same as Fig. 4E. **F.** Correlation between the change in %TF between MW and On-matched episodes and the change in SD of the SSRT estimate between MW and On-matched episodes. Rest of the details same as Fig 5E. $p \leq 0.05$ & $p > 0.01$: *, $p \leq 0.01$ & $p > 0.001$: **, $p \leq 0.001$: ***.

Unlike study 1 where we observed no effect of MW on mean go RT, here we found that MW significantly slowed down responses. There was a significant effect of episode on the estimated mean go RT ($F(2,20) = 7.0$, $p = 0.002$, $\eta_p^2 = 0.2$; Fig. 6C). Mean go RT during MW episodes (525 ± 14 ms) was significantly greater than that in On-Task (513 ± 13 ms; $t(39) = 2.6$, $p_{BH} = 0.027$, $d = 0.4$, $BF_{10} = 3.6$) and On-matched (513 ± 13 ms; $t(39) = 2.8$, $p_{BH} = 0.027$, $d = 0.4$, $BF_{10} = 0.4$). Next, we tested if MW affected the variability of stopping-latency. There was a significant effect of episode on the SD of the SSRT distribution ($F(2,20) = 14.4$, $p < 0.001$, $\eta_p^2 = 0.3$; Fig. 6D) and the SD of SSRT distribution was significantly greater in the MW episodes (259 ± 11 ms) compared to both On-Task (177 ± 15 ms; $t(39) = 4.6$, $p_{BH} < 0.001$, $d = 0.7$, $BF_{10} > 100$) and On-matched (201 ± 13 ms; $t(39) = 3.8$, $p_{BH} < 0.001$, $d = 0.6$, $BF_{10} = 60.8$). Thus, during MW, TF and the mean and variability of stopping-latency increased.

As before, we correlated the change in TF between MW and On-matched episodes with the change in the mean and variability of the SSRT distribution between the two episodes. Again, we observed a high positive correlation with the change in mean SSRT ($r_s = 0.82$, $p < 0.001$; Fig. 6E). Further, the change in TF was also well correlated with the change in the SD of the SSRT distribution ($r_s = 0.72$, $p < 0.001$; Fig. 6F). Thus, the change in TF explained 67% and 52% of the variance of the change in the mean and variability of the SSRT distribution, replicating the results of study 1. Taken together, this suggests that during mind-wandering, stopping becomes slower and more variable, and this is largely because of the hit on the trigger stage.

Discussion

We conducted two studies where participants were intermittently probed to report their mental-state (focused on the task, On-Task; mind-wandering, MW; or unfocused, Off-focus) while they performed the Stop Signal Task. Based on the probe responses, we classified trials prior to the probe, as On-Task, MW, or Off-focus episodes. We then performed paired comparisons of

stopping performance between the episodes. Using this within-subject design, we observed that both Stop Signal Reaction Time (SSRT) and Trigger Failures (TF) increased during MW episodes, compared to On-Task. Further, this change in TF was well correlated with the change in both the mean and the variability of the SSRT distribution. These studies provide strong evidence that MW has a detrimental effect on response inhibition and suggests that this is largely due to (attentional) failures to trigger the inhibitory brake rather than a deficit in the brake itself.

Our key finding was that TF and SSRT increased during MW compared to On-Task, and that across participants this change in TF explained 67% and ~52% of the variance in the change in the mean and variability of SSRT, respectively. This suggests that poorer action-stopping during MW is primarily due to a failure to trigger the inhibitory brake, and not a failure of the brake *per se*. This result has several important implications. First, whereas, previous studies have provided mixed results on the effect of MW on response inhibition, this was probably due to methodological differences or because many of these studies were not set up to answer this specific question. Our study provides a clear demonstration that response inhibition *is* affected during MW and provides a mechanism by which this is mediated. Relatedly, some clinical populations like Attention-Deficit Hyperactive Disorder patients who have longer SSRT (Alderson et al., 2007) also have greater TF (Weigard et al., 2019). Interestingly, these patients also have increased MW (Seli et al., 2015), and based on our results, we hypothesize that poorer action-stopping in these patients might relate to their increased MW. Future studies could test this. Second, our result has theoretical importance in validating TF. Whereas some have argued that TF may not point to separate trigger and brake stages (Bissett et al., 2019), here we show that TF change with the mental state (On-Task vs. MW) and that they partly explain the change in SSRT, which together suggests that TF really pick out a distinct stage (also see Supplementary Material *Fig. S2* where age affects SSRT but not TF-dissociating the two stages). Other neurophysiological evidence also supports the veracity of TF. For example, the frontocentral auditory N1 potential (which is sensitive to attentional manipulations (Näätänen and Picton, 1987; Woods, 1995)) is smaller in those with higher trigger failures (Skippen et al., 2020). Third, our demonstration that state-level-MW related to trait-level-MW suggests a strategy for reducing variability of action-stopping studies. One could simply acquire trait-level-MW at the end of the study and use it as a covariate.

These results were acquired in a controlled experimental set-up where we could test how a self-reported episode of MW affected the requirement for executive control. This potentially has

useful implications for modeling real-world situations such as how episodes of MW affect rapid requirement for executive control during driving or handling machinery. In the future, it might be possible to measure MW in real time and use to guide better behavior.

Note

After preregistering the results of study 1, we later realized that we had erroneously calculated SSRT and had used a parametric test on the difference between TF which we then rectified. However, consistent with our preregistered report, we enlisted N = 40 participants who had >5 episodes in study 2, and used all the selection criteria as outlined in our preregistered report. Furthermore, we performed additional analyses to confirm effect sizes (see *Fig. S8* in Supplemental Material).

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Supplementary Materials

Supplementary Methods

Detailed study design

The task was designed using JavaScript, HTML, CSS, and PHP. The data and scripts were housed on the web server of the Department of Psychology, UCSD. The study had 6 sections and took ~1 hour to complete:

- 1) Sound test: Participants were asked to set the volume at 40% of their max system volume and maintain it throughout the study. Then they were presented with a sequence of 3-9 tones which they counted and reported. This ensured that the volume was set at an appropriate level.
- 2) Go practice: Participants then performed 20 Go trials. Each trial began with a black fixation square for 500 ± 50 ms. After this, black left and right arrows were presented and they had to press the left and right arrow keys with their right hand, as quickly and accurately as they could, within a 1 s response deadline. To satisfy the criteria of this section, they had to achieve, *a*) a mean go reaction time (RT) of 300-600 ms, and, *b*) a go accuracy > 90%. They got 3 attempts for this. After that they were prompted to either exit the study and receive partial payment for their time, or keep trying to satisfy the criteria.
- 3) Stop practice: Participants then performed 40 trials of the auditory stop signal task (*Fig. 1A*). Each trial began with a fixation for 500 ± 50 ms, followed by a left or right arrow, and they had to respond quickly with the corresponding left/right key press. In 25% trials, after a delay, called Stop Signal Delay (SSD), a tone was presented and, in these trials, they had to try to stop their response. The SSDs were tracked such that it reduced by 50 ms after a failed stop response, and increased by 50 ms after a successful stop response, so as to achieve successful stopping in roughly 50% of trials. The duration of each trial including the inter trial interval was 2.5 s. To satisfy the criteria of this section, they had to achieve, *a*) a mean go RT of 300-600 ms, *b*) a go accuracy > 90%, and *c*) a successful stop % of 25-75%. They got 3 attempts for this. After that they were prompted to either exit the study and receive partial payment for their time, or keep trying to satisfy the criteria.
- 4) Stop practice with mental-state probe: Same as the Stop practice except that after every 16-22 trials (40-55 s), participants received a mental-state probe: “In the previous trial, was your

mind: 1. Focused on the task, 2. Wandering or thinking of something else, 3. Blank or unfocused”, where they responded by pressing the 1, 2, or 3 keys with their left hand (*Fig. 1B*). These corresponded to On-Task, MW, and Off-focus mental-states, respectively. They performed 45 trials, which included 2 such probes. To satisfy the criteria of this section, they had to achieve, *a*) a mean go RT of 300-600 ms, *b*) a go accuracy > 90%, and *c*) a successful stop of 25-75%.

- 5) Experiment: Same as Stop practice with mental-state probe, except that there were 640 trials in 8 blocks (32 mental-state probes; 160 stop trials). Participants were given the option of taking breaks in between blocks.
- 6) Questionnaire: Participants completed the Mind-wandering questionnaire (Mrazek et al., 2013) and the Barrett Impulsivity Scale (BIS-11) (Stanford et al., 2009).

In study 1, 47 participants started the study, 15 stopped the study midway, 32 completed it, and 30 were selected for the analyses but only 11 met the number-of-MW-episodes criterion. In study 2, 356 participants started the study, 149 stopped the study midway, 207 completed the study, and 145 were selected for the analyses but only 40 met the-number-of-MW-episodes criterion.

Estimation of trigger failures

Trigger failures was estimated using the Bayesian Estimation of Ex-Gaussian STop-Signal (BEESTS) model developed by Matzke and colleagues (Matzke et al., 2017). This model assumes a race between two stochastically independent processes- a go- and a stop-process. It estimates the SSRT distribution by using the go RT distribution, and by considering the failed stop RT as a censored go RT distribution. On each stop trial, the censoring points are sampled randomly from the SSRT distribution. The RT distribution underlying the go- and stop-process is assumed to be ex-Gaussian with a gaussian and an exponential component and is characterized by 3 parameters (μ_{Go} , σ_{Go} , τ_{Go} and μ_{Stop} , σ_{Stop} , τ_{Stop}). For such distributions, the mean and variance of the RT distribution are determined as $\mu + \tau$ and $\mu^2 + \tau^2$, respectively. The model also determines the probability of trigger failures for each participant. The model uses Bayesian Parametric Estimation (BPE) to estimate the parameters of the distributions. We used a hierarchical BPE, where individual subject parameters are modeled with the group-level distributions. This approach is thought to be more accurate than fitting the data of individual participants and is effective when there is less data per participant (Matzke et al., 2013). The priors were bounded uniform

distributions ($\mu_{Go}, \mu_{Stop}: U(0,2)$; $\sigma_{Go}, \sigma_{Stop}: U(0,0.5)$ $\tau_{Go}, \tau_{Stop}: U(0,0.5)$; pTF: $U(0,1)$). The posterior distributions were estimated using the Metropolis-within-Gibbs sampling and we ran multiple chains. We ran the model for 5000 samples with a thinning of 5. The Gelman-Rubin ($\hat{R}$) statistic was used to estimate the convergence of the chain. Chains were considered converged if $\hat{R} < 1.1$. For further details about the model please refer to Heathcote et al. (2019).

Supplementary Results

Study 2: Off-focus episodes

There were 11 participants who reported >5 instances of Off-focus. In these participants, SSRT_{OFF} (345±17 ms) was significantly less than SSRT_{ON} (315±12 ms; $t(10) = 2.6$, $p = 0.038$, $d = 0.8$, $BF_{10} = 2.7$, *Fig. S1A*). This was observed in the context of no significant difference in mean go RT between Off-focus (488±11 ms) and On-Task episodes (495±15 ms; $t(10) = 0.8$, $p = 0.417$, $d = 0.3$, $BF_{10} = 0.4$; *Fig. S1B*).

The BEESTS estimate of mean SSRT was marginally greater during Off-focus episodes (383±34 ms) than On-Task (313±20 ms; $z(11) = 1.8$, $p = 0.075$, $r = 0.5$; *Fig. S1C*). Further, the SD of the SSRT distribution was greater during Off-focus episodes (285±23 ms) compared to On-Task (208±30 ms; $t(10) = 2.5$, $p = 0.032$, $d = 0.8$, $BF_{10} = 2.4$). Thus, stopping became slower and more variable in Off-focus episodes compared to On-Task. Further, there were greater TF in the Off-focus episodes (25±3 %) compared to On-Task (17±2 %; $z(11) = 2.1$, $p = 0.033$, $r = 0.6$; *Fig. S1D*). The change in TF between Off-focus and On-Task episodes was well correlated with the change in mean SSRT ($r_s = 0.84$, $p = 0.003$). Also, there was also a moderate but non-significant correlation between the change in TF and the change in the SD of the SSRT distribution ($r_s = 0.53$, $p = 0.101$). Thus, taken together, these results demonstrate that stopping becomes slower and more variable during Off-focus state and that this is mostly driven by the detrimental effect of Off-focus state on the trigger stage.

Since the impact on MW and Off-focus states (compared to On-Task) on stopping performance was largely similar, we contrasted the behavior between MW and Off-Focus episodes. Unfortunately, there were few participants who had both >5 episodes of MW and >5 episodes of Off-focus so we could not perform a paired comparison. Instead, we compared the performance in the MW episodes in the MW-participants to that in the Off-focus episodes in the Off-focus-participants (i.e. unpaired comparison). There was no significant difference for each of the following comparisons: 1) SSRT (MW: 332±10 ms; Off-focus: 345±17 ms; $t(49) = 0.6$, $p = 0.537$, $d = 0.2$, $BF_{10} = 0.4$; *Fig. S1E*); 2) mean go RT (MW: 531±14 ms; Off-focus: 495±15 ms; $t(49) = 1.3$, $p = 0.197$, $d = 0.4$, $BF_{10} = 0.6$; *Fig. S1F*); 3) the BEESTS estimate of mean SSRT (Off-focus: 383±34 ms; MW: 339±15 ms; $z = 1.1$, $p = 0.277$, $r = 0.2$; *Fig. S1G*); 4) TF% (Off-focus: 25±3 %; MW: 21±1 %; $z = 1.2$, $p = 0.221$, $r = 0.2$; *Fig. S1H*). Thus, behaviorally there did not

seem to be a difference between the MW and Off-focus episodes, albeit the metrics of action-stopping tended to be worse in the Off-focus episodes and the percentage of Off-focus reports were far fewer than MW reports.

Figure S1 | Behavior and BEESTS estimates in the Off-focus episodes. *A.* Comparison of behavioral estimate of SSRT during the On-Task (blue) and Off-focus (orange) episodes in Off-focus-participants. Other details same as Fig 4B. *B.* Same as A but for mean go RT. *C.* Same as A but for the mean SSRT estimated from BEESTS. *D.* Same as A but for the % trigger failures estimated from BEESTS. *E.* Beeswarm plot of the behavioral estimate of SSRT between the MW-participants in the MW episodes (green) and the Off-focus-participants in the Off-focus episodes (orange). Each dot represents a participant, overlaid by the box-plot. The notch represents the 95% confidence interval of the median, and the dotted line represents the mean. *F.* Same as E but for mean go RT. *G.* Same as E but for the mean SSRT estimated from BEESTS. *H.* Same as E but for % trigger failures estimated from BEESTS. $p > 0.1$: ns, $p \leq 0.1$ & $p > 0.05$: #, $p \leq 0.05$ & $p > 0.01$: *, $p \leq 0.01$: *.

Pooled studies 1 and 2: Correlation with age

We performed an exploratory analysis of the effect of age on SSRT, mean go RT, and TF (across all trials). Previous studies have reported that SSRT increases with age (Hsieh and Lin, 2017; Williams et al., 1999). Similarly, we observed a weak positive correlation between age and SSRT (age vs. SSRT_{Beh}: $r_s = 0.18$, $p = 0.015$; *Fig. S2A*; age vs SSRT_{BEESTS}: $r_s = 0.16$, $p = 0.033$) and a weak positive correlation between age and mean go RT ($r_s = 0.19$, $p = 0.011$; *Fig. S1B*), similar to previous reports (Hsieh and Lin, 2017; Sebastian et al., 2013; Williams et al., 1999). As mentioned in the main text, SSRT includes the contribution of both the trigger and brake stages. So, if this increase in SSRT is due to worse triggering then one would also expect a positive relationship between age and TF. However, there was no significant correlation between age and TF ($r_s = -0.07$, $p = 0.355$; *Fig. S2C*). If at all, there seemed to be a negative relationship. While this lack of significant correlation between age and TF might be due to under-sampling of older adults, the negative relationship is consistent with two other pieces of evidence in existing literature. First, MW decreases with age (Jackson and Balota, 2012; Maillet and Schacter, 2016). Thus, it is possible that this decreased MW leads to lesser TF. Second, older adults are more distracted by external events (Healey et al., 2008; Verhaeghen and Cerella, 2002), which in the Stop Signal Task would mean that the salient stop signal would more readily capture attention and trigger the brake, again resulting in lesser TF.

To test whether the factors age and mental-state could affect response inhibition in dissociable ways, we compared the correlation between age and SSRT and that between age and TF using the web utility provided by Lee and Preacher (2013). Briefly, first, this converts each correlation coefficient to a z -score using Fisher's r - to $-z$ transformation, then, uses Steiger's equations (1980) to compute the difference between the two correlations. The two correlations were significantly different from each other (z -score = 3.2, $p = 0.001$). This suggests that mental-states and age might affect response inhibition in dissociable ways: mental-states primarily affect the trigger stage while age might primarily affect the brake stage. This could be investigated by future studies.

Figure S2 | Relationship between age and behavior and TF. A. Correlation between behavioral SSRT and age across study 1 (red) and 2 (yellow). Each dot represents a subject. The line and the shaded region represent the linear fit and 95% prediction intervals, respectively. **B.** Same as A but for the correlation between behavioral mean go RT and age. **C.** Same as A but for the correlation between TF and age. $p > 0.1$: ns, $p \leq 0.05$ & $p > 0.01$: *.

Pooled studies 1 and 2: BIS ratings

At the end of the study participants also filled out the Barrett Impulsivity Scale (BIS) (Stanford et al., 2009). Using the BIS ratings, we aimed to replicate previous results that have shown a correlation between TF and BIS ratings (Skippen et al., 2019). The BIS rating (Study 1: 56 ± 2 ; Study 2: 58 ± 1 ; Pooled: 58 ± 1) reported was similar to that study. However, contrary to that study, we did not observe any significant relationship between BIS ratings and the behavioral and BEESTS results (*Table S1*).

Table S1: Correlation between BIS and behavioral and BEESTS estimates

Parameter	SSRT _{Beh}	SSRT _{BEESTS}	%TF
Attentional BIS	$r_p = -0.05, p = 0.476$	$r_p = -0.06, p = 0.465$	$r_p = -0.04, p = 0.637$
Motor BIS	$r_p = 0.12, p = 0.120$	$r_p = 0.12, p = 0.134$	$r_p = 0.12, p = 0.132$
Non-planning BIS	$r_p = 0.02, p = 0.868$	$r_p = 0.04, p = 0.598$	$r_p = 0.24, p = 0.768$
Total BIS	$r_p = 0.03, p = 0.696$	$r_p = 0.04, p = 0.599$	$r_p = 0.04, p = 0.596$

Supplementary Tables

Table S2: Behavioral responses for the MW-participants in the MW and On-Task episodes in study 1 and 2 (Values represent mean $\pm$ s.e.m.)

Parameters	Study 1		Study 2	
Group	On-Task	MW	On-Task	MW
Mean Correct Go RT	514 $\pm$ 21 ms	502 $\pm$ 21 ms	522 $\pm$ 13 ms	531 $\pm$ 14 ms
Mean Failed Stop RT	475 $\pm$ 18 ms	464 $\pm$ 20 ms	474 $\pm$ 11 ms	488 $\pm$ 11 ms
Correct Go	99 $\pm$ 0 %	98 $\pm$ 0 %	99 $\pm$ 0 %	98 $\pm$ 0 %
Error Go	1 $\pm$ 0 %	1 $\pm$ 0 %	1 $\pm$ 0 %	2 $\pm$ 0 %
Successful Stop	57 $\pm$ 3 %	38 $\pm$ 3 %	50 $\pm$ 2 %	45 $\pm$ 2 %
SSRT	290 $\pm$ 18 ms	335 $\pm$ 19 ms	306 $\pm$ 9 ms	332 $\pm$ 10 ms
Mean SSD	194 $\pm$ 17 ms	183 $\pm$ 18 ms	202 $\pm$ 14 ms	199 $\pm$ 14 ms

Supplementary Figures

Fig. S3 | Behavior when 10 s (4 trials) prior to the probe report is used instead of 15 s (6 trials).

A. Behavioral estimate of SSRT in the MW participants in the On-Task (blue) and MW (green) episodes in Study 1 and 2. Each dot represents a participant and the bar and crosshairs represent the mean $\pm$ s.e.m. across the population. [Study 1: $SSRT_{ON} = 293 \pm 16$ ms, $SSRT_{MW} = 340 \pm 23$ ms; $t(10) = 3.0$, $p = 0.013$, $d = 0.7$, $BF_{10} = 5.0$; Study 2: $SSRT_{ON} = 303 \pm 17$ ms, $SSRT_{MW} = 329 \pm 20$ ms; $t(39) = 3.4$, $p = 0.001$, $d = 0.4$, $BF_{10} = 22.6$]. **B.** Same as A but for mean correct Go RT [Study 1: $Go RT_{ON} = 516 \pm 21$ ms, $Go RT_{MW} = 505 \pm 20$ ms; $t(10) = 0.9$, $p = 0.404$, $d = 0.2$, $BF_{10} = 0.4$; Study 2: $Go RT_{ON} = 524 \pm 13$ ms, $Go RT_{MW} = 534 \pm 14$ ms; $z(40) = 2.6$, $p = 0.008$, $r = 0.4$]. Thus, the effect remained irrespective of the episode duration used. $p > 0.1$: ns, $p \leq 0.05$ & $p > 0.01$: *, $p \leq 0.01$ & $p > 0.001$: **.

Fig. S4 | Difference between behavioral SSRT_{MW} and SSRT_{ON} for different number of MW episodes. **A.** (Left) Mean difference between behavioral SSRT between the MW episodes and On-Task episodes for different (minimum number of MW episodes) cutoffs, pooled across both studies. The dot and cross-hairs represent the mean $\pm$ s.e.m. of the difference. (Right) Number of participants (purple triangle) selected when that MW episode cutoff is used. **B.** (Left) Same as A but for the t-statistic of the difference between SSRT_{MW} and SSRT_{ON}. The p-value was significant for all the values. (Right) Same as A but for Cohen's d. Thus, the effect remained irrespective of the cutoff used.

Fig. S5 | Correlation between the behavioral and BEESTS estimate of mean SSRT and mean go RT. **A.** Correlation between SSRT estimate from the entire experiment across all participants (Study 1 – red, Study 2 - yellow). Each dot represents a subject while the line and shaded region represents the linear regression fit and the 95% prediction interval, respectively. **B.** Same as A but for the mean SSRT in the On-Task episodes estimated from the behavior and BEESTS in the MW-participants. **C.** Same as A but for mean SSRT in the MW episodes estimated from the behavior and BEESTS in the MW-participants. **D.** Same as A but for mean correct Go RT from the entire experiment across all participants (Study 1 – dark green, Study 2 – light green). **E.** Same as B but for mean correct Go RT in the MW episodes. **F.** Same as C but for mean correct Go RT in the On-Task episodes. Thus, the BEESTS estimates were well correlated with that observed from behavior. $p \leq 0.001$: ***.

Fig. S6 | Correlation between the change in %TF and change in SSRT estimated from behavior.
A. Each dot represents a participant (Study 1 – red, Study 2 – yellow). The line and shaded region represent the linear regression and its 95% prediction interval. There is a significant positive correlation between the change in %TF (MW – On-matched) and the change in SSRT_{Beh} (MW – On-Task), replicated that seen in the BEESTS results. $p \leq 0.001$: ***.

Fig. S7 | Correlation between trait and state mind-wandering. **A.** Across-participants correlation between trait MW based on the MW questionnaire and % MW reports during the entire experiment in Study 1 ($r_s = 0.38$, $p = 0.037$). Each dot represents a subject. The line represents a linear fit and the shaded region represents the 95% prediction interval. **B.** Same as A but for Study 2 ($r_s = 0.42$, $p < 0.001$). $p \leq 0.05$ & $p > 0.01$: *, $p \leq 0.001$: ***.

Fig. S8 | Reliability of the main results. **A.** (Left) Effect size of the difference between the behavioral estimate of SSRT in the MW and On-Task episodes (green line and circles) as a function of participant number in study 1. Filled circles represent significant difference in SSRT. The black triangle at the bottom represents the subject from which the p-values become consistently significant. (Right) The t-statistic of the difference (purple dotted line and triangles). Filled triangles represent significant difference in SSRT. **B.** Same as A but for the difference between %TF between the MW and On-matched episodes. Other details same as A. **C.** Same as A but for study 2. **D.** Same as B but for study 2. Note that the p-value becomes significant for N = 6 and 7 but becomes non-significant again and then becomes consistently significant from N = 14 onwards.

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