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Compliant activity rather than difficulty accelerates thought probe responsiveness and inhibits deliberate mind wandering

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ABSTRACT

Mind wandering is a commonly intruding cognitive state that leads to diminished performance and increased error risk during a primary task. A controversy over whether easier or more difficult tasks increase mind wandering has led to mind wandering being proposed as two different states: deliberate and spontaneous. We hypothesise that forced engagement via persistent compliant activity may both increase responsiveness and inhibit non-instrumental activities including deliberate mind wandering. Twenty-eight healthy adults interacted with 2 pairs of stimuli, each pair having one low-interactivity version and a high-interactivity version requiring compliant activity. Mind wandering was assessed by thought probes, and subjective responses were rated using visual analogue scales. Reaction times were measured using Superlab. Compliant activity decreased the prevalence of deliberate mind wandering episodes but not of overall mind wandering. Thought probe durations were accelerated significantly by compliant activity, near-significantly by thinking on-task thoughts, and additively by the combination of both. Deliberate and spontaneous mind wandering elicited equivalent thought probe durations. We conclude that compliant activity works synergistically with lack of mind wandering to accelerate the difficult task of thought probe response but not simple reaction times. These results fit with an arousal model but not the attentional resources model.

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Mind wandering; NIMI; engagement; difficult; TOVA

1. Introduction

It is essential in cognitive ergonomics that we understand the basis of mind wandering (MW), which is a descriptor for several related cognitive states (Seli et al. 2016b) resembling daydreaming that result in diminished ability and higher error rates for many work tasks (Yanko and Spalek 2014). According to the attentional resources model (Wickens et al. 2003), if MW is a separate activity, then permitting attentional resources to be co-opted by MW would diminish the performance of tasks (Smallwood and Schooler 2006; Seli et al. 2018a). In many cases, mind wandering has been shown to be increased by easier tasks (Yanko and Spalek 2013; Seli et al. 2016b), which may produce the paradoxical effect that when humans are working as fail-safe monitors of semi-automated systems (e.g. self-driving cars), increasing automation will increase the risk of human inattention and catastrophic safety failures (Berboucha 2018; Griggs and Wakabayashi 2018). Don Norman and colleagues have suggested that this effect may be addressed by automobile designers by adding extra tasks for the driver to perform, even when a computer could easily do those tasks (Casner, Hutchins, and Norman 2016). The rationale is that the driver's additional tasks would inhibit non-instrumental activities and thoughts (Witchel et al. 2016b, 2014a).

The causes of mind wandering remain a hot topic of research that may relate to its substrates in the brain, including the default mode network and the executive network (Christoff et al. 2009). The default mode network is normally associated with resting wakefulness (as well as autobiographical thought) and includes the medial prefrontal cortex, the posterior cingulate, and the temporo-parietal junction. The executive network resides in the frontal cortex and is responsible for attention, inhibition, decision-making, judgement and planning. These two networks had been thought to act in opposition, but in mind wandering they are both active. Although many researchers search for the causes of mind wandering, MW may be the default state of the healthy waking brain (Killingsworth and Gilbert 2010), while

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attention and persistent, task-related thought may be the exceptional states.

Research in the last two years suggests that mind wandering states can be differentiated based on whether they are spontaneous (i.e. unintentional) or deliberate (i.e. intentional) (Seli et al. 2016b). To define mind wandering, a model of different MW states that are related by family resemblances has proposed four relevant properties that are potentially shared by this family of cognitive states (Seli et al. 2018a). Thus an episode of mind wandering would have thoughts with one or more of these properties:

- unrelated to the primary task currently being performed,
- unguided,
- not tied to an external stimulus, and
- unintentional.

The different varieties of mind wandering would be classified according to which combination of the above properties are true. For example, a safe type of MW can occur when there is no primary task, such as when sitting on a park bench and deliberately daydreaming, while a dangerous type of MW might occur when bored and performing a task operating heavy machinery.

The relationship between task difficulty and mind wandering has become controversial, because some experiments have deviated from most previous data by showing that mind wandering is increased in a more difficult task, compared to an easier one (Xu and Metcalfe 2016; Seli et al. 2018b). Our hypothesis is that compliant activity, rather than difficulty, could be the inhibitor of intentional mind wandering, although not unintentional mind wandering. To test this in this study, we used two sets of highly comparable tasks: a staring task ± reaction to interference, and a Go/No-go task (based on the Test of Variables of Attention, ToVA; Leark et al. 2008) with two different levels of target frequency. Two of those tasks (the higher frequency ToVA and the staring task + the reaction to interference) require the participant to make increased compliant activity. Compliant activity is defined here as continued behavioural engagement with a task as requested and within the designed time frame. The compliant activity tasks were not necessarily more difficult, but they elicited more frequent interaction. To test the effects of compliant activity on cognitions, we used forced-choice thought probes, in which participants are stopped throughout a task and asked to indicate where their attention is focused (Weinstein 2018). We also used post-task VAS assessment to gather subjective ratings of intentional vs. spontaneous mind wandering.

2. Methods

2.1. Participants

Twenty-eight healthy subjects (19 females, and 9 males) took part in this experiment. The age range was between 19 and 35 with a mean of 22.7 (SD = 4.6). Participants were students or staff recruited from the University of Sussex via the SONA system, who each received $15 for their time and travel costs. Ethical approval was provided by the Brighton and Sussex Medical School Research Governance and Ethics Committee (RGEC) and written informed consent was obtained from all subjects prior to initiation of the experiment.

2.2. Stimuli

Four stimuli were presented to participants in a counterbalanced (Latin Square) order: two were based on the Visual Test of Variables of Attention, and two were based on a 3-min gaze fixation task (i.e. staring) with Cross-hairs on the monitor. Stimuli were presented using a Toshiba laptop running Windows 7, with the display in the duplicate mode: a desktop video monitor was connected to the laptop's VGA port, such that the laptop (and its controls) were facing away from the participant. Interaction with the Cross-hairs Staring stimuli was mediated by a handheld trackball (which participants often held in their lap), while interaction with the ToVA stimuli was performed with an RB530 response pad (Cedrus, San Pedro, U.S.A.), which was held in the lap of the participant (see Figure 1).

During the ToVA stimulus participants were instructed to click when a target square (little black square in the upper half of large white square) is present, and refrain from clicking when a non-target square (little black square in the lower half of large white square)

Figure 1. Experimental set-up showing the ToVA target and the RB530.

appears on the screen (Figure 2). The frequent-target (75% target) and infrequent-target (25% target) versions of ToVA were presented as two separate stimuli in our investigation, each lasting approximately 5.4 min. The sequence of targets vs. non-targets were presented in randomly ordered blocks of eight presentations (approximately every 3 s), and approximately once per minute a thought probe (Figure 2(c)) was presented.

The Cross-hairs Staring task was presented with the following instructions:

> In a moment you will be asked to perform a control task: you will look directly at the centre of some cross hairs in the middle of the screen for three minutes. Please do your best to look directly at the cross hairs. You should be comfortable while doing this, and you can blink when you need to.

The active version of the Cross-hairs task included an interference screen (the entire screen turned grey, see Figure 2(d)) that prevented the participant from seeing the cross-hairs, as well as prompting the participant to click with the handheld trackball. After clicking, the grey screen disappeared and the participant stared at the cross-hairs again. The instructions for the task were:

> In a moment you will be asked to perform an interference test. We are testing how well people can focus on the cross hairs, but every few seconds the screen will become grey so the cross hairs are obscured, and then you must click anywhere on the screen. After you click, the grey screen will disappear. Please do NOT click when the screen is not grey – only click once each time the screen becomes grey.
>
> Between each grey screen you should look directly at the centre of the cross hairs in the middle of the screen. You should be comfortable while doing this, and you can blink when you need to.

The interference screens appeared at standardised times with pseudo-random intervals of approximately 2 s.

2.3. Subjective measurements

At the end of each stimulus, participants were asked to assess their cognitive state during the stimulus by rating a set of mental state descriptors using a 10 cm visual analogue scales (VAS). The primary variables being investigated were the response times and cognitive responses. The occurrence of spontaneous and deliberate mind wandering during the two stimuli were subjectively determined by two methods: thought probes and visual analogue scales.

2.3.1. Thought probes

During the course of the 5-min ToVA stimuli, at five different points during each task, participants were interrupted on the screen by a forced-choice thought probe asking:

> In the moment that just passed, were you focused on the task, mind wandering deliberately, or mind wandering spontaneously (without meaning to)?

The RB530 interactive device had three keys clearly labelled with 'DELIBERATE Mind Wandering', 'SPONTANEOUS Mind Wandering', and 'ON TASK' (2(c)); furthermore, during the instructions phase, participants practised answering this question. To clarify the meaning of deliberate and spontaneous mind wandering, during the instructions phase, participants were told the following:

> Occasionally you will be asked if you are 'mind wandering'. This is asking whether you were not fully paying attention to the task and had other thoughts going through your mind. There are two kinds of mind wandering. Spontaneous mind wandering is when your thoughts drifted without meaning to, as if you lost control of what you were trying to do. Deliberate mind wandering is when your thoughts have drifted with your 'permission', as if you knew that the main task or experience did not require your full attention and thus you allowed your mind to drift.

Their choice selected, along with the response time needed to answer these questions, were recorded on the Superlab software.

2.3.2. Visual analogue scales

At the end of each stimulus, participants completed a subjective questionnaire that took between 1 and 3 min to complete. The questionnaires consisted of one open-ended question, and a series of a visual analogue scales (VAS) in a counterbalanced order. The free text question (which was always presented first), was: 'While you were watching/experiencing the previous stimulus, what did you feel?'. Each VAS was a 10 cm line ranging from 0 (not at all) to 100 (extremely). The VAS questions included rating the statements, 'my mind was wandering deliberately', 'my mind was wandering spontaneously', 'I felt lethargy', 'I felt it was challenging for me', 'I felt restlessness', 'I felt boredom', 'I was engaged by the experience', and 'I felt happy/content'. Reaction time measurements for ToVA were made using Superlab 4.5 and an RB530 response pad. Reaction time measurements for the Cross-hairs tasks were made using Inputlog 5.0 (Leijten and Van Waes 2013).

2.4. Experimental protocol

All participants were briefed on the nature of the study and completed background questionnaires including a

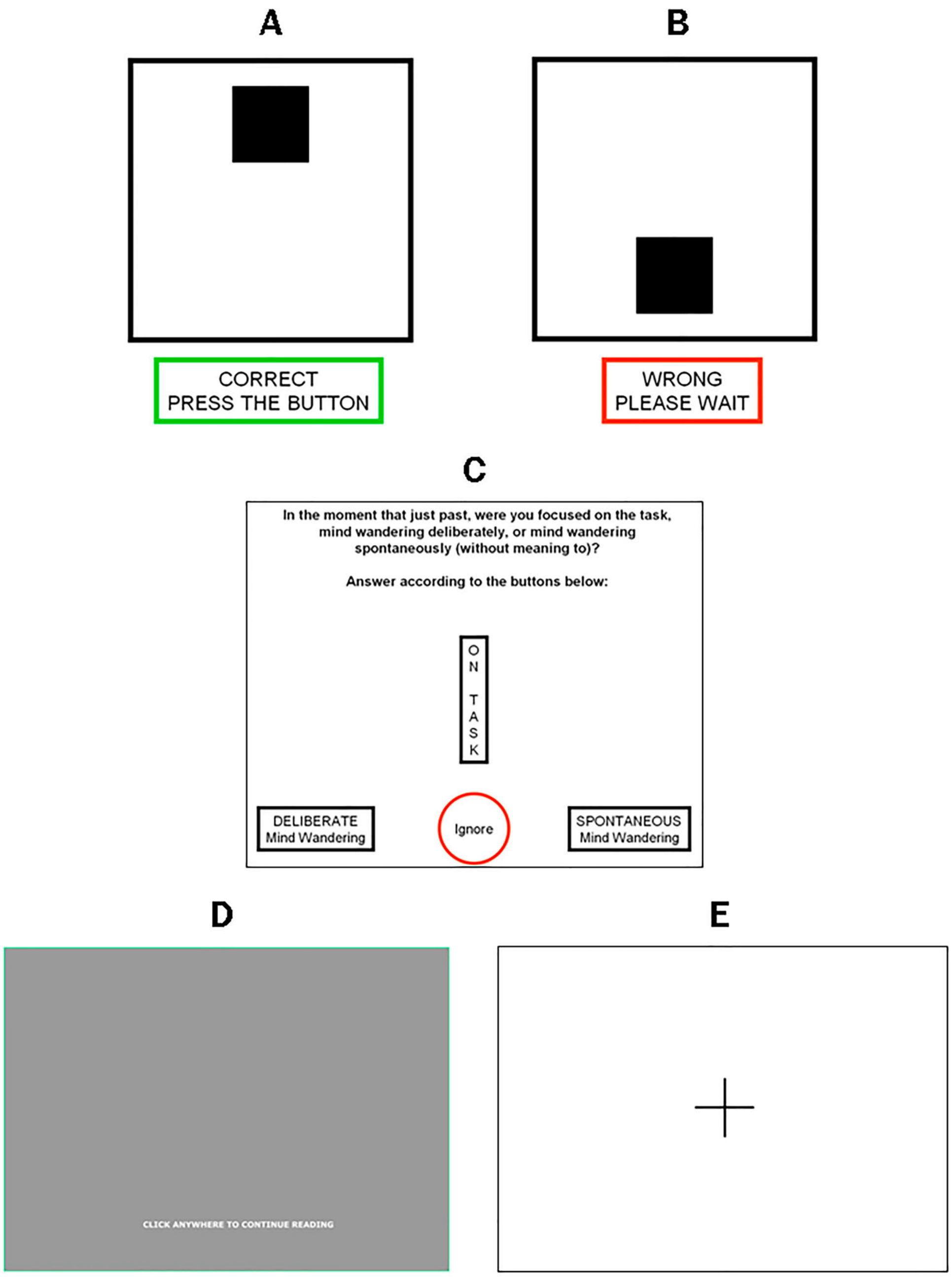

Figure 2. Stimuli as shown on monitor. Panels A (target), B (non-target) and C (thought probe) show the ToVA task. Note that the instructions (from the instruction task) are shown below the squares here, but do not appear in the actual ToVA task. Panels D (grey interference screen) and E (Cross-hairs) show the Cross-hairs Staring task.

demographics form. Each subject was seated on an armless, cushioned, 4-leg reception chair in front of a desk facing a 47.5×20 cm monitor, placed at the eye level of the volunteer, and adjustment of the seat position was allowed for optimal comfort. The mean eye to screen distance was 67.8 ± 12.3 cm.

Before the start of each stimulus all investigators left the room. The stimuli being investigated were presented in a counterbalanced order, and before starting the experiment, volunteers were given a brief practice run with ToVA to become accustomed to the stimuli and equipment. At the end of the experiment, volunteers were de-briefed and paid, with each experiment lasting approximately 60 min.

2.5. Analysis and statistics

Output files from Superlab were in the form of csv files, which were initially inspected in Microsoft Excel. All subjective data had non-Normal distributions and were analysed using non-parametric statistical tests (e.g. the Wilcoxon sign-rank test) in Matlab. Subjective data correlations (Spearman) were performed in Matlab (*corr*). For effect sizes of compared groups that are non-parametric, we used Cliff's delta, and we have maintained the convention of calling a small effect 0.11, a medium effect 0.28, and a large effect 0.43 (Vargha and Delaney 2000). Comparisons of the reaction times and the thought probes were performed using linear mixed-effects (LME) models in Matlab (*fitlme*).

3. Results

3.1. Subjective VAS ratings

In order to verify that the addition of the persistent compliant activity added to the perceived difficulty of the task, we determined the mean VAS rating for 'I felt it was challenging' for the Cross-hairs Staring task ± activity (Figure 3(a)). Counter-intuitively, when only staring at the cross-hairs without activity, the mean challenging rating was significantly higher than when that task was combined with compliant activity (P=0.003, Wilcoxon Signed Rank, signed rank value = 88.5, Cliff's delta = 0.411). This is likely to be due to the fact that the staring task is challenging due to eye activity, and in the open text description of the task 15% of the participants mentioned their eyes (which was not true for the staring task with activity). It is worth noting that other investigators who used easy and difficult tasks did not report explicitly asking their participants to rate the challenge or difficulty of the tasks (Konishi et al. 2017; Seli et al. 2018b). The ToVA tasks (high target frequency vs. low target frequency) were also rated for challenge, and the mean rating for these tasks were nearly equivalent (Figure 3(b)). These unexpected results reinforce the idea that when tasks are made objectively more physically effortful, they may not feel more challenging to the participant, and clearer standards for how researchers determine task difficulty are needed (Campbell 1988; Seli et al. 2018b).

To determine whether the addition of compliant activity altered either the amount of mind wandering, or the relationship between spontaneous and deliberate mind wandering, at the end of each stimulus the participants used the VAS to rate both spontaneous and deliberate mind wandering (Figure 4). Unlike thought probes, these VAS measurements do not involve a forced binary choice between two poles. Participants rated all stimuli as eliciting high levels of both types of mind wandering. When comparing spontaneous mind wandering to deliberate mind wandering, the only stimulus with a significant difference was Cross-hairs + Activity (P<0.01, signed rank statistic = 232, Wilcoxon signed rank, delta = 0.374). When comparing between stimuli, the target-infrequent version of ToVA was rated highly significantly higher in deliberate MW than the target-frequent version (P<0.01, signed rank = 232, Wilcoxon Signed rank test, delta = 0.364) as might be expected if deliberate MW resulted from diminished attentional demands. A similar but non-significant result was observed between the two Cross-hairs tasks (no activity was rated higher for deliberate MW, P<0.1, Wilcoxon signed rank, delta = 0.247). For spontaneous MW, there was no difference detected between the two ToVA stimuli (P>0.2, Wilcoxon signed rank, delta = 0.143), and there was a trend for the active Cross-hairs task to be rated more highly for spontaneous MW (P<0.1, Wilcoxon signed rank, delta = 0.262).

To determine how well mind wandering ratings in this small data set (of exclusively boring stimuli)

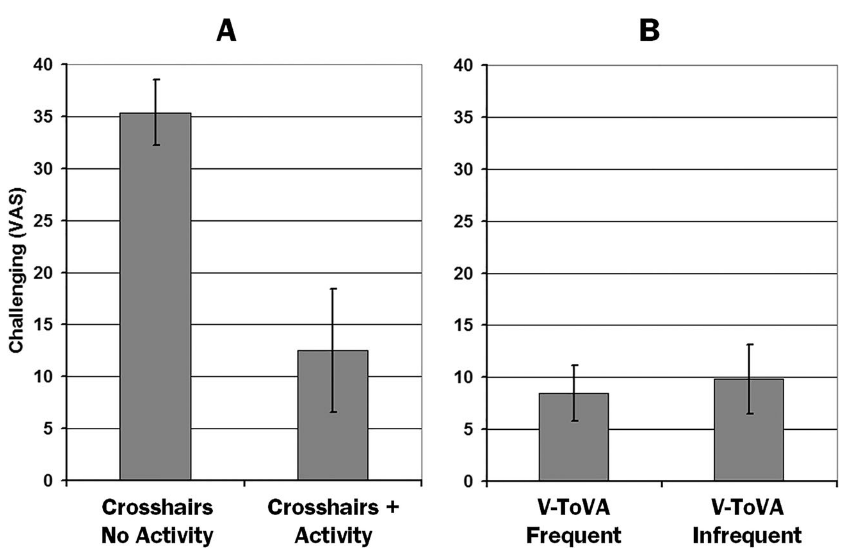

Figure 3. Mean VAS ratings (±*SEM*) for challenging.

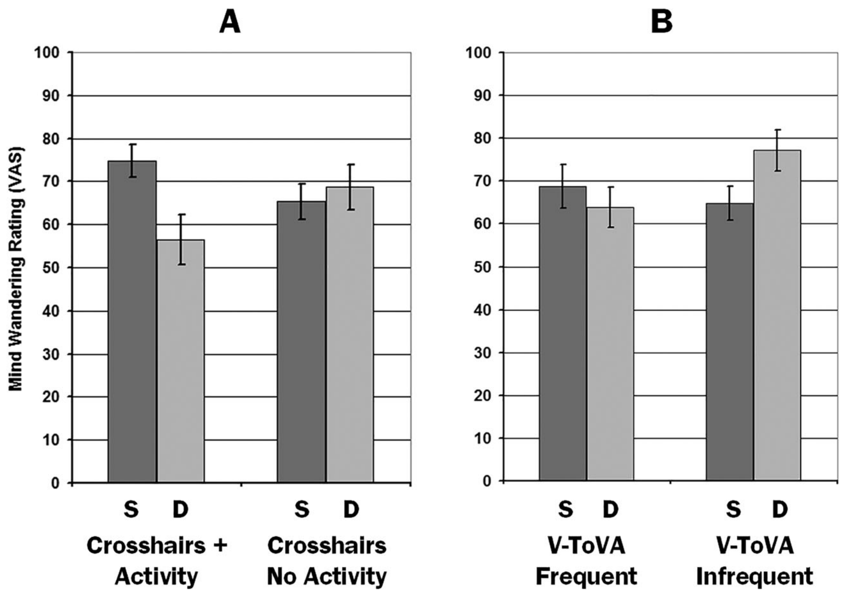

Figure 4. Mean VAS ratings for spontaneous (S) and deliberate (D) mind wandering.

correlated with other subjective descriptors, a complete panel of 21 Spearman's rank order correlations were run (Table 1). Typically, in large data sets with a wide range of stimuli, many ratings of cognitive states are either correlated or anti-correlated (Witchel et al. 2016a); for example, ratings for the descriptor 'boring' are normally strongly inversely correlated with 'interesting'. Usually both types of mind wandering are highly correlated with boredom, and the two types of mind wandering are usually moderately correlated with each other. In this small data set of exclusively boring stimuli, deliberate and spontaneous MW were inversely correlated ($rho = -0.284$, see Table 1). This correlation had

Table 1. Spearman's correlations of subjective ratings.

Descriptor 1	Descriptor 2	Rho	P	Sig.
Spontaneous MW	Deliberate MW	−0.284	0.0036	#
Spontaneous MW	Restless	0.164	0.0983	
Spontaneous MW	Bored	0.104	0.2961	
Spontaneous MW	Lethargic	0.099	0.3212	
Spontaneous MW	End Earlier	−0.057	0.5671	
Spontaneous MW	Frustrated	−0.051	0.6091	
Spontaneous MW	Challenging	0.045	0.6515	
Spontaneous MW	Motivated	0.040	0.6912	
Spontaneous MW	See More	−0.032	0.7513	
Spontaneous MW	Totally Engaged	−0.030	0.7609	
Spontaneous MW	Interested	−0.008	0.9388	
Deliberate MW	Restless	0.414	< 0.0001	+
Deliberate MW	Bored	0.399	< 0.0001	+
Deliberate MW	End Earlier	0.341	0.0004	+
Deliberate MW	Totally Engaged	−0.211	0.0326	
Deliberate MW	Lethargic	0.210	0.0332	
Deliberate MW	Interested	−0.161	0.1033	
Deliberate MW	See More	−0.140	0.1587	
Deliberate MW	Frustrated	0.136	0.1692	
Deliberate MW	Challenging	−0.128	0.l975	
Deliberate MW	Motivated	−0.065	0.5133	
Interested	Bored	−0.523	< 0.0001	+

Note: + is significant at $P<0.002$, # is trend to significance $P < 0.004$.

a trend toward significance (Bonferroni corrected significant $P = 0.05 \div 21 = 0.0023$). Deliberate MW was significantly correlated with several descriptors related to boredom (e.g. restlessness (rho $= 0.4138$), boredom (rho $= 0.3989$), and 'wanted it to end earlier' (rho $= 0.3407$), while spontaneous MW was not significantly correlated to any of the descriptors related to boredom or interest. The only descriptors that correlated even vaguely (i.e. non-significantly) with spontaneous MW were restlessness (rho $= 0.164$), boredom (rho $= 0.104$) and lethargy (rho $= 0.099$). Note that restlessness and lethargy are considered two different types (the high-energy and low-energy versions) of boredom (Witchel et al. 2014b). These differences strongly support the concept that spontaneous and deliberate mind wandering are recognised as different (and somewhat incompatible) states in the minds of our participants.

3.2. Order effects during ToVA

In line with other research studies comparing deliberate and spontaneous mind wandering, we presented thought probes during the ToVA tasks to assess cognitive states. Each ToVA task had five thought probes during the 6-min task (although the participants were not informed of the number of thought probes or the length of the stimuli in advance). We found that there were some order effects associated only with the first thought probe, despite the fact that the participants had practised a short version of the task during the instruction period. The average duration for the first thought probe was >6000 ms, which was patently longer than the average durations for thought probes 2–5, which were 4000-5000 ms (TVR) and 3000–4000 ms (TVO). In a linear mixed-effects model of the thought probe duration, the order of the thought probe was a significant predictor ($t = -5.4$, $P = 1.5 \times 10^{-7}$). However, if the timings for the first thought probe were removed, the query order was not significant (t=–0.9,P=0.37). The order was not significant in a linear mixed-effects model of reaction times to the Go/No-go task ($P > 0.5$); this is probably because the reaction time tests were numerous, and the first reaction time we analysed was approximately 1 min into the stimulus, such that learning effects would have already occurred.

3.3. Thought probe choices

In Figure 5 the percentage for each state identified during the task is shown. The results of these subjective thought probes clearly show that the frequent-target task did not increase being on task; there was almost no difference in the percentage of time the participants felt on task. Thus total mind wandering was unchanged by compliant activity. By contrast, compliant activity elicited a clear switch in ratings from deliberate MW to spontaneous MW (P=0.00049, chi-square = 15.23, df = 5).

3.4. Duration of thought probes during ToVA

In addition to using the thought probes to determine subjective mental states, we also timed the duration of the thought probe responses. The task of answering the thought probe can be considered more difficult and demanding than a simple reaction time task because it requires:

(1) Recognition of the task starting
(2) Mentally switching from the reaction time task to the thought probe
(3) Making a subtle decision between similar subjective states
(4) Selecting and pressing one of three buttons.

In Figure 6 the mean durations (±*SEM*) for the thought probes are shown. These selections are based on a forced choice. As predicted, the average duration of the thought probes was much longer (7-fold, $P = 7.0 \times 10^{-36}$, Wilcoxon Sign rank) than the average of the reaction times. Also, as expected, being on task was associated with a reduced thought probe duration compared to either MW state (estimate = 842.4/862.4 ms for spontaneous/deliberate, $t = -2.12/-2.17$, $P = 0.035/0.031$, LME). Furthermore, the two MW states resulted in no difference in thought probe duration (P>0.5). However, it was striking that the frequent-target resulted in a large, highly significant decrease (estimate = 810.3 ms, 95% CI: 304.1 to 1316.5, $t = -3.15$, P = 0.0018, LME) in thought probe duration, even when the participants claimed that they were on task.

3.5. Reaction times for ToVA

We also tested whether the simple reaction time task was affected by either spontaneous or deliberate MW, and whether compliant activity accelerated reaction time. Figure 7 shows the mean reaction times (±*SEM*) for the Go/No-go target stimulus that was shown just before the thought probe for the ToVA stimuli. In the frequent-target task, the reaction times did not differ irrespective of whether the participants rated themselves as on task or MW (P>0.2, LME). In the infrequent-target task, the mean reaction times for on task and spontaneous MW cognitive states did not differ, but there was a trend for a slowing effect when the participants described themselves as deliberately mind wandering (estimate = 50.6 ms, t = 1.90, P=0.0580, LME). The reaction times for

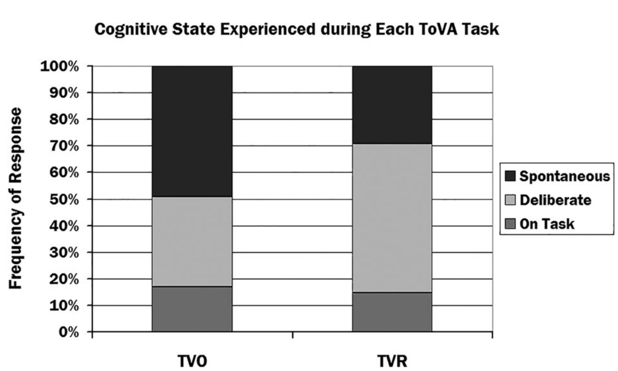

Figure 5. Thought probes for mind wandering.

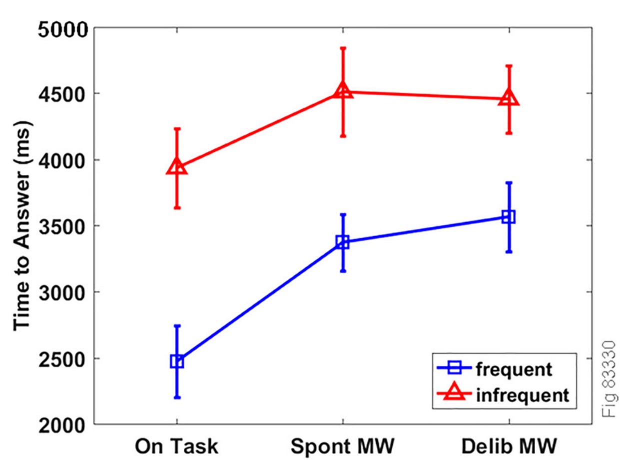

Figure 6. Duration of thought probes for mind wandering.

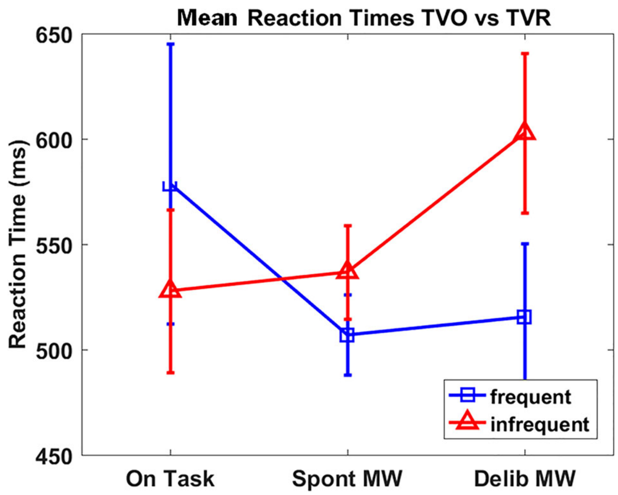

Figure 7. Reaction times during ToVA.

thought probes two to five were correlated with their following thought probe duration (Spearman's rho $= 0.2737, P = 6.32 \times 10^{-5}$); the first thought probe duration was not included in this correlation calculation due to order effects that were limited to the first query (see above).

4. Discussion

4.1. Overview of compliant activity effects

Previous research has led to some controversy as to whether increasing task difficulty would consistently diminish mind wandering (Seli et al. 2018b); this is relevant to ergonomics as it would impact on the design of safety systems when a human worker oversees or monitors moment-by-moment an automated system such as a partially automated car (Casner, Hutchins, and Norman 2016). The recent literature has approached this controversy by breaking apart mind wandering into a family of related states such as spontaneous and deliberate mind wandering (Seli et al. 2016b). It is possible that by more carefully defining mind wandering, 'difficulty' may be shown to affect one kind of mind wandering but not another (Seli, Risko, and Smilek 2016a). For example, in an inverted-U-shaped relationship between arousal and performance, deliberate MW may result from under-arousal while spontaneous MW may result from over-arousal (Neiss 1988; Arent and Landers 2003). It has also been suggested that there are different types of difficult stimuli, with divergent effects (Seli et al. 2018b).

In the current study, we sought to test the effects of compliant activity (which we predicted would increase difficulty) on three output variables: subjective ratings of mind wandering, thought probe duration and reaction times. Our three primary results showed that:

(1) whether it caused increased difficulty or not (Figure 3), compliant activity inhibited deliberate mind wandering in comparison with spontaneous mind wandering (Figures 5 and 4), but it did not inhibit mind wandering overall;
(2) compliant activity had a different (accelerating) effect compared to compliant inactivity (i.e. attention plus waiting, cf. Smallwood, McSpadden, and Schooler 2007) on thought probe response duration (Figure 6), and;
(3) compliant activity has a synergistic effect with on-task cognitive states, and shortens the duration of thought probe responses (Figure 6), which implies that the effects of compliant activity on performance are at least partially independent of its effects on mind wandering.

These results support Seli et al.'s (2016b) proposal that deliberate and spontaneous mind wandering are different cognitive states. It also suggests that only deliberate mind wandering is consistently diminished by adding compliant activity; spontaneous mind wandering can be increased by compliant activity. Most importantly, in the context of deliberate mind wandering (but not spontaneous MW), compliant activity seems to shorten reaction times. Thus, Don Norman's (Casner, Hutchins, and Norman 2016) suggestion to retain some driving activity for drivers of partially automated cars might (for rapid reactions such as emergency braking Berboucha 2018) only relate to deliberate MW, but not necessarily spontaneous MW. Furthermore, the thought probe results suggest that adding compliant activity to the task has a useful effect on decision performance/speed that is at least partially independent of its effects on mind wandering.

This study also set out to clarify the distinction between, and elicitation of, deliberate vs. spontaneous MW, so that the effects of either state can be more consistently disambiguated. We found, as expected, that both states are associated with restlessness and boredom (deliberate MW, more so). Surprisingly, spontaneous and deliberate MW states were inversely correlated with each other (in this small data set of exclusively boring stimuli). This supports the idea that they are distinct states and somewhat incompatible with each other. The subtle differences between the two MW states were much more clearly delineated by an immediate forced-choice thought probe than by the post-stimulus VAS questions, which allowed participants to rate their feelings of deliberate and spontaneous mind wandering as nearly equal.

4.2. Difficulty's effects on mind wandering

In terms of how difficulty affects mind wandering, this study reiterates the original issues about how to define 'difficulty' (Campbell 1988) in ergonomics, as well as for psychological studies (Seli et al. 2018b). Difficulty is defined as effortful (Campbell 1988), although this does not distinguish between physical effort (digging a foundation vs. planting a flower) and mental effort (concentrating vs. mind wandering). Difficulty can also be discussed as an objective quality of a task (effort required) or as a *person* × *task* interaction (subjective effort expended); for example, compare flying an airplane for a veteran pilot vs. a student pilot (Campbell 1988), where the objective requirements of the task are identical. In this study, the compliant activity versions of tasks, which all increase response rates to every ∼ 3 s, had very different effects on how participants subjectively rated how 'challenging' they found the task.

Participants viewed the response-free Cross-hairs Staring task as somewhat challenging (i.e. skilful and unlikely) because it requires persistent eye focus and unbroken attention to perform successfully. As such, adding the clicking task to the Cross-hairs task makes it subjectively significantly less challenging (Figure 3 (a)), presumably because it is less mentally effortful (allowing for breaks in attention and gaze focus), although it is more physically effortful. This fits with the executive control model (McVay and Kane 2010; Seli et al. 2018b) rather than the attentional resources model (Wickens et al. 2003; Seli et al. 2018b). By contrast, in the ToVA task an increase in target frequency does not increase subjective challenge, although it plainly increases how physically effortful the task is. By making the participant 'busy' and more attentive, even with a trivial Go/No-go task, it improves many aspects of performance, including orienting to the sudden appearance of the thought probe; this occurs even when the participant already thinks that they are on task. Furthermore, neither small increases in subjective difficulty *per se* nor low-effort compliant activity are sufficient to diminish total subjective MW. The issue is the cognitive state that difficulty elicits.

The effects on task speed that this cognitive state (or states) elicit seem to differ depending on how difficult the task is (i.e. the effects on thought probe durations in Figure 6 differ from the effects on reaction times in Figure 7). Yet, there seems to be a relationship between these two adjacent tasks because there was a strong correlation between reaction times and thought probe durations. This suggests that there is some mental state lasting at least on the order of seconds that contributes to both the Go/No-go task and to the thought probe task. More research needs to be undertaken to understand how very easy tasks reflected by simple reaction times are affected by difficulty and mind wandering (Smallwood, McSpadden, and Schooler 2007; Seli et al. 2018b).

The current data suggest that, so long as the relationship between effort made vs. effort required is still monotonically increasing (i.e. before anxiety or hopeless surrender are elicited), increasing effort required by a task will diminish deliberate mind wandering due to executive awareness of the diminished capacity to multitask. That result fits with Smallwood, McSpadden, and Schooler's (2007) result that mind wandering without awareness is decreased by increased metacognitive monitoring elicited by higher target frequency. Mechanistically, when the physical engagement of compliant activity elicits a cognitive state that improves task performance (e.g. engagement Witchel 2013; Witchel et al. 2016b or forced engagement Chalkley et al. 2017), it can do so by a means other than inhibiting subjectively identifiable mind wandering states (e.g. by inhibiting many other non-instrumental activities). This finding deviates from predictions of an attentional resources model, which predicts that adding tasks (even simple physical tasks such as responsive clicking) would lead to performance decrement (Wickens et al. 2003; Smallwood and Schooler 2006), except when those tasks diminish MW. Instead, the prolongation of the thought probes during the infrequent-target version of ToVA suggests that executive control is failing (McVay and Kane 2010; Seli et al. 2018b). This fits with the concept that engagement inhibits the initiation of non-instrumental activity, i.e. NIMI (Witchel 2013; Witchel et al. 2016b).

In terms of ergonomics, this study suggests that it is advantageous to design system interaction for partial automation such that the human overseer has a role that is more responsive to the external task (Casner, Hutchins, and Norman 2016). To test this in the current study, we added compliant activity, which is operationalised as a form of behavioural engagement with a task in which:

(A) the end-user must attend to the external activity/stimulus,
(B) the end-user must respond as requested in the desired time frame, and
(C) the required responses occur on multiple occasions over an extended duration.

Psychological studies of mind wandering have elicited subjective difficulty using tasks with mental effort such as working memory tasks Seli et al. 2018b). Mental effort (e.g. memory tasks and complex calculation) may minimise mind wandering (especially intentional/deliberate mind wandering). However, in this study, we showed that mind wandering *per se* is not the only influence on responsiveness. In activities where human attention and speed of reaction are important (e.g. driving or supervising partial automation), complex mental tasks and calculations may create attentional resource conflicts akin to multitasking, which is also known to lead to performance decrement (Wickens et al. 2003). We propose that when deliberately adding effort or difficulty to tasks to vouchsafe operator responsiveness, one must consider:

- Is the effort mental or physical?
- Does the effort lead to an internal or external focus?
- Is the added effort minor or all-encompassing?

4.3. Limitations

The entirety of the field of conscious thought is highly dependent on the accuracy of people's self-assessments. The ability of our participants to accurately assess their own mind wandering, and in particular to distinguish between spontaneous and deliberate MW, is open to doubt (Seli, Risko, and Smilek 2016a). This issue is endemic in the field of mind wandering because currently subjective self-assessment is the only reliable method for identifying either deliberate or spontaneous MW states. A similar argument can be made with assessing 'difficulty' or 'challenge', both by the lay participants and by the research community. Others have already pointed out that 'difficulty' is not necessarily uniform (Campbell 1988; Seli et al. 2018b).

4.4. Conclusions

The data gathered in this study demonstrates that frequent human interaction rates (i.e. being kept busy and outwardly responsive) improves performance/decision speed on thought probes, independently of mind wandering (Figure 8). However, we found that our intervention of increased compliant activity was not consistently related to subjective difficulty. Based on our findings, we suggest that it is not the level of difficulty *per se* (i.e. effort required) that accelerates task performance, but rather the issue is the responsive cognitive state that difficulty elicits. Nor is subjective 'difficulty' *per se* sufficient to diminish total subjective MW. We propose that mind wandering is the default state of the active brain (Killingsworth and Gilbert 2010), and that the associated restlessness is inhibited by a member of the family of the states of engagement and attention, which are known to inhibit non-instrumental behaviours, similar to NIMI (Witchel 2013; Witchel et al. 2016b).

Our data suggest that future research needs to clarify the relationship between physical engagement (e.g. clicking) and cognitive engagement, and how this relates to both kinds of mind wandering. To vouchsafe that these observations are more relevant for tasks such as driving, future experiments should be performed for activities with longer durations. Finally, to tease apart the relationship between deliberate and spontaneous mind wandering versus reaction times, a more careful analysis for highly affected subgroups of MW using histograms should be performed. While there were no differences in some of these mean results, there may be a subgroup of highly affected responses that would lead to rare accidents. Assessing the effects of MW on reaction times in this light will allow designers and researchers to think

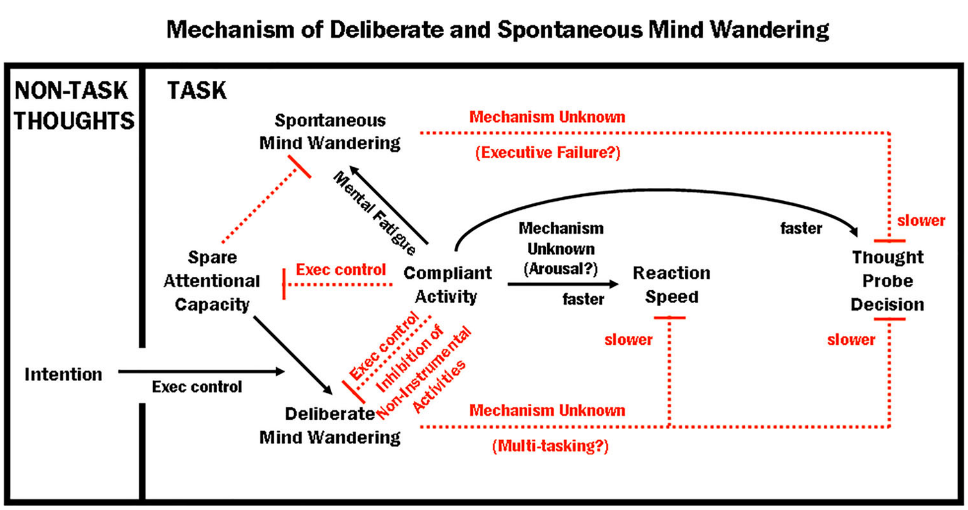

Figure 8. Schematic of mechanisms relating compliant activity to deliberate and spontaneous mind wandering. Black arrows represent stimulation while dotted red-capped lines represent inhibition.

more clearly about the role of the system user, which is salient to the discussion of partial automation for applications and situations where human reaction times remain important or critical (Casner, Hutchins, and Norman 2016).

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