Compliant activity accelerates all thought probe responses and inhibits deliberate mind wandering

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ABSTRACT

Introduction: Mind wandering is a cognitive state that leads to diminished performance and error risk. A controversy over whether easier or more difficult tasks enhance mind wandering has led to mind wandering being proposed as two different states: deliberate and spontaneous. We hypothesise that forced engagement may inhibit non-instrumental activities including deliberate mind wandering. **Methods:** Twenty-eight seated, healthy participants (age range 19-35, 9 male) interacted with two 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 mind wandering and challenge and boredom were also tested using visual analogue scales at the end of each stimulus. Reaction times were measured using Superlab with an RB530 interaction device. **Results:** Compliant activity decreased deliberate mind wandering but not overall mind wandering. Thought probe durations were significantly shortened by increasing interaction frequency, while deliberate and spontaneous mind wandering elicited equivalent thought probe durations. **Conclusion:** Compliant activity works synergistically with lack of mind wandering to accelerate the difficult task of thought probe response. This does not fit with the attentional resource model, and may require a clearer definition of how tasks may be labelled as difficult.

CCS CONCEPTS

• **HCI design and evaluation methods**;

KEYWORDS

mind wandering, NIMI, engagement, difficult, TOVA

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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 [9] that result in diminished ability and higher error rates [16]. According to the attentional resources model, if MW is a separate activity [12], then permitting attentional resources to be co-opted by MW would diminish performance of tasks [7, 10]. In many cases, mind wandering has been shown to be increased by easier tasks [8, 15], 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 lead to an increased risk of human inattention and catastrophic safety failures [1, 3]. Don Norman and colleagues have suggested that this effect may have to be addressed by automobile designers by adding extra tasks for the driver to perform, even when a computer could easily do them [2]. Research in the last two years has suggested that mind wandering states can be differentiated based on whether they are spontaneous or deliberate [9], and a model of different MW states related by family resemblances has suggested four relevant properties that are potentially shared by this family:

(1) unguided thought,
(2) not tied to an external stimulus,
(3) unintentional, and
(4) unrelated to the task at hand [7].

The relationship between task difficulty and mind wandering has become controversial, because some experiments have differed from most previous data by showing that mind wandering is increased in a more difficult task compared to an easier one [8, 14]. In this study in addition to using forced-choice thought probes, we also used post-task VAS assessment to allow for comparisons of subjective ratings of intentional vs. spontaneous mind wandering. We also used two sets of highly comparable tasks: a staring task ±

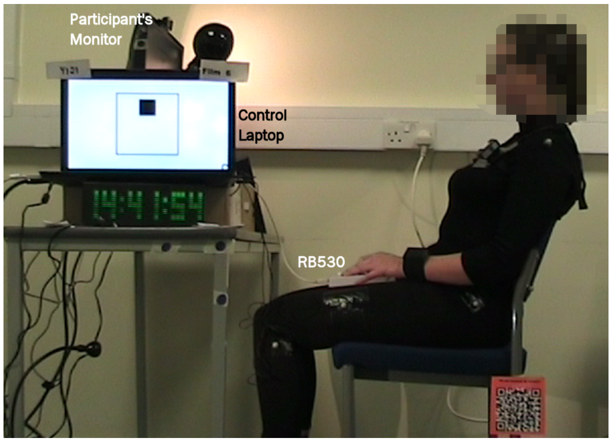

Figure 1: Experimental set-Up showing the ToVA target and the RB530.

reaction to interference, and a Go/No-go task (based on the Test of Variables of Attention [5]) with two different levels of target-frequency. The compliant tasks were not necessarily more difficult, but but they elicited more frequent interaction. Our hypothesis was that compliant activity, rather than difficulty, was in fact the inhibitor of intentional mind wandering, although not unintentional mind wandering.

2 METHODS

2.1 Participants

28 healthy subjects (19 females, and 9 males) took part in this experiment. Age range was between 19-35 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 and 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 a three-minute gaze fixation task (i.e. staring) with Crossha Stimu the monitor.li were irs onpresented using a Toshiba laptop running Windows 7, with the display in the duplicate mode: a desktop video monitor was connect to the laptop's VGA port, such that the laptop (and its controls) were facing away from the participant. Interaction with the Crosshairs Staring stimuli was using 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, USA), 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 upper half of large white square) is present, and refrain from clicking when a non-target square (little black square in lower half of large white square) appears on the screen (Figure 2). The frequent-target and infrequent-target versions were presented as two separate stimuli in our investigation, each lasting approximately 5.4 minutes.

2.3 Subjective Measurements

At the end of each stimulus, participants were asked to rate a set of emotions using a 10 cm visual analogue scale. The primary variables being investigated were the response times and The occurrence of spontaneous and deliberate mind wandering during the two stimuli were subjectively determined by 2 methods: thought probes and visual analogue scales (VAS).

2.3.1 Thought Probes. During the course of the five-minute 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 past, 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"; 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.

This information, 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 1-3 minutes to complete. The questionnaires consisted of one open-ended question, and a series of a visual analogue scales (VAS) in a counter-balanced 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 motivated'.

2.4 Reaction Time Measurements

Reaction time measurements were made using Superlab 4.5 and an RB530 response pad. Sets of target and non-target stimuli were presented in random order such that either the target stimulus was presented 75% of the time (frequent target) or 25% of the time (infrequent target).

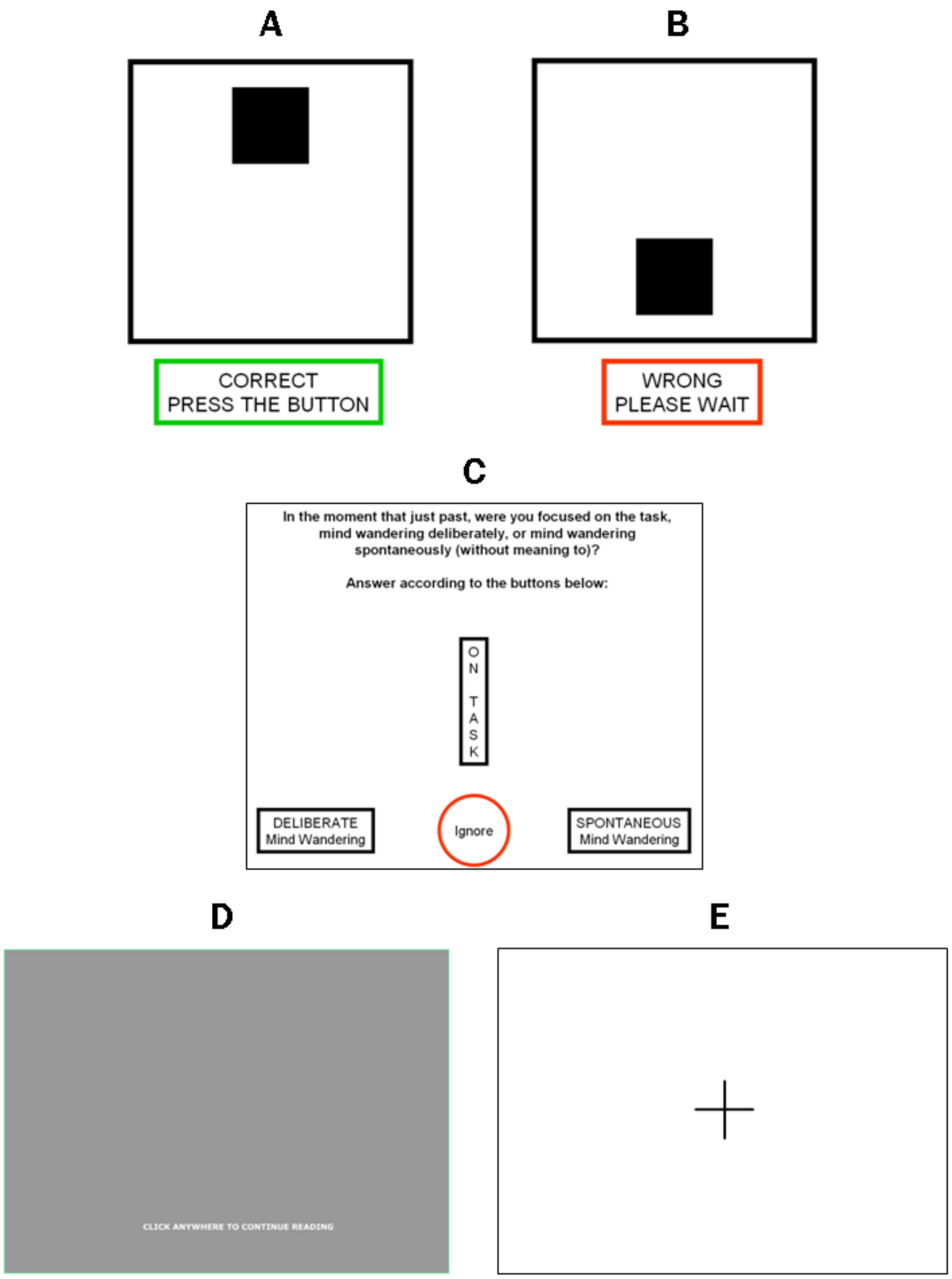

Figure 2: Stimuli as shown on monitor. Panels A (target), B (non-target) and C (thought probe) show the ToVA task. Note that the instructions (from the instruction task) are shown below the squares here, but do not appear in the actual ToVA task. Panels D (grey interference screen) and E (crosshairs)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

2.5 Experimental Protocol

All participants were briefed on the nature of the study and completed background questionnaires including a demographics form. Each subject was seated on an armless, cushioned, 4-leg reception chair in front of a desk facing a 47.5 x 20 cm monitor, placed at the eye level of the volunteer, and adjustment of the seat position was allowed for optimal comfort. The eye to screen distance ranged from $67.8 \pm 12.3 cm$.

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 practise run with ToVA to become accustomed to the stimuli and equipment. At the end of the experiment, volunteers

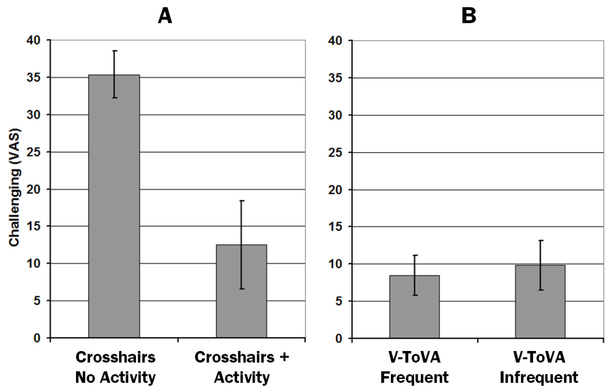

Figure 3: Mean VAS Ratings for Challenging

were de-briefed and paid, with each experiment lasting approximately 60 minutes.

2.6 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 statistics in Matlab. 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 [11].

3 RESULTS

3.1 Subjective VAS Ratings

In order to verify that the addition of the interventions regular compliant activity added to perceived difficulty, we determined the mean VAS rating for "I felt it was challenging" for the Crosshairs Staring task with/without activity (Figure 3A). Counter-intuitively, when only staring at the crosshairs without activity, the mean challenging rating was significantly higher than when the 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 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 explicitly ask their participants to rate the challenge or difficulty of the tasks [4, 8]. 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 3B). These unexpected results reinforce the idea that when tasks are made more objectively more laborious, they may not feel more challenging to the participant, and clearer standards for how researchers determine difficulty are needed.

To determine whether the addition of compliant activity altered to either the amount of mind wandering, or the relationship between spontaneous and deliberate mind wandering, at the end of

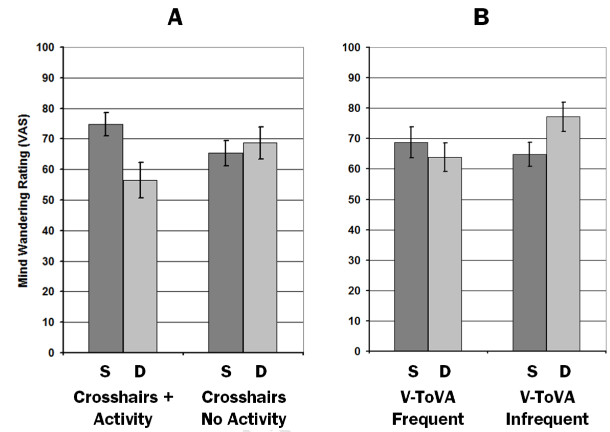

Figure 4: Mean VAS Ratings for Spontaneous (S) and Deliberate (D) Mind Wandering

each stimulus the participants used the VAS to rate both spontaneous and deliberate mind wandering (Figure 4). These VAS measurements do not involve a forced choice between them. 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 Crosshairs + Activity ($P < 0.01$, signed rank statistic = 232, Wilcoxon signed rank). 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 Crosshairs tasks (no activty was rated higher for deliberate MW, $p < 0.1$, Wilcoxon signed rank). For spontaneous MW, there was no difference detected between the two ToVA stimuli ($p < 0.2$, Wilcoxon signed rank), and there was a trend for the active Crosshairs task to be rated more highly for spontaneous MW ($p < 0.1$, Wilcoxon signed rank).

3.2 Thought Probe Choices

In line with other research studies comparing deliberate and spontaneous mind wandering, we also used thought probes for the ToVA tasks In Figure 5 the percentage for each state identified during the task is shown. These selections are based on a forced choice that occurred approximately once every minute during the five minute tasks. The results of these subjective thought probes clearly show that the frequent-target task did not increase being on task; there was 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.

3.3 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

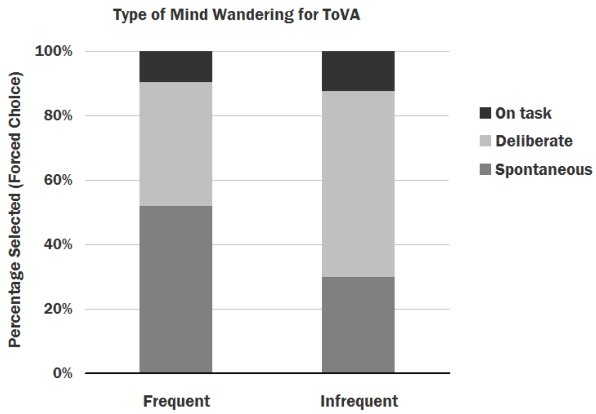

Figure 5: Thought Probes for Mind Wandering

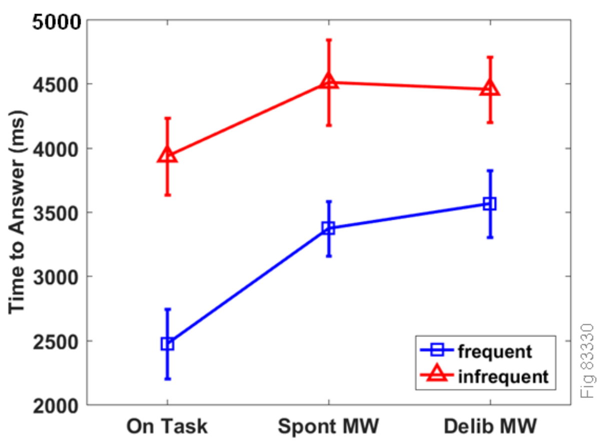

Figure 6: Duration of thought probes for mind wandering

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 duration for the thought probes are shown. These selections are based on a forced choice. As predicted, the average duration of the thought probes were much longer (8-fold) than the reaction times. Also, as expected being on task was associated with a significantly reduced (25%) thought probe duration compared to either MW state. Furthermore, the two MW states resulted in no difference in thought probe duration. However, it was striking that the additional compliant activity associated with the frequent-target resulted in a large decrease (38%) in thought probe duration, even when the participants claimed that they were on task.

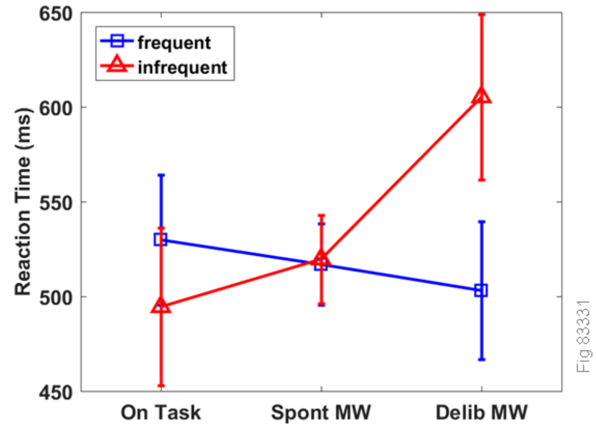

Figure 7: Reaction times during ToVA

3.4 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 for the target stimulus that was shown just before the thought probe for the ToVA stimuli. These selections are based on a forced choice. In the frequent target task, the reaction times did not differ irrespective on whether the participants rated themselves as on task or MW. A similar reaction time was found in the infrequent-target task, except that there was a combined slowing effect when the participants described themselves as deliberately mind wandering.

4 DISCUSSION

Previous research has led to some controversy as to whether increasing task difficulty would consistently diminish mind wandering [7]; this is relevant to ergonomics because 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 [2]. The recent literature has approached this controversy by focusing on breaking apart mind wandering into a family of related states such as spontaneous and deliberate mind wandering, it is possible that by more carefully defining mind wandering, textitdifficulty may be shown to affect one kind of mind wandering but not another. It has also been suggested that there are different types of difficult stimuli, and that they have differing effects [8].

In this study we sought to test the effects of compliant task-related activity on three output variables: subjective ratings of mind wandering, thought probe duration and reaction times. Our two primary results showed that

(1) Whether it caused increased difficulty or not (Figure 3), compliant activity inhibited deliberate mind wandering with respect to spontaneous mind wandering (Figures 5 and 4), but it did not inhibit mind wandering overall, and
(2) Compliant activity has a synergistic effect with on-task cognitive states in shortening the duration of thought probe

response (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 [9] proposal that deliberate and spontaneous mind wandering are different cognitive states, and that only deliberate mind wandering seems to be diminished by adding compliant on-task activity. More importantly, in the context of deliberate mind wandering (but not spontaneous MW), compliant activity seems to shorten reactions times. Furthermore, the thought probe results suggest that adding compliant on-task activity 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 highly associated with boredom, and that they are strongly related. 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. This leads to a query about how accurately lay participants can accurately distinguish between these two different states; currently subjective self-assessment is the only reliable method for identifying either deliberate or spontaneous MW states.

In terms of how difficulty affects mind wandering, this study leads to issues about how to define 'difficulty'. By definition, there are (at least) two different types of difficulty, in which tasks are not easily done because they require either extensive

- labour or
- skill.

For example, to perform a back flip is difficult (i.e. skillful and unlikely) in a different way from how walking uphill for 10 kilometres is difficult (i.e. laborious). In this study the task variations of increasing response rates to every 1-3 seconds had very different effects on how participants subjectively rated how 'challenging' they found the task.

The Crosshairs Staring task is viewed as somewhat challenging (i.e. skillful and unlikely) because it requires persistent eye focus and unbroken attention to perform successfully. As such, adding the clicking task to to this task makes it subjectively significantly less challenging (Figure 3A), presumably because it is less effortful and more likely to subjectively succeed. This fits with the executive control model [6, 8]. By contrast, in the ToVA task an increase in target-frequency does not increase subjective challenge, but it plainly increases how laborious the task is. By making the participant 'busy', even with trivial response tasks, it improves many aspects of performance, even when the participant thinks that they are on task. neither subjective difficulty *per se* nor mindless compliant activity are sufficient to diminish total subjective MW. The issue is the cognitive state that difficulty elicits. This finding deviates from predictions of an attentional resources model, which predicts that adding tasks would lead to performance decrement [10, 12], 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 [6, 8]. This fits with the concept that engagement inhibits non-instrumental activity [13].

4.1 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. 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 the limits how uniform difficulty is [8]; the fact that the English language has such clear ambiguities means that the difficulty issue will have to be addressed in future research.

4.2 Conclusions

The data gathered in this study demonstrates frequent human interaction rates (i.e. being kept busy) improves performance/decision speed on thought probes, independently of mind wandering. However, we found that our intervention of increased compliant activity was not consistently related to subjective difficulty. We propose that subjective difficulty *per se* is not sufficient to diminish subjective MW. The issue is the cognitive state that difficulty elicits. Optimal difficulty may prevent both boredom and demotivation from hopelessness. Based on our findings, we propose that it is not the level of difficulty *per se* that affects reaction times, but rather how much of a challenge the task presents. Our data suggest that future research needs to clarify the meaning of 'difficulty', as the skillful/precarious type of difficulty (or challenge) is not identical to laborious difficulty.

Perhaps future research, especially on mind wandering, needs to consider multi-tasking, which is also known to lead to performance decrement [12]. Multi-tasking does not necessarily cause subjective difficulty. Assessing the effects of MW on reaction times in this light allows designers and researchers to think more clearly about the role of the system user, which is salient to the discussion of automation for applications and situations where human reaction times are important or critical [2]. This study suggests that it is advantageous to design system interaction in such a fashion that the role of the human participant demands either more close attendance to the task [2], or (as per the conclusions of [8]) a subjectively greater degree of difficulty, where human attention and speed of reaction is important.

Future work in this research are needs to solidify this information. To unpick the two types of 'difficulty, these experiments should be run with a set of different response rates and they should also be run with more complicated tasks (i.e. skillful/unlikely difficulty). To vouchsafe that these observations are more relevant for tasks such as driving, these tests should be performed for longer activities. finally, to tease apart deliberate from spontaneous mind wandering, a more careful analysis for highly affected subgroups of MW using histograms should be performed. While there were no differences in some mean results, there may be a subgroup of highly affected responses that would lead to rare accidents.

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