Intentional mind wandering is objectively linked to low effort and tasks with high predictability

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ABSTRACT

BACKGROUND: Intentional Mind Wandering (IMW) is proposed to be a low arousal state resulting from boredom, to distinguish it from unintentional mind wandering (UMW), which may be a low executive control state resulting from exhaustion of resources.
AIM: To demonstrate that there are objective differences between IMW and UMW reflecting the subjective difference that IMW is a low effort and high predictability strategy.
METHODS: The metronome response task (MRT) requires participants to predict when the next tone in a regular series will occur. Inter-Trial Interval (ITI) variants of the MRT were presented in blocks of ~ 90 seconds.
RESULTS: The most predictable version of MRT resulted in the percentage of reported IMW doubling, whereas UMW remained similar in all three versions of the MRT. IMW necessitated subjective effort to be low (maximum 5 on a 1-9 scale). IMW in easy and predictable versions of the task resulted in normal performance, whereas IMW during difficult tasks that required sustained attention led to poor performance and occasional errors. IMW during the least predictable MRT led to a significantly higher rate of omission errors (compared to on-task or UMW), and also to a higher maximum-in-block reaction time, as predicted by the worst performance rule. Conscientiousness was linked to reduced IMW (but not reduced UMW), higher on-task probes, increased effort, and improved prediction accuracy.
CONCLUSIONS: Subjective assessment of low task difficulty predisposes to IMW, evoking increases of both omission errors and slow lapses and decreases in willingness and in compliant allocation of cognitive resources.

CCS CONCEPTS

• **Applied computing → Psychology**; • **Human-centered computing → Laboratory experiments**; **User studies**.

KEYWORDS

mental strategy, mind wandering, attentional resources, effort, SART

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1 INTRODUCTION

1.1 Performance Decrement: Mind Wandering versus Effort

Mind wandering (MW) is a cognitive state (or family of states) in which attention is directed away from the environment and towards task-unrelated thought [24]. It is estimated that 30-50% of daily thought may be occupied by mind wandering states in healthy individuals [10, 11]. Task difficulty seems to affect the propensity to mind wander, but the direction remains controversial. It has often been shown that mind wandering increases during easier tasks [20, 21, 27, 31], especially increased intentional mind wandering [22]. Crucially, when mind wandering intrudes into a primary task, it has been associated with higher error rates and diminished performance

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[31]. This has significant implications given contemporary changes toward radically increasing automation. It has been suggested that designers of partially automated vehicles should include extra tasks for the driver/overseer to inhibit non-task related thought [4, 28]. However, previous studies have suggested that mind wandering is increased in more difficult tasks [7, 21, 29]. Findings from studies that modify task conditions could help inform the optimisation of such tasks to minimise the safety risks of MW. The present study hopes to explore whether changes in the inter-trial interval (ITI) in a simple metronome response task can increase difficulty and thus influence the effects and type of MW.

1.2 Intentional Mind Wandering

There is a major controversy in the literature over whether MW is a family of related states [20], and if the absence of a singular definition increases scientific confusion [5]. It is thought that mind wandering can be differentiated into at least two distinct states: MW may be spontaneous (i.e. unintentional, hereafter called UMW) or deliberate (i.e. intentional, hereafter called IMW) [21–23]. The distinction between intentional and unintentional MW, and the scientific benefits of this distinction, remain controversial. It has been suggested that boredom may predispose to deliberate mind wandering, whereas over-taxation and exhaustion of resources may predispose to unintentional mind wandering [2, 19, 23]. That is, in order to remain on-task, and to avoid MW, one must be both *willing* and *able* to do the task compliantly.

Mind wandering is known to lead to performance decrement and accidents [30]. One possible cause of MW during work (e.g. aviation) is complacency [16], where insufficient monitoring of a system occurs due to satisfaction that all is well in an automatic system. Here we extend that idea to the context where very simple human responses (e.g. predictable metronome response tasks) can be considered "automated" by the person performing the task, so that some of the person's attentional and executive resources can be redeployed for multi-tasking or MW.

We suspect that the apparent inconsistencies in the literature occur because the relationship between MW and difficulty depends on a rational choice as to whether the participant is confident that they can perform the task to the standard required. In this perspective, task difficulty has a critical challenge point (determined by the participant's ability or their belief in it), such that below the critical challenge point, the participant can multitask successfully, but above it the participant will have to make an effort to attend to the task in order to succeed (see Figure 1). Below the critical challenge point, we propose that there is relatively constant ratio between being on-task and mind wandering [25], and the ratio is probably determined by the balance of their motivation for the task with the task's demands. Thus, when the participant's effort is below the critical challenge point, increasing their effort improves willingness (suppressing intentions to MW), but the will power is only sufficient to perform the task compliantly, not to completely suppress MW, which is then attributed to UMW. Above the critical challenge point, as effort is increased, MW must be reduced to remain compliant, so the participant is more likely to be on-task.

Thus, effort is a decision based not only on motivation, but also on a personal judgement on the cross-over between ability and task demand. That is, a person's performance is determined by their ability and their effort, and the person's effort is determined by their motivation and their internal belief about their future performance. We propose that the 2×2 table in Figure 1A implies the following pathways, where each double arrow implies increasing demand (when matched by appropriate effort):

Engagement Pathway - *often on-task*
Ready ⇒ Attentive ⇒ Focused
Overwhelmed Pathway - *often unintentional MW*
Distracted (but able) ⇒ Willing (but not able) ⇒ Surrender
Bored Pathway - *often intentional MW*
Detached ⇒ Complacent ⇒ switch to On-Task or Unintentional MW

1.3 Aim and Hypotheses

Our aim was to demonstrate that there were both subjective differences between intentional and unintentional MW, and more importantly, objective differences between them. Our hypotheses were: [H1] Intentional MW is a low effort strategy. [H2] Very easy tasks encourage IMW as a rational decision for a low effort strategy that could still be performed successfully, even while thinking about something else. [H3] The lowest effort strategy would be a form of "auto-pilot" based on responding using effortless prediction that did not involve persistent attention. [H4] The longer versions of the MRT would be objectively more difficult to perform correctly (with prediction). [H5] Poor performance would appear as lapses, i.e. blocks with either omission errors or occasional slow responses (seen as the maximum reaction time for any trial in the block). [H6] Lapses in attention would only manifest when the task was more difficult and demanding persistent attention.

2 METHODS

2.1 Experimental Participants

Eighty-eight online volunteers were recruited via Prolific and received £2.50 for their time. This study was carried out in accordance with the approval of BSMS's Standard Risk Ethics Protocol. Prolific allows for specifying and pre-selecting participants; we specified: English speaking, UK based, aged 18-70, using a laptop/desktop computer (i.e. not using a mobile phone or a tablet). All participants gave explicit informed consent (by pressing a letter signifying "I agree") in accordance with the Declaration of Helsinki.

2.2 Protocol

Once recruited by advertising on Prolific, participants were sent to Gorilla.sc; this web platform allowed presentation of the stimuli on the participant's local computer and then uploaded the anonymised results to the platform. The online protocol had the following steps: informed consent including description of how to withdraw instantly and button press for "I agree", detailed instructions for both the experimental task (Metronome Response Task, MRT) and for the subjective ratings that they would make, four personality questions from the rapid Big Five Inventory (BFI-10, [17]), an explicit practice block (4 trials), announcement that the experiment would begin, a rehearsal block that was never included in the analyses, 6 experimental blocks (90 seconds each) presented in a random

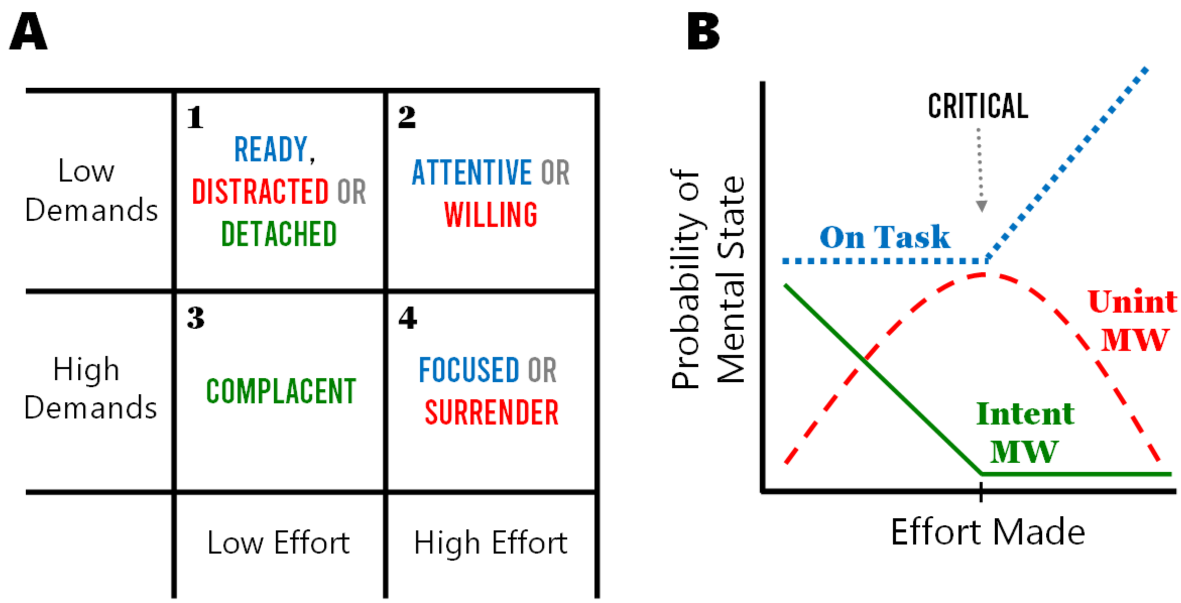

Figure 1: Schematic diagrams of our predictions relating mind wandering to effort via task demands and ability. Panel A: 2×2 **table of different strategies relating to the demands of the task versus the effort made by the participant. The simplification of high and low demands is nominally divided at the point of critical challenge. Each box (e.g. box 1 is low effort and low task demands) may relate to more than one state of mind, depending on whether the person is on-task (blue lettering), unintentional mind wandering (red) or intentional mind wandering (green). Panel B: Likelihood of on-task (dotted blue), intentional (continuous green) and unintentional (dashed red) mind wandering (MW) mental states depending on the degree of effort made by the participant. The point of critical challenge (grey dotted arrow) is the level of effort needed for this level of task demands (matched to the participant's ability) such that if the task was any easier, the participant could multitask successfully and mind wander while consistently performing the task successfully.**

order, and the "thank you" screen that sent participants back to Prolific for confirmation and payment. The entire experiment would take approximately 18 minutes, although it could be longer if the participant delayed during the subjective responses.

2.3 Personality Questions

There have been previous associations between mind wandering and the personality traits conscientiousness and neuroticism [3, 15]. During the instructions phase of the experiment, we asked four personality questions from the BFI-10, which is a validated instrument for eliciting self-rated personality traits in under one minute [17]. We asked the two questions each (one positively scored, one negatively scored) for conscientiousness and extroversion. The questions we asked were *I see myself as someone who ...*:

- ... does a thorough job
- ... tends to be lazy
- ... is outgoing, sociable
- ... is reserved

2.4 Stimuli and Subjective Rating Scales

The online Metronome Response Tasks were similar to those previously described [18], in which all responses were gathered by keyboard (i.e. not via mouse). For each block, a series of equally spaced tones (each lasting 200 ms) sounded, and the participant was instructed to press the button (<*right arrow*> key) at the same time as the tone, and they were explicitly instructed to attempt to predict when the tone will occur, so that their presses were exactly at the same time as the tone. As expected, in some cases people were unable to precisely predict the tone, in which case once they heard the tone, they responded as if it was a reaction time task. The inter-trial interval (ITI) between the tones varied in different versions of the task: 1.3 seconds (s), 2.6s, and 5.2s. We chose non-integer times to prevent participants from potentially using a ticking clock to help them; participants were instructed to be in a quiet room without a ticking clock. We predicted that the 1.3s version (similar to the previously published versions [1, 18]) would be easy to predict, that the 2.6s version would demand focus, and that the 5.2s version would be almost impossible to consistently perform correctly for most people. The number of trials in a block was set to be approximately 90 seconds, to encourage mind wandering. Each block ended with a series of 3-4 subjective tasks.

2.5 Thought Probes and Subjective Rating Tasks

The first rating task was a forced-choice, binary thought probe, "In the moment just preceding this thought probe were you:" and the choices were "On Task" (<*up arrow*> key) or "Mind Wandering" (<*down arrow*>). If, and only if, the participant answered "Mind Wandering", the next part of the thought probe was presented, "Just before these thought probes, was your mind wandering:", and the choices were "Intentional" (<*up arrow*>) or "Unintentional" (<*down arrow*>). The next subjective task was the subjective effort rating: "Please rate how much EFFORT you put into the task you just completed. In comparison to other tasks you might do on a computer (from 1 to 9). 1 = Minimum 9 = Maximum". Two more brief subjective ratings were performed, but they are not described in this paper due to space limitations.

2.6 Analysis and Pre-determined Data Exclusion Criteria

Gorilla files were read into Matlab using a specially designed script, and all statistics were performed in Matlab. Individual trials were dropped if the reaction time > 1.5 seconds after the tone. Trials that were responded to more than 400 ms in advance were considered wild. A block was dropped if the block had more than 30% omission errors. The entire participant was dropped if a participant's data included more than 2 dropped blocks. The entire participant was dropped if the participant did not complete the experiment or if the participant's experimental duration was greater than 30 minutes (i.e. they took a break in the middle of the experiment). Previous analyses of the MRT focused on metrics of consistency (RRTv, [1, 18]), but we chose to focus on accuracy, as we predicted that the longer versions would be very difficult to be accurate at all. Our main measure of inaccuracy was Mean Absolute Reaction Time (meanAbsRT0), in which the magnitude of the difference in time between the beginning of the tone and the button press was averaged. Thus, 100 ms early or 100 ms late were considered equally inaccurate. Higher numbers imply greater inaccuracy. Another metric we made was anticipation rate. For each tone, if the button press occurred some time between 400 ms before the start of the tone and 100 ms after the start, it was considered a successful anticipation; by contrast, later presses, very early presses, or no press were considered not an anticipation. We are using the maximum reaction time in each block as an indicator of momentary lapses in goal maintenance [14]; other groups have looked at the longest reactions to understand the "worst performance rule" [12]. Nearly all statistics were performed with Linear Mixed Effects (LME) models, where the participant was considered a random effect, whereas the variables named in the results sections were the predictors with fixed effects. LME models were used to allow for correction of incomplete block designs and each participant performing 6 blocks. All LMEs were run in Matlab using the *fitlme* command.

3 RESULTS

3.1 Task Versions with Longer Inter-Trial Intervals Have Much Lower Predictability

We predicted that long waits (>5s) with no explanation make task action less predictable, which proved correct (Figure 2, Panel A). To measure predictability of a given ITI, for each trial (ignoring the first two, which are needed to set a pattern), we assumed that any button presses that occurred between 400 ms before the tone to 100 ms after the tone were successful prediction attempts. We chose these numbers because it is almost impossible to respond to a heard tone in less than 100 ms (minimum human reaction time [26]), and we consider any press more than 400 ms early is a wild early press. Testing these results using an LME model, we found that the anticipation rate of the tone (i.e. predictability, whether due to intention or inability) was highly significantly lower with longer ITIs ($t = -22.86, P = 1.99 \times 10^{-79}$) as seen in Figure 2A. The average person would be able to anticipate nearly all of the trials at 1.3s (highly predictable), about half the trials at 2.6s (challenging to predict), and only the occasional trial at 5.2s (very difficult to predict).

3.2 Intentional Mind Wandering Is Elicited by the Predictable Task

The responses to thought probes for the different ITIs are shown in Panel B of Figure 2. Each participant attempted each ITI twice in a random order, so after removing rejected blocks (too many errors), there were 156, 182, and 178 blocks for each of the conditions (1.3s, 2.6s, and 5.2s). The percentage of IMW responses were approximately double in the 1.3s task (11.54%) compared to the 2.6s task (5.81%) and the 5.2s task (5.35%). According to an LME model, the probability of IMW for 1.3s is significantly higher than the others ($t < -2.3, P < 0.03$ for both). Note that the differences between on-task responses do not reach significance, and that the values for UMW are nearly the same (16.03%, 16.86% and 15.48%). Thus, the predictable version of the task has double the IMW compared to the others, although the response to the predictable task continued to be mostly on-task.

3.3 Intentional Mind Wandering Is Linked to Low Subjective Effort

Figure 3 panel A compares the average subjective effort ratings for each mental state for each task. There is a clear difference in effort between intentional MW and on-task (>3 points on a 1-9 scale), and an LME model shows that IMW is significantly lower than others ($t < -6.70, P < 6 \times 10^{-11}$ for both). Changing task does not significantly alter the effort associated with each mental state, except for UMW (1.3s differs from 5.2s, $t = 3.23, P = 0.0018$). Panel B in Figure 3 combined all the tasks to see the relationship between subjective effort rating and mental state. Increasing effort is strongly linked to on-task thought probes (blue dotted lines) when effort is above 4; this is significant (LME for all tasks and all effort values, $t = 7.82, P = 3.22 \times 10^{-14}$). By contrast, decreasing effort is linked with greater levels of intentional MW (green solid line); this is significant (LME $t = -9.80, P = 7.49 \times 10^{-21}$). Thus, for lower effort (≤ 4) UMW decreases as effort is rated lower (because the MW becomes increasingly intentional), and for higher effort (≥ 6) UMW decreases as effort is rated higher (as the extra effort changes the MW into an on-task state). Note that Panel B in Figure 3 is quite similar to Panel B in Figure 1.

3.4 At 5.2s IMW Increases Both Omission Errors and Maximum Reaction Time

In panel A of Figure 4 the rate of omission errors is shown for the different ITIs for each mental state. There is a significant increase in omission error rate for ITI = 5.2s compared to the other two task versions (LME at least $t = 4.76, P = 2.56 \times 10^{-6}$ for both). For ITI =

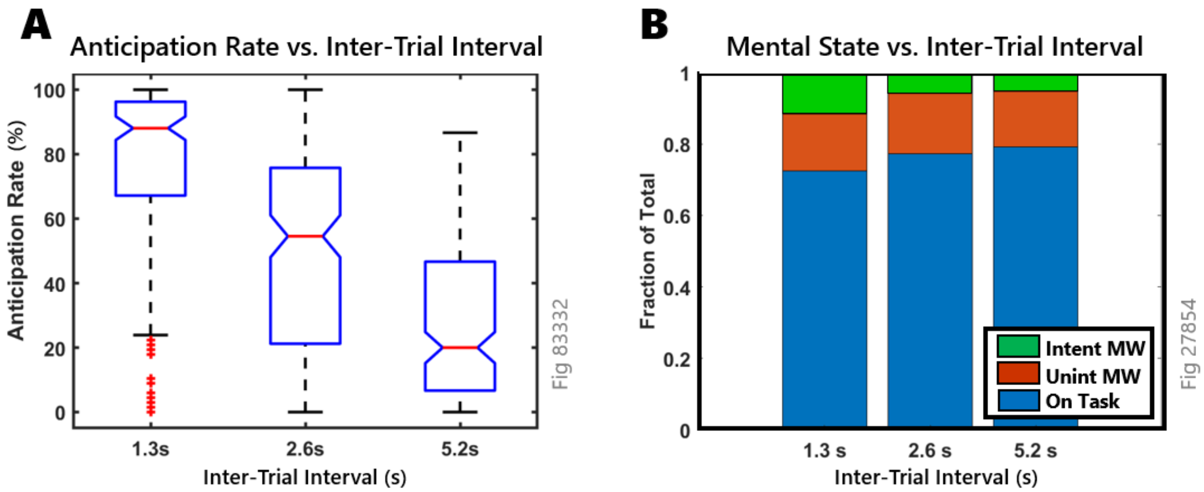

Figure 2: Mental response to task difficulty. Panel A: Anticipation Rate versus Inter-Trial Interval. Red lines are medians, indents are 95% confidence intervals for the medians. Box heights are the inter-quartile range. Whiskers represent the furthest range of non-outlier data. Small red plus signs are outliers that are more than $1.5\times$ the inter-quartile range from the 25th centile. Panel B: Mental state versus Inter-Trial Interval: subjective thought probes at the end of each block type. Green (top) = intentional mind wandering, red (middle) = unintentional mind wandering, blue (bottom) = on-task. MW = mind wandering.

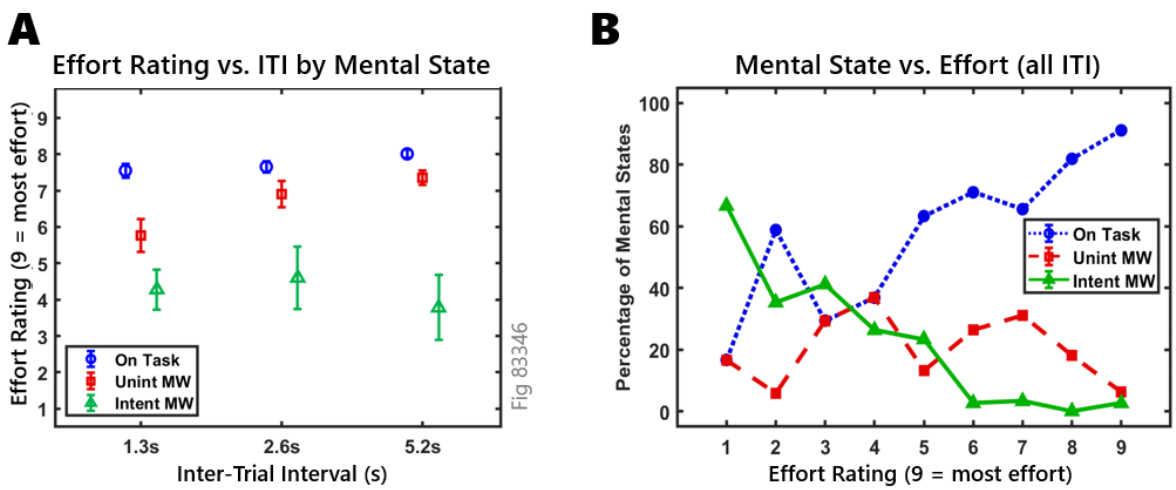

Figure 3: Effort Ratings: Panel A: Mean effort ratings on a 1 (lowest) to 9 (highest) scale (Y-axis) for each task (ITI, X-axis). MW = mind wandering. Panel B: Combining all three tasks, for each level of rating, the percentage of subjective responses corresponding to each mental state. On-Task (blue circles, dotted line) versus Unintentional Mind Wandering (red squares, dashed line) versus Intentional Mind Wandering (green triangles, solid line). Errors bars are SEMs.

5.2s (the very difficult to predict task), IMW elicits on average more omission errors (almost double) compared to OT and UMW (LME with interaction terms ITI × State, $t = 2.68, P = 0.007$ for both). At the other ITIs, mental state seems not to have an effect.

In Panel B of Figure 4 the maximum reaction time for each block is shown for each ITI and each mental state. The maximum reaction time for the highly predictable 1.3s task was significantly lower than in the other two ITIs (LME, $t > 2.97, P < 0.003$ for both). Again, only at ITI = 5.2s there is a greater maximum reaction time for IMW than in OT or UMW (LME with interaction terms, $t = -3.21, P = 0.0014$ for both).

3.5 Conscientiousness and Effort

Before the participants were exposed to any of the tasks, they were asked to make very quick ratings of their conscientiousness, based on two questions from the BFI-10 [17]. In LME models where the

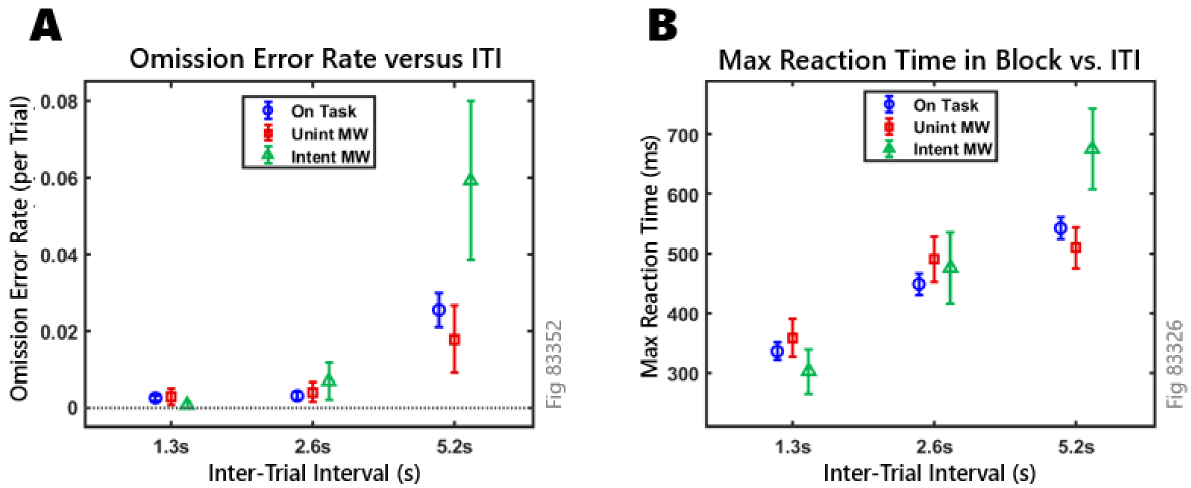

Figure 4: Objective Measures of Degraded Performance: Panel A is omission error rate (not including the first trial). Panel B shows the maximum reaction time for the entire block (not including the first trial). MW = mind wandering, intent = intentional, unint = unintentional.

participant's frequency of IMW (out of 6 blocks) was the outcome variable, conscientiousness was highly significant as a predictor variable ($t = -2.94, P = 0.0042$). In other LME models, "on-task" was also predicted by conscientiousness (LME $t = 2.21, P = 0.030$), but UMW was not (LME $t = -0.45, P = 0.65$). In an LME model for subjective effort as the outcome, increased conscientiousness was a significant predictor (LME $t = 1.97, P = 0.049$). Finally, an objective measure of inaccuracy (mean absolute reaction time) was improved by higher conscientiousness (LME $t = -2.31, P = 0.021$).

4 DISCUSSION

4.1 Overview of the Intentional Mind Wandering

Previous work has divided mind wandering into intentional MW and unintentional MW [22], possibly to address the inconsistencies between whether task difficulty increases or decreases MW. Here we rechecked the issue whether subjective responses match between intentional MW and subjective effort. [H1] We wanted to demonstrate that IMW is a low effort strategy, which is true (Figures 1 & 3A). [H2] We proposed and found that tasks that are both very predictable and easy would encourage a rational choice of IMW (Figure 2B). [H3] IMW was linked to low subjective effort (Figure 3), and thus the objectively easiest task (ITI = 1.3s) was linked to increased IMW (Figure 2B). [H4] As expected, the long ITI versions of the MRT were more difficult to perform correctly (Figure 2A). [H5] and [H6] IMW was linked to poor performance (omission errors and high maximum reaction time), but only in the least predictable task, which demanded persistent attention (Figure 4).

This information shows that there are objective, as well as subjective, differences between the poles of IMW and UMW, such as eliciting fidgeting and posture changes [28]. These objective differences in our experiment are quite noticeable, although they are only detectable in the version of the task that was least enabled by prediction and required the most sustained attention. The objective performance decrements linked to IMW relate to very occasional failures rather than to a consistently manifested problem. Given that automation increases MW frequency [8], our evidence supports the proposal that automation-induced MW is (a) due to complacency, (b) relates to intentional MW, and (c) supports the *unwillingness hypothesis* rather than the *resource depletion hypothesis*. Thus, it is likely that Gouraud et al.'s [9] intervention to increase mental demand by reducing automation reliability occurs below the point of critical challenge; our data and their surprising results fit together.

Our results are quite similar to those in [13], which showed that a high arousal task (e.g. a high-compliance activity task such as in our ITI = 1.3s) was characterised by more IMW, whereas a high executive control task (e.g. a task that demands constant attention and calculation such as our ITI = 5.2s) was characterised by more UMW. This supports our claim that IMW may result in partial attentional decoupling whereas UMW relates more to attentional overload; intentional partial decoupling is likely to be more difficult to detect, have fewer detectable consequences (because of an ability to perform successfully while partially decoupled), and result in more catastrophic accidents due to complete lack of situational awareness in the rarer occasions when safety deteriorates. Our results support Casner et al.'s [4] suggestion that partially automated cars would be safer with more (rather than less) driver effort to vouchsafe that the driver remains vigilant during automation oversight, and furthermore, that the total driver mental effort must exceed the point of critical challenge.

The main limitation of these results is that self-assessed thought probes are of questionable accuracy, a problem that dogs this field [25]. Previous MRT experiments [1] detected a subtle but statistically significant difference between UMW and IMW in the fatigue-induced deterioration of RRTv (a measure of inconsistency). In fact, by the end of their experiment, both UMW and IMW had

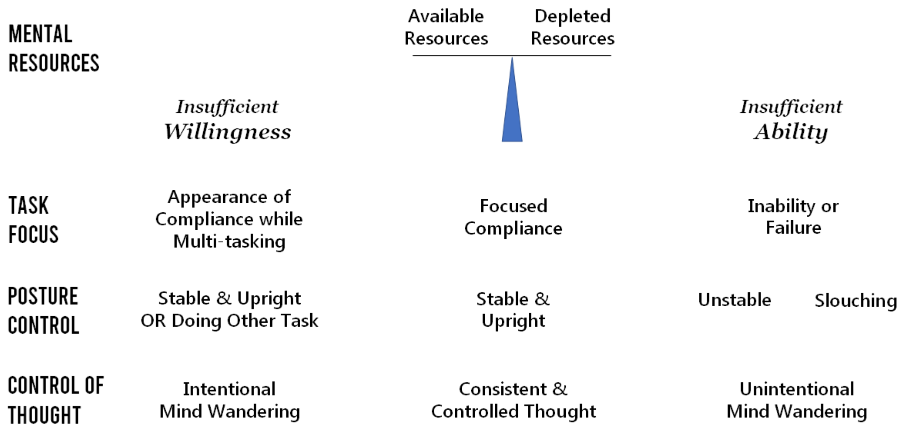

Figure 5: Proposal separating intentional MW from unintentional MW: balancing resource depletion (right) versus unwillingness (left).

similar levels of RRTv, but at the beginning of their experiment IMW started with more inconsistency, and UMW during additional blocks caught up. The implication is that UMW is a more likely response to fatigue and difficulty, whereas IMW is linked to executive failure and can potentially elicit poor performance from the beginning of an experiment if motivation starts low.

4.2 Conclusions and Future Research

In this work we supported the idea that the three poles of attentional states (on-task, unintentional MW, and intentional MW) are a conflict balancing between ability and willingness (Figure 5). This conflict is reminder of the long-standing tension between demands and ability from the flow literature, in which flow is situated between boredom and anxiety [6]. This supports the idea that both underlying theories of MW (*exhaustion of resources* and *executive failure*) play a role in triggering MW or undermining persistent attention on the task. A crucial *caveat* is that whereas nearly all instances of intentional MW are result in low effort, not all low effort situations result in IMW (see Figure 2). Intentionally mind wandering is a decision: many easy tasks will not result in IMW, and likewise, occasionally participants will inappropriately engage some difficult tasks with IMW. For example, here we show that personalities with low self-assessed conscientiousness are linked to IMW. Therefore, because strategies of intentional MW are nominally rational, and yet in tasks that are more difficult to predict (e.g. ITI = 5.2s), IMW does arise, this situation can lead to poor performance (Figure 4). Complacency [16] may be the basis of these nominally rational decisions that result in performance degradation and lapses in attention. Future work on this topic requires that predictable and unpredictable tasks are tested subjectively for both perceived difficulty and willingness/motivation.

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