Lingering delays in a go/no-go task: mind wandering delays thought probes reliably but not reaction times

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ABSTRACT

BACKGROUND: In a go/no-go task, lengthening the time between stimuli (e.g. changes to the inter-trial interval (ITI) or to the press percentage (PP)) are known to have decelerating effects on rapid reaction times and possibly on thought probe response time. The cause for these delays may be mind wandering (MW). MW-induced delays theoretically arise from serial mental resources being decoupled, leading to poor stimulus detection and perception.

AIMS: To see whether the delaying effects of ITI and PP are mediated by mind wandering (MW), and to explore the mental mechanisms of delay in a simple and a complex task.

METHODS: An 18-minute online experiment with 60 participants who each performed 8 versions of a sustained attention task (Test of Variables of Attention, ToVA) with different ITIs and PPs. After each block there were MW thought probes.

RESULTS: The slowing effects of long ITIs, low PPs, and MW seem to be synergistic, but the effects of individual factors are inconsistent. On ToVA reaction times (simple task), long ITIs caused delays, low PPs interacted with those delays, and MW seemed to have little consistent effect except when the certainty was maximized in the on-task condition. On thought probe response times (complex task), MW had strong effects, whereas there seemed to be no pattern to the lingering effects of longer ITIs or low PPs.

CONCLUSION: The decoupled resources theoretically linked to MW may be parallel and related to task-reorienting, introspection, or decision-making events comprising thought probe responses, rather than to perceptual detection events.

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CCS CONCEPTS

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

KEYWORDS

mental strategy, mind wandering, attentional resources, caution, effort, awareness, speed-accuracy tradeoff

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1 INTRODUCTION

1.1 Performance Decrement: Mind Wandering during Go/No-Go Tasks

Mind wandering (MW) is a family of states similar to daydreaming in which the thoughts stray from the task at hand [9, 12] Mind wandering is known to lead to performance decrement and accidents in a variety of work and vehicular contexts [15]. MW may contribute to increased accidents when supervising automated tasks [4], and paradoxically more automation may lead to worse human performance when the automation fails [2]. A laboratory system for observing performance decrement over time and fatigue or accidents with computers is Go/No-Go tasks. In a go/no-go task the computer user must make a very simple decision and then respond as quickly and as accurately as possible. By doing these simple tasks repeatedly over a longer time, go/no-go tasks allow experimenters to test users' ability to sustain their attention and to resist boredom or mental fatigue.

In each trial of a go/no-go task, an image appears on screen and the participant must press a response button as quickly as possible whenever one kind of image appears on the screen (the 'Go-stimulus'), but they must not press (i.e. inhibit) their response if a different kind of image appears (the 'No-Go-stimulus'). This means that these go/no-go tasks require both attention and arousal to detect the stimulus plus executive control to inhibit their instinctive actions during the no-go stimuli. Therefore, go/no-go tasks are linked with three types of performance decrement: slow responses, commission errors (pressing during a no-go-trial), and omission errors (failing to press when the go-stimulus appears). Two well-known examples of go/no-go tasks used to test participants' ability to sustain attention are the Sustained Attention to Response Task (SART) [7, 8] and the Test of Variables of Attention (ToVA) [6].

The traditional SART has an inter-trial interval (ITI, time between experimental trials) of 1150-3000 milliseconds (ms) and a press percentage (PP, the probability that in a given trial the participant will have to respond as opposed to withholding any action, i.e. the % of go-trials divided by the total number of trials) of 89% [8, 11]. Under these circumstances, healthy participants make many commission errors, an error type where a participant responds when they should have withheld any response. Such commission errors have been proposed to represent risks to innocent victims when law officers must make split second decisions between shooting at a perpetrator versus recognising an innocent bystander [14]. Commission errors are categorically linked to mind wandering [7].

However, the relationship between mind wandering and reaction time in go/no-go tasks remain controversial. Initially MW was shown to speed up responses to SART [11], presumably due to truncating serial mental processes, i.e. skipping a verification step after detecting a stimulus. An alternative view is that MW will slow down responses due to "perceptual decoupling" [12, 14]. Perceptual decoupling remains inconsistently defined. It could be the failure of a parallel (executive) process linked to paying attention, and this additional process either helps scanning the environment, or works purely at an executive level to maintain goal focus (see Figure 1A at left). Or perceptual decoupling could be complete failure of all outward attention, resulting in the addition of a serial (executive) refocusing and resumption step after a temporary discontinuity in scanning the environment (see Figure 1A at right). Or it could be a combination of both parallel and serial processes, in which a failure of a parallel process results in an extra serial process. At an experimental level, the direction of change of go/no-go reaction times during MW is not agreed, and may depend on which of the two processes above is dominant in a given individual [10].

The mental strategy in a go/no-go task may be changed in response to changing the press percentage, the inter-trial interval, or both additively; currently the effects of changing both PP and ITI are unknown. It is possible that the combined effects are no greater than the effects of either one, particularly if the effects are mediated by eliciting a uniform mental strategy, as would be predicted by a take-the-best heuristic [3]. When the press percentage in a go/no-go task is increased, there is a change in strategy that speeds up reaction times by up to 100 ms as well as increasing error rates. [14]. In addition to reaction times, we have shown at a previous ECCE conference [1] that when increasing the press percentage during a go/no-go task (from 20% to 80%), participants would unequivocally speed up (by nearly one second) their subsequent thought probe response time (to the question, "In the moment that just passed, were you focused on the task, mind wandering deliberately, or mind wandering spontaneously (without meaning to)?") [13]. The tentative conclusion from this extraordinary result is that MW leads to a lingering state of delay and lapsed attention that has an even greater effect on complicated tasks such as thought probes than it does on simple go/no-go tasks. Note that the additional compliant activity at 80% did not have clear effects on the reaction time element of the go/no-go task. If the *serial executive delay* hypothesis is true, then this might suggest that the additional refocusing executive step should delay the complex thought probe by a similar amount of time as the delay of the simpler reaction time. The observation that MW leads to far greater delays during a complicated task would mean that supposed short lapses occurring during go/no-go task, like a momentary break for looking away, cannot fully explain the much longer MW-induced delay of the thought probe. A momentary break during a go/no-go task would imply a serial process (see Figure 1A, right), where the delay would be an extra step of reorientation, and in a serial process model, that reorientation would be a constant time, irrespective of the following step. By contrast, in a parallel processing model of reorientation, where the reorientation step requires several attentional resources simultaneously, then a more complex task (such as task switching or introspection) could be much more delayed by the previous deployment of resources to the mind wandering thought than a simple button pressing task would be.

The main critique of the conclusion from this extraordinary result (i.e. MW causes longer delays in complex tasks) is that the thought probe decision itself may have led to unequal response times, in the absence of a previously lingering state of MW. The thought probe in [13] gave a choice of three options: on-task, deliberate mind wandering, and spontaneous mind wandering. One can easily imagine a situation where a person who has no thinking delays would answer with the on-task option instantly, but if they had actually been mind wandering, this undelayed person may have spent a moment thinking, "Okay, I was mind wandering, but was I doing it deliberately? And what is deliberate mind wandering, anyway?" To address this criticism, we needed a thought probe where the mind wandering option required no more introspection than the on-task option, such as a binary choice, where you were either mind wandering or not.

1.2 Aim and Hypotheses

Our aim was to extend our previous data [13] showing that a latent state (that is, MW) could linger from a go/no-go task (where it was elicited purposefully) to a subsequent rating task, where this state would no longer be strategically relevant. Our hypotheses were: (H1) Lower PPs and longer ITIs would add together in how they elicit MW, (H2) MW would lead to no consistent delay of the ToVA reaction time task, (H3) MW would lead to a consistent delay in the thought probe response time.

2 METHODS

2.1 Experimental Participants

Sixty 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

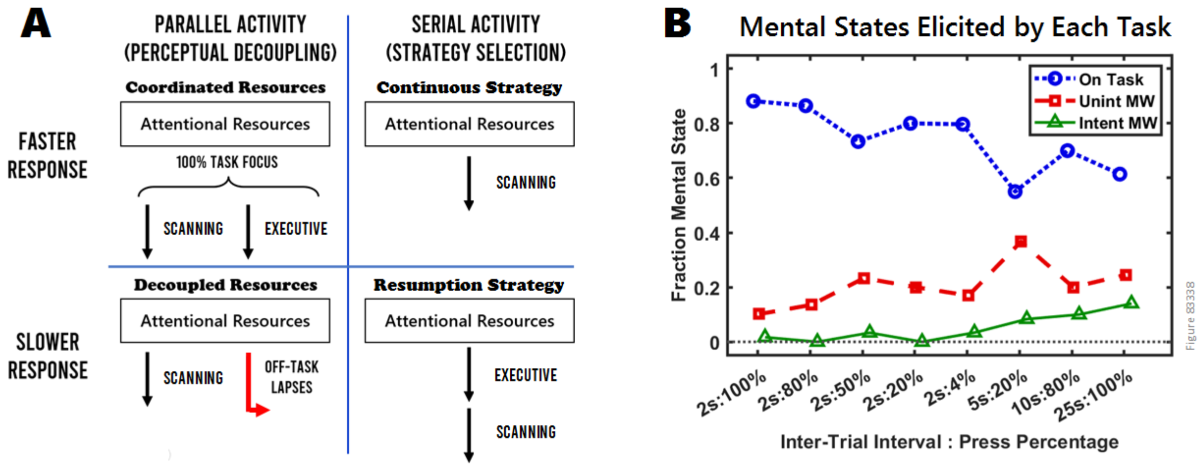

Figure 1: Panel A: Schematic of parallel vs. serial attentional resources relating to Mind Wandering (MW). Executive = verification + goal upkeep. Scanning is more related to detection and perception. Panel B: Responses to thought probe during different versions of the task. Unint = unintentional, Intent = intentional.

explicit informed consent (by pressing the letter "A", signifying "I agree") in accordance with the Declaration of Helsinki.

2.2 Protocol

Once recruited by advertising on Prolific, participants were sent to Pavlovia; 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: open text for participant number (provided by Prolific) and simple demographic data, informed consent including description of how to withdraw instantly and button press for "I agree", detailed instructions for both the experimental task (Test of Variables of Attention, ToVA) and for the subjective ratings that they would make, an explicit practice block (4 trials), announcement that the experiment would begin, a rehearsal block (50 seconds) that was never included in the analyses, 8 experimental blocks (50 seconds each) presented in a pseudo-random 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 Stimuli

The online go/no-go task (ToVA visual stimulus) was as described [6, 13], in which all responses were gathered by keyboard (i.e. not via mouse). For each trial, one of two easily distinguished images was presented: a go-stimulus (small box uppermost) and a no-go-stimulus (small box lower).

The entire trial (including the participant's response) was set to be the inter-trial interval (ITI). The combination of ITI and the ratio of go-stimuli versus no-go-stimuli (Press Percentage, sometimes referred to as "non-target" in the literature) were set differently for each block (see Results). The number of trials in a block was set to be approximately 50 seconds. Each block ended with a series of 3-4 subjective 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" (spacebar) or "Mind Wandering" (any other letter). If, and only if, the participant answered "Mind Wandering", the next part of the thought probe was presented, "Was your mind wandering:", and the choices were "Intentional" (spacebar) or "Unintentional" (any other letter). Two other ratings tasks followed the thought probes, and they will be described in a subsequent paper.

2.4 Analysis and Data Exclusion

Pavlovia 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 > 0.9 seconds. Individual subjective ratings were capped at 15s if the response time (e.g., thought probes and subjective ratings) > 15 seconds. A block was dropped if the block had more than 4 omission or commission errors. The entire participant was dropped if a participant's data included more than 3 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).

3 RESULTS

There were a total of eight versions of the go/no-go task that this cohort experienced (ToVA). Of the 474 non-excluded blocks, 122 (25.74%) were reported as mind wandering. Figure 1B shows the breakdown by task. There were subtle increases in mind wandering when more false alarms appeared (when press percentage was lower, as tested among the blocks with 2s inter-trial intervals), but these did not reach significance (LME, $t = 1.60, P = 0.11, N = 297$). There were slightly larger increases in MW when ITIs were longer (compare 2s:80% to 10s:80%, LME $t = 3.57, P = 0.0004, N = 474$ observations for entire cohort), but substantially larger increases in MW appeared when there was a co-occurrence of both slow ITI and many false alarms (5s:20%, interaction term, $t = 3.03, P = 0.003, N = 474$).

It appears as though intentional MW is elicited more by longer ITIs, whereas unintentional MW is elicited equally by both longer ITIs and by low PPs.

3.1 Mean Reaction Times

Figure 2 shows how mean reaction times (not including the first trial) varied when both the ITI was made longer and the PP was lower. Panel A shows that mean RT0 slowed down when the PP was lower for four versions of the task that all had an ITI = 2s. In an LME model for mean RT0 in these tasks, the effect of PP was highly significant ($t = -10.56, P = 2.6 \times 10^{-22}$) but the effect of mind wandering was not ($P = 0.29$). Panel B shows for two examples that when ITI is lengthened (i.e. the task becomes slower, but not longer), reaction time increases. Again this effect was significant ($t = 4.90, P = 2.13 \times 10^{-6}$) and the effect of mind wandering was not ($P = 0.18$). Panel C attempts to change the two features oppositely (to determine if one effect dominates) by maintaining a stable expected activity rate (button presses per minute). At left 2s:20% and 10s:80% both expect presses approximately once every 10s. The effect of the task was significant ($t = 2.75, P = 0.007$) while the effect of MW was not ($P = 0.40$). At right 5s:20% and 25s:100% both expect a button press every 25s. The effect of the task was significant ($t = 24.1, P = 6.40 \times 10^{-31}$) and so was the effect of MW ($P = 0.013$). When considered in total, 3 of the 8 task versions seemed to be significantly slowed by MW (2s/100%, 2s/20%, and 25s/100%), one of the task versions was significantly sped up by MW (2s/50%), and the remaining 4 of the 8 tasks were apparently modestly slowed down by MW but in a way that was not significant. Considering all of the task versions in one model, MW slows ToVA reaction times by 23.5 ms (LME for all blocks together, with predictors task type and MW, $t = 3.08, P = 0.002$); however, if data for ITI = 25s is removed from the model, the delay becomes non significant (11.7 ms, $t = 1.64, P = 0.10$). The implication is that ITI has a slightly stronger effect on slowing reaction time than does PP, and that MW has only a weak slowing effect unless it is combined with another factor that slows down reaction times (in this case, an ITI of 25s or a PP of 100%).

3.2 Lingering Mental Effects on Thought Probe Response Time

We previously detected a difference in the thought probe response time between blocks that were on-task versus those that were mind wandering [13], so we looked to see that this result was repeated here. Figure 3A shows that there is a fairly clear delay in thought probe response time elicited by MW for virtually every version of the task (LME, $t = 6.13, P = 1.84 \times 10^{-9}$, except 2s:20%, which did not reach significance). The estimate for the additional time needed to respond to the thought probe is 890.5 ms. So MW delays the response to the thought probe by nearly one second, whereas it only delays the mean reaction time (see Figure 2) by 23.5 ms.

The implication is that the demands of the thought probe allow for the detection of MW-induced effects, whereas the lesser demands of the ToVA reaction time task do not. In addition, it must be assumed that whatever MW state is elicited during the ToVA task, it lingers into the thought probe task.

4 DISCUSSION

The effects of mind wandering *per se* on reaction times are controversial [10, 11], and in many cases no consistent delay can be found [13]. However, our team has previously found evidence that a three-way thought probe (between on-task, deliberate MW and spontaneous MW) manifested unequivocally slower thought probe responses when mind wandering than when on-task [13]. However, this delay could have been due to the nature of the thought probe used in that study. Furthermore, there is no established theory for why a thought probe would be delayed by MW but a simple go/no-go task would not be. In the current experiment we re-designed the thought probe into a simpler two-way choice to minimise the chance that thought probe delay is due to the phrasing of the thought probe. We also used many more versions of the go/no-go task to determine if these inconsistent delays might be ascribed to another state, such as caution or uncertainty, which are elicited based on the specific ITI or PP used in the task.

Our results were: (H1) Both longer ITIs and lower PPs led to increased MW, and there was an additive effect between ITI and PP, which means that there was not (in this experiment) a ceiling effect or a single heuristic such as a "take-the-best" strategy [3]. (H2) MW led to a weak and inconsistent delay of the ToVA reaction time, and when considered en masse, any delay would be on the order of 20-50 ms. (H3) MW led to a delay of the thought probe response time of nearly 900 ms.

Thus, there is a vast difference in the size of the effect of MW on go/no-go reactions times of ToVA versus response times for the interpretive and introspective decisions of the thought probe. The mental events allowing for the response to the ToVA reaction time are:

(1) Detect visual stimulus
(2) Decide between the go and no-go options
(3) Double check that you have correctly matched the image to the response (optional)
(4) Press the button (which your finger is already on)

In this list, performing optional steps causes serial delays (see Figure 1A). There has been an ongoing argument in the literature that MW-induced effects might be limited to delayed detection (1), but Wilson et al. have used varied press percentages with go/no-go tasks to suggest that the go/no-go reaction time was actually being slowed by a slower mental strategy, not decoupled perception [14]. By contrast, although the delaying effects of ITI and PP on go/no-go reaction times of ToVA are clear, the effects of ITI and PP on thought probe response time seem to have no pattern. Thought probe response times take about five-times longer than the ToVA reaction times because it is a much more complicated task that requires more mental events:

(1) Detect visual stimulus
(2) Orient away from reaction times and to a new task
(3) Read the instructions to the thought probe (optional)
(4) Introspectively consider one's own previous attentional state
(5) Decide between potential competing options
(6) Figure out which button to press, and press it

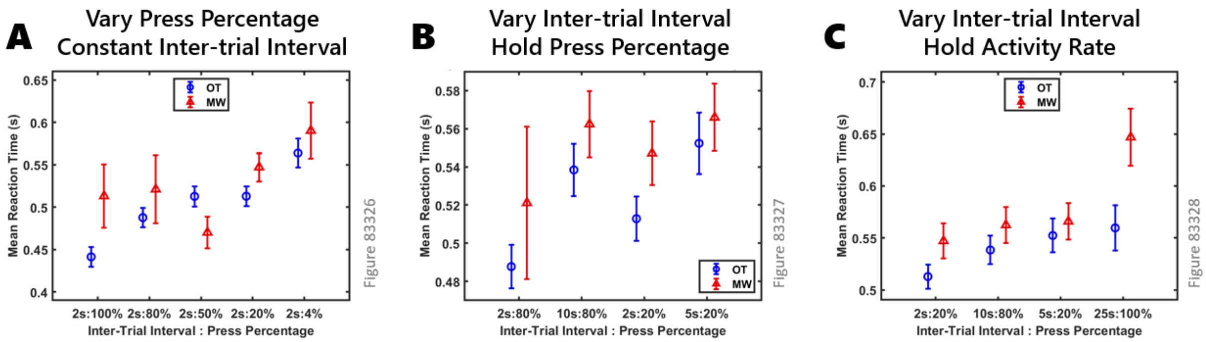

Figure 2: Mean reaction times are slowed by longer Inter-Trial Intervals and lower Press Percentages. Panel A: As press percentage is decreased, reaction times slow down. Panel B: Two pairs of tasks showing that when inter-trial interval is lengthened, reaction times are slowed down. Panel C: Two pairs of tasks with the same activity rate (10 seconds and 25 seconds) despite having altered both press percentages and inter-trial intervals. Error bars are SEMs. OT = on-task (blue circles); MW = mind wandering (red triangles).

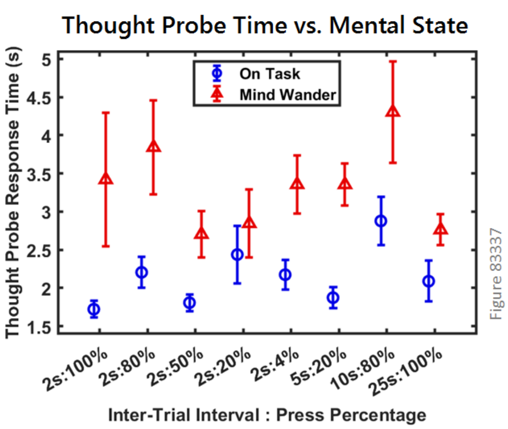

Figure 3: Slowed response lingers into thought probe response time. On-task (blue circles) responses are compared to mind wandering (red triangles) for each task version.

Given that MW slows thought probe response times, presumably one or more of those mental events are slowed down by MW. All or most of the above may contribute to the MW-induced delay, or possibly only one.

Although the brittle and inconsistent effects of MW on ToVA reaction times might at first blush suggest random variation due to low N numbers (see Figure 2C), the data for ITI = 5s and ITI = 25s are split almost evenly between on-task and MW (see Figure 1B), so each of those graphed points represents about 30 participants. Because we have tested so many variations of ToVA, we have been able to detect that MW does tend to slow the reaction time, but really noticeable slowing only occurs when the comparator on-task measurements are faster due to certainty (PP = 100%). This may suggest that MW and uncertainty are causing the same form of short mental delay, and this uncertainty delay is uniform and cannot be extended by having both MW and mid level PP (see 2s/50%, Figure 2A). This fits with the observation that increased automation leads to increased mind wandering because there is less to do [4]. Furthermore, unreliable automation when participants supervise an autopilot increases mental demand but without changing the probability of mind wandering [5]; it seems as if the MW and the uncertainty are competing for the same serial mental resources during the ToVA reaction time. The implication is that certainty, in both our experiments and Gouraud et al.'s supervising automation experiments [5], can make people careless leading to a shortening in serial activity (i.e. a truncated strategy in the PP = 100% version), which does not occur during most forms of MW [11].

4.1 Conclusions and Future Research

Our experiments show that MW induces a lingering state that strongly slows down subjective response times (but not most ToVA reaction times) via a decoupled parallel strategy. MW only slows down ToVA reaction times when the comparator on-task reaction time is during a task of high certainty (PP = 100%). If these on-task responses represent the simple, continuous serial strategy, then MW and uncertainty may both equally prevent the continuous strategy and elicit a uniform resumption strategy. Instead of MW causing a gross change in awareness slowing all attentional resources (so-called decoupling of perception, see Figure 1A), it seems more likely that mental resource decoupling may slow down complex mental actions such as orienting, reading, introspection, and decision-making. Future research should focus on isolating these mental events to determine whether MW has delaying effects on orienting, introspection and decision-making. The main limitations in this experiment are the reliability of thought probes in representing conscious states, which is described elsewhere [13]. It is possible that the resumption strategy we observed in simpler tasks is due to more caution or to less certainty, so future experiments should have subjective measures of both caution and certainty.

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