Modelling mind wandering : investigating the effects of fatigue on mind-wandering through a SART test

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Abstract

This study examined the effects of fatigue on mind wandering by simulating 25 participants in a SART test. Two models were made, one to use as a control model to compare the fatigued model to. The fatigued model was designed with the theories of vigilance in mind and tested using the same number of trials and participants. Results show that the accuracies of the participants simulated by the fatigued model were significantly lower than the base model, showing that a fatigued mind mind-wanders more than the base model.

Keywords: Mind-wandering; SART; fatigue ; Cognitive modelling ;

Introduction

Mind wandering, an ever-present phenomenon in the human experience, is estimated to take up to 50 percent of our daily life (Killingsworth & Gilbert, 2010). Ruminations during mind wandering are widely categorized into two main categories: Task-Related Interferance (TRI) or Task Unrelated Thoughts (TUT). Where the former is cued by contextual triggers highly associated with an individual's ability and experience with the task at hand, while the latter are thoughts completely unrelated to the task and may come in the form of prospective future planning or even autobiographical thoughts(McVay & Kane, 2009).

Previous studies define mind wandering as a failure of cognitive control in which our attention decouples from the task at hand (McVay & Kane, 2012). It can be triggered by environmental and situational factors, but may also be facilitated by tasks that required low cognitive processing. Krimsky, Forster, Llabre, and Jha (2017) found that during a working memory task, performance declined with the progress of time while mind-wandering increased. Risko et al. (2012) discovered that during a lecture, mind-wandering increased as a function of time, while memory for lecture content decreased. While Walker and Trick (2018) detected that in a driving task, difficulty focusing increased over time, while driving speed and speeding variability increased as well. Similarly, (Thomson, Seli, Besner, & Smilek, 2014) found that mind-wandering and performance over time were closely connected.

From these papers, it can be seen that mind wandering is facilitated by states of mental tiredness when the brain has exhausted mental resources to pull from. The papers above highlight how mind wandering increase due to 'mental tiredness' or fatigue that induces attenuation of attention on cognitively expensive tasks such as driving and paying attention to a lecture. However, this study has not been studied on a smaller scale. Therefore we decided to look into how we could implement fatigue in a mind-wandering model.

The word fatigue can be interpreted in many ways. In this study, fatigue is used to refer to mental fatigue, a state where the brain fails to complete mental tasks that require self-motivation and internal cues in the absence of demonstrable cognitive failure(Smallwood & Schooler, 2015). In terms of cognition, mental fatigue can be seen in two different ways, it can be thought to occur as a result of low arousal levels, in which performance decrements are due to the lack of stimulation needed to maintain alertness on a task (Ballard, 1996). Or, it can be seen as a result of monotonous and prolonged perceptual processing that exhausts the brain of cognitive resources, making it hard to maintain attention (Parasuraman, 1986), often resulting in habituation (Mackworth, 1969).

Based on these two aspects of mental fatigue, we can see an overlap between mind-wandering and fatigue in which both have a clear lack of cognitive resources and a monotonous task on which an individual has to spend their attention span on. The mindlessness theory of vigilance stresses this link by stating that tasks that are repetitive and monotone lead to disengagement and mind wandering with TUTs in a way that attentional resources are drawn away and attentional lapses occur (Körber, Cingel, Zimmermann, & Bengler, 2015). Moreover, A study done by Stawarczyk and D'Argembeau (2016) found that there were interacting and additive effects between mind wandering and sleepiness, something also characterized by mental fatigue. Due to the literature presented above, we theorize that mental fatigue will have an additive effect and increase the frequency of mind wandering. Hence our research question: "How does implementing fatigue affect the accuracy of a mind-wandering model in a SART task?"

To investigate the effects of fatigue on mind wandering, we will be using a cognitive model to simulate the performance of individuals on a Sustained Attention to Response Task (SART) Test. The SART test is a psychological test used to measure individuals' attention by testing how well they are able to inhibit responses to certain target stimuli. The test is described as a GO/NO-GO task in which a series of letters are singularly presented on a screen and participants are informed of a designated button to press every time a 'non-target stimulus' is presented. If the letter presented is a 'target stimulus', then the participants have to withhold their response and not press any buttons. Based on the literature above, we infer that when an individual is mind-wandering, they will create a habitual response where they press the button regardless of the stimulus on screen. Therefore, we will quantify the frequency of mind wandering by observing the average accuracy score of the participants.

Model

The model used in this experiment was built on the ACT-R Architecture, a cognitive modeling tool that puts emphasis on the interaction effects of declarative memory and procedural knowledge in the human cognitive process. We decided to use ACT-R as it provides us with a theoretical framework that has a solid foundation for modeling cognitive processes as its mechanisms reflect the cognitive assumptions needed to model cognitive processes such as mind-wandering

Our implementation was inspired by van Vugt et al's model in which mind-wandering was simulated by a primary production rule that retrieves two competing goal chucks, i.e. the *wander* chunk and the *attend* chunk. Figure 1 shows how the model responds to the SART test, depending on which goal chunk is currently active. The top circle in the diagram represents the *check current goal* production rule which was designed to either retrieve the *attend* chunk or the *wander* chunk depending on which chunk has a higher activation level. This then triggers two different pipelines of production rules which work as follows.

When the *attend* chunk is retrieved, a chain of production rules fire showing how an individual notices the appearance of a stimulus, identifies what it is, and retrieves the correct corresponding response. This process is linearly driven forward by the use of sub-goals which makes sure that the production fire consecutively.

On the other hand, when the model is wandering, the *mind-wander* production rule fires and retrieves a memory chunk from the declarative memory. This production rule serves as a fork that either retrieves a *random-memory* that keeps the model in the mind-wandering loop or retrieves the *remember-to-attend* memory chunk that returns the model back to the attend pipeline. Both models in this study implement one *random-memory* that points back to mind wandering and one *remember-to-attend* memory. If a *random memory* is retrieved, then the check-memory-wander production rule fires. This production rule then checks if there is an appearance of a stimulus in the visual buffer, if so, the mind-wandering standard response fires, and the model gives a habituated response to the SART test before resuming the *mind-wander* loop production rule. Due to the nature of the stimulus in the SART task, the model assumes that individuals stay in a mind-wandering state despite the presentation of stimuli. This is in line with "Dias" (n.d.)argumentation that low-arousing stimulus should not disrupt the state of mind wandering.

In order to create a fatigued model, we used the same implementation as the base model but altered how the chunks are retrieved and cleared. Aligning with the literature above, a fatigued mind is known to be more susceptible to mind-wandering (Stawarczyk & D'Argembeau, 2016), therefore to simulate fatigue over time, we manipulated goal chunk activation levels through production rules in the model in order to strengthen the *wander* goal chunk over time, making it higher than the *attend* goal chunk. As a result, the likelihood of the model selecting the *wander* chunk over the *attend* chunk will be augmented, resulting in increased mind wandering.

To increase the activation of the *wander* goal chunk over time, we altered how the production rules retrieve chunks and clear the retrieval buffer, recognizing that activation levels increase with a greater number of retrieval requests and implicit clearings.

As the *check-current-goal* production rule serves as the main fork that chooses between the two goal chunks, we decided to explicitly clear its retrieval buffer so as to not have any goal-strengthening mechanism there. Instead, we left implicit clearings in either of the two pipelines. In the wander pipeline, we explicitly clear the retrieval of the *remember-to-attend* memory chunk that points back to the retrieval of the *attend* goal chunk. This was done so that in the *mind-wander* production rule, we decrease the likelihood of that chunk being chosen, and instead inflate the likelihood of the *random-memory* chunk to be retrieved. This should then trigger *check-memory-wander* which retrieves the *wander* chunk thereby activating and strengthening it when it is cleared by the *mind-wander* production rule.

On the flip side, in the attend pipeline, we inhibit the strengthening of the *attend* goal chunk by explicitly clearing it from the retrieval buffer of the *identify-stimulus* production rule. This reflects how individuals experience increasing fatigue over time, which impairs their ability to focus on a task.

As a result of this, when the *check-current-goal* production rule fires, it will slowly lean to retrieve the wander chunk more than the attend chunk, which also further strengthens the wander goal chunk and make the model mind wander more.

This implementation was based on previous papers that concluded that when an individual is fatigued, they have lower motivation to attend to tasks.By constructing these two models (base mind wandering and fatigued mind wandering), we are able to test our hypothesis by running the model with the same experimental setup and quantitatively comparing the results.

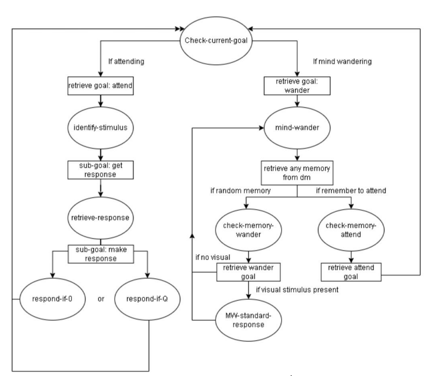

Figure 1: Implementation of mind wandering

Methods

In order to investigate the effect of fatigue on mind wandering, we have made two models that simulate mind wandering during the SART test with and without the effects of fatigue.

This experiment makes use of a simple version of the SART test that requires participants to differentiate between the letter ”O” (target stimulus) and the letter ”Q” (non-target stimulus). It will be run with random occurrences of stimulus, with the target stimulus appearing 180 times (90%) and the non-target stimulus appearing 20 times (10%). The participants have to withhold their response when the letter ”Q” appears. Each stimulus appearance will last for 2 seconds with an interstimulus interval of 0.5 seconds.

By using this setup, we aim to observe the frequency of mind wandering by measuring the accuracy of responses. We hypothesize that habituation occurs as a result of mind-wandering and that individuals who are mind-wandering will respond with a standard response regardless of the stimulus on the screen. This habituated response is implemented by simulating a button press regardless of the stimulus on the screen. This way, we can quantify and observe how frequently mind-wandering occurs by looking at the number of errors that an individual makes. To evaluate the results of the experiment, we will be running the model on a SART Test with 25 participants with 200 trials each.

Results

In this section, we present the findings of our experiment. Figure 2 shows the distribution of participant accuracies between models. It is observed that there is a small difference in the means between the accuracies of participants simulated by the base and fatigued model. Due to violations of normality, we tested this difference using a one-way Wilcoxon rank sum test between the accuracy of participants from the base model ($mdn = 0.92$) and the fatigued model ($mdn = 0.92$) and it was found that there is a significant difference between the two groups, $W = 465, p - value < 0.05$, with the base model's participants scoring significantly higher.

Figure 3 shows the accuracies of participants across non-target trials. We focus our analysis on the non-target trials as the implementation of the model (discussed above) facilitates mind-wandering identification through the occurrence of habituated responses. Therefore, we specifically examined the responses to non-target trials as a measure of how often the model is mind-wandering. Comparing figure 3 to figure 2, we can see that participants generally score lower on non-target trials. This is because the model's design does not have a mechanism to answer falsely during target trials, therefore all inaccuracies are produced by responses to non-target trials.

Figure 3 highlights how the base model's participants score relatively higher on the non-target trials compared to the participants of the fatigued model. Due to violations of normality, We conducted a one-sided Wilcoxon rank sum test to compare the accuracies of participants on non-target trials between the base model ($mdn = 0.20$) and the fatigued model ($mdn = 0.15$), and it was found that the base model's participant accuracy on non-target stimulus was significantly greater ($W = 132750, p < .05$).

Moreover, we also decided to look into the average reaction times of participants between models. It was found that the base model has a higher average reaction time than the fatigued model. Since the data was normally distributed, a one-way T-test was conducted between the reaction times of correct responses in the base model ($\mu = 0.227$ and $\sigma = 0.00742$) and the fatigue model ($\mu = 0.215$ and $\sigma = 0.00647$). It was found that the participants in the fatigued model have a significantly faster reaction time than the participants from the base model ($t(df = 47.12) = 6.01, p < .05$).

Figures 4 and 5 show the binned activations of goal chunks in both the base model and the fatigued model. The former shows that the base model strengthens both the *attend* and *wander* chunk over time while the latter shows that the fatigued model strengthens the *wander* chunk and weakens the *attend* chunk over time. The accuracies presented above show that the fatigued model mind wanders more over time. Non-parametric tests were conducted to verify this, as the data violated the assumption of normality. A two-tailed unpaired Wilcoxon rank-sum test on the activations of the *wander* chunk between the base model ($mdn = 5.52$) and the fatigued model ($mdn = 5.50$) was conducted and it was found that there was a significant difference ($W = 135129, p < 0.05$). Moreover, a one-way unpaired Wilcoxon rank-sum test was conducted on the activations of the *attend* chunk between the base model ($mdn = 5.52$) and the fatigued model ($= 5.38$) and it was found that the *attend* chunk activation levels of the base model was significantly higher ($W = 239607, p < 0.05$).

In support of the lower accuracies found in the fatigued model that indicate a higher rate of mind wandering, a one-way wilcoxon rank-sum test was conducted on the differences of goal chunk activations[1] between the fatigued model ($mdn = 0.122$)and the base model ($mdn = 0.0004045$) and it was found that the difference in goal chunk activations of the fatigued model was significantly greater. ($W = 226832, p < 0.05$)

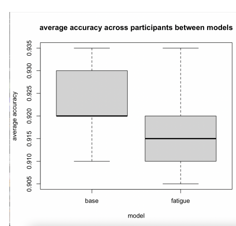

Figure 2: Average accuracies of participants between models.

Discussion

The results section of this study validates our hypothesis that the mind mind wanders more when it is fatigued as the ob-

[1] *wander* chunk activation - *attend* chunk activation

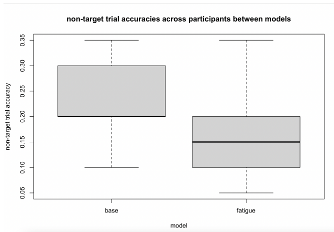

Figure 3: Average accuracies of participants on non-target trials

Figure 4: Average binned goal chunk activations of base model

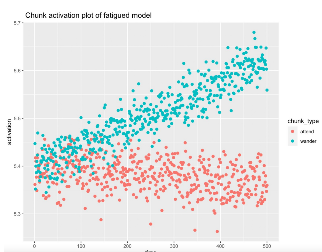

Figure 5: Average binned goal chunk activations of fatigued model

served differences in participant accuracies between models indicate that the fatigued model mind-wanders more than the base model. The significantly lower accuracies of participants on non-target trials in the fatigued model provided further evidence to validate this since incorrect (habituated) responses during non-target trials indicate that the model is mind-wandering. Therefore our hypothesis was proved to be true.

The model's trace of chunk activations indicates that the difference between the activations of the *wander* and *attend* goal chunks was significantly higher in the fatigued model, with the *attend* chunk's activation being significantly lower in the fatigued model than the base model. Therefore, the increased frequency of mind wandering in the fatigued model can be attributed to the increased difference of goal chunk activations with respect to the decreasing *attend* goal chunk activations of the fatigued model. This is because having a higher *wander* activation with respect to the *attend* chunk's activation immediately increases the likelihood of the model mind wandering regardless of *wander* activation differences between models. This comes as a result of explicit clearings that inhibits the strengthening of the *attend* chunk, which in turn, promotes the production rules in the mind-wander pipeline to fire and strengthen the *wander* chunk. These results and reasoning align with the literature that suggests that mental fatigue produced by a lack of cognitive resources is likely to increase the rate of mind wandering (Risko, Anderson, Sarwal, Engelhardt, & Kingstone, 2012) due to the scarcity of attentional resources (Walker & Trick, 2018)

The model's performance further reflects the cognitive plausibility of its implementation through accuracies and reaction times that align with (Thomson et al., 2014)'s findings, wherein accuracies of non-target trials were found to be worse as a result of habituation. Moreover, the faster response times to target trials in the fatigued model also reflected the theories of habituation during mind-wandering in which habituated responses are said to occur faster. However, this design choice has proven to be unfavorable as it does not work well with the experimental setup of the SART test.

Due to the nature of the habituated responses that can only indicate mind-wandering episodes during non-target stimulus appearances, it becomes difficult to track the rate of mind wandering over time through the experiment. This is because the experiment is designed to present the non-target stimulus with random intervals. Therefore, the accuracy results of the experiment do not show an increased rate of mind wandering over time despite the activations levels in figure 6 that point in that direction. This weakness could be a point of improvement for future researchers to come up with a different implementation or experiment design that has better operationalisation.

On the other hand, the simple architecture of the model may require further evaluation with other tasks in order to validate its generalisability. It is important to note that the model does not have real-world data to compare against, which raises the question of whether the observed increase in mind-wandering rate aligns with actual experimental results. Highlighting the fact that models have 'perfect conditions' means that it might not produce the same results as experiments that make use of thought probes and external indicators of mind wandering. Despite this limitation, the simplicity of the model's design allows for versatile use in future studies that may use different tasks to investigate the links between mind-wandering and fatigue. Specifically, it may be a good base model to work with to investigate further aspects of mind wandering and fatigue such as the effects of fatigue on mind-wandering episode durations.

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