Tuned In or Zoned Out: Investigating the Influence of Meta-Awareness in Mind Wandering on Working Memory under Varying Task Difficulty

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Abstract

Mind wandering, the shift of attention from external tasks to internal thoughts (Smallwood & Schooler, 2014), affects executive functioning, particularly working memory. While traditional theories explain its mechanisms and relationship to task difficulty, they often overlook distinctions between different mind wandering states. However, it has been suggested that mind wandering is not a singular process but a multidimensional phenomenon, with meta-awareness being a key factor (Seli et al., 2018b). This study was inspired by Smallwood et al. (2007), who demonstrated that EF task performance differs depending on whether mind wandering occurs with or without meta-awareness. This study aimed to investigate how the presence or absence of meta-awareness in mind wandering influences working memory performance under varying levels of cognitive demand. Participants completed an n-back task with experience sampling probes to assess their attentional state. Results revealed that working memory performance was highest when participants were on task, followed by tuning out, and lowest during zoning out episodes, but this pattern was more pronounced under low task difficulty. Contrary to predictions, participants performed better under high than under low task difficulty. These findings ultimately contribute to the growing understanding of mind wandering and executive functioning, supporting the idea that meta-awareness plays a crucial role in mitigating the negative impact of mind wandering on performance. Furthermore, they challenge existing theoretical assumptions about task difficulty, highlighting the need for more nuanced models.

Keywords

Mind wandering, Meta-awareness, Working memory, Task difficulty, Executive functioning, Cognitive load

Introduction

We get lost in our thoughts every day, even though we tend not to notice it right away. Depending on what is counted as mind wandering, some studies suggest that we spend up to around 45% of our days engaged in thoughts which are unrelated to the task at hand (Killingsworth & Gilbert, 2010). Considering that mind wandering seems to be so fundamentally embedded in our day-to-day lives, it comes as no surprise that this phenomenon has piqued the interest of poets, authors and researchers alike.

Mind wandering describes a phenomenon in which attention shifts from external tasks to internal thoughts (Smallwood & Schooler, 2014). While it can facilitate creative thinking (Gericke et al., 2022), it generally impairs executive function performance (Kam & Handy, 2014). Executive functions are defined as top-down mental processes enabling goal-directed behaviors, which are crucial for self-regulation, focus, and problem-solving. In practice, executive functions allow individuals to control behavior, such as resisting dessert while on a diet or remembering a password to access their email. The core components of executive function include inhibition, working memory, and cognitive flexibility (Miyake et al., 2000). Although all three of these functions are essential for navigating daily life, working memory stands out as being particularly important (Diamond, 2012). Working memory is defined as a cognitive function which enables temporary holding and use of information (Diamond, 2012). It allows for complex reasoning and problem-solving and has even been credited with enabling tool use in human evolution (Engle, 2010). All crucial features that, to some extent, make us humans who we are. Fortunately, working memory can be trained and improved through various styles of cognitive training, helping us perform better on a range of complex tasks (Klingberg, 2010).

The relationship between mind wandering and executive functioning has been the focus of several theoretical accounts, including the Attentional Resource Theory (Smallwood & Schooler, 2006) and the Control Failures x Concerns Theory (McVay & Kane, 2010). The primary difference between these theories lies in their explanation of the mechanisms behind mind wandering. The Attentional Resource Theory posits that mind wandering arises from a competition for limited cognitive resources between task-related and task-unrelated thoughts. According to this theory, mind wandering requires the active engagement of executive resources to support the generation and maintenance of task-unrelated thoughts (Smallwood & Schooler, 2006). On the other hand, the Control x Concerns Theory suggests that mind wandering results from a failure of the executive control system to suppress automatically generated thoughts while engaged in a task (McVay & Kane, 2010). So, from this viewpoint, mind wandering occurs not because of an excess of available resources but rather due to insufficient cognitive control to maintain task focus. Both theories thus provide different explanations for how executive functions, including working memory, are disrupted by internally directed attention.

Task difficulty plays a central role in understanding the relationship between mind wandering and working memory. As tasks become more challenging, they place greater demands on working memory, drawing on increased cognitive load. According to Cognitive Load Theory, cognitive load refers to the demand placed on working memory during learning (Bannert, 2002). Research shows that increases in task difficulty elevate cognitive load, which in turn influences both working memory performance and mind wandering. For example, Krimsky et al. (2017) found that under higher cognitive load, participants made more errors over time, indicating a decline in working memory efficiency. Interestingly, participants also reported fewer instances of mind wandering during these more demanding tasks, suggesting that fewer mental resources were available for internally

directed thoughts. However, since the study focused solely on visual working memory, further research is needed to determine whether similar patterns occur across other domains of cognitive demand.

Drawing from the framework of Attentional Resource Theory by Smallwood & Schooler (2006) it is suggested that, while performing easier tasks, the surplus of executive resources that are not needed for the task can be used to let the mind wander, without interfering with the task (Thomson et al., 2015). In contrast Control Failures x Concerns Theory by McVay and Kane's (2010) theory posits that easier tasks tend to allow for more intrusions, because easier tasks require less cognitive effort, therefore needing fewer executive resources to be actively engaged (Seli et al., 2018a). Since there is less engagement, there is also less of an active control barrier that can keep out the mind wandering thoughts. In short, both theories agree that an easier task leads to more wind wandering, but they differ in their explanations of the mechanism. The Attentional Resource Theory emphasizes available surplus resources being used for mind wandering, while the Control Failures x Concerns Theory focuses on weakened cognitive control, which allows thoughts to intrude. Even though the claims brought forward by these theories about the interplay of mind wandering and task difficulty have been supported (Brosowsky et al., 2021), there is evidence of the contrary, with other findings suggesting a different effect. For instance, Feng et al. (2013) found that participants reported more mind wandering when reading difficult texts as opposed to easy texts. This inconsistency highlights the importance of further research to clarify how different task difficulties shape mind wandering tendencies and how these can affect working memory performance.

Although the above-mentioned theories acknowledge the role of task difficulty, they have largely treated mind wandering as a monolithic construct, failing to differentiate between different types of mind wandering states (Seli et al., 2018b). However, mind wandering is a highly complex phenomenon that extends beyond the simplistic notion of "task-unrelated thought" (Mills et al., 2017). Its heterogeneous nature varies across multiple dimensions, and failing to consider these variations may lead to profound misinterpretations (Seli et al., 2018b). Mind wandering and its effect on executive functioning represents a fundamental challenge to human performance across virtually all domains. Given that we spend almost half of our waking hours engaged in task-unrelated thoughts (Killingsworth & Gilbert, 2010), understanding this phenomenon is not just academic curiosity, but essential for optimizing human cognitive functioning. Mind wandering research can be used to inform attention strategies which are applicable in many different domains. For example, in educational settings, where students engage in tasks of varying difficulty everyday, understanding when different types of mind wandering are most detrimental can inform teaching strategies and interventions. Moreover, working in high risk environments, where being unaware during routine tasks can pose a serious safety risk, attention strategies can help to significantly increase workplace safety. To address the problem of a binary definition of mind wandering, research by Smallwood et al. (2007) distinguished between two types: tuning out and zoning out. Tuning out is described as mind wandering episodes in which the person is aware of their drifting off. For instance, when reading a book, someone might notice that they are not focused anymore but can quickly refocus their attention. Other times, one's mind drifts off, but they only become aware of it after the fact; this is called zoning out. The main distinction between these two terms is the presence or absence of meta-awareness. Meta-awareness is defined as the ability to observe and reflect on the content of one's thoughts and mental state (Schooler, 2002). Although it was long thought to be redundant (Seli et al., 2017), research has shown that it can be actively trained (Seli et al., 2017), which makes it an important dimension to consider, since it can help to reduce mind wandering and therefore improve executive functioning (Kam & Handy, 2014). This is demonstrated by Price et al. (2023), who aimed to investigate how increased meta-

awareness, facilitated through mindfulness-based attention training, could help reduce mind-wandering episodes. They found that participants who underwent mindfulness training (i.e, increased meta-awareness) became more aware of their actions, leading to a decrease in mind-wandering frequency. In a similar vein, Smallwood et al. (2007) examined the relationship between meta-awareness and mind wandering, discovering that individuals who were unaware during episodes of mind wandering tended to make more errors. Although research has found effects of meta-awareness on mind wandering on various task performances, such as reading (Baird et al., 2013), driving (He et al., 2011), or attending a lecture (Varao-Sousa & Kingstone, 2019), there is a notable lack of studies examining how meta-awareness in mind wandering specifically influences working memory.

Given the findings presented above, two key gaps remain in the current literature. First, meta-awareness may mitigate the disruptive effects of mind wandering on cognitive performance (Smallwood et al., 2007), however, the nature of this relationship across varying levels of task difficulty has yet to be empirically established. Second, while mind wandering and task difficulty have each been shown to influence working memory independently (Krimsky et al., 2017), it remains largely unexplored how meta-awareness during episodes of mind wandering affects working memory performance, particularly across varying levels of task demand. To address this gap, this study aims to explore how the presence or absence of meta-awareness in mind wandering states (i.e. tuning out and zoning out) can influence working memory performance under varying task difficulties. The results are aimed to contribute to developing interventions aimed at improving meta-awareness and further inform theoretical models on the relationship between meta-awareness in mind wandering and executive functioning. In line with previous research and theories (Kam & Handy, 2014; McVay & Kane, 2010; Smallwood & Schooler, 2006), this study expects that maintaining on-task focus will yield the highest working memory performance compared to any mind wandering state. This expectation is grounded in the idea that focused attention on the task allows for optimal use of cognitive resources and thus optimal performance, whereas mind wandering introduces interference with task-unrelated thoughts Therefore, it is hypothesized that:

Hypothesis 1a: *Working memory performance is higher during on-task focus than during episodes of tuning out.*

Hypothesis 1b: *Working memory performance is higher during on-task focus than during episodes of zoning out.*

Moreover, evidence suggests that not all forms of mind wandering are equally disruptive. Specifically, zoning out, characterized by a complete lack of meta-awareness, has been shown to impair response inhibition more than tuning out, where individuals retain some awareness of their mental drift (Smallwood et al., 2007). According to Smallwood et al. (2007), the deeper engagement in internal thoughts during zoning out consumes more cognitive resources, which in turn leaves fewer resource available for the task at hand. Based on this reasoning, it is hypothesized that:

Hypothesis 1c: *Working memory performance is higher during tuning out than zoning out.*

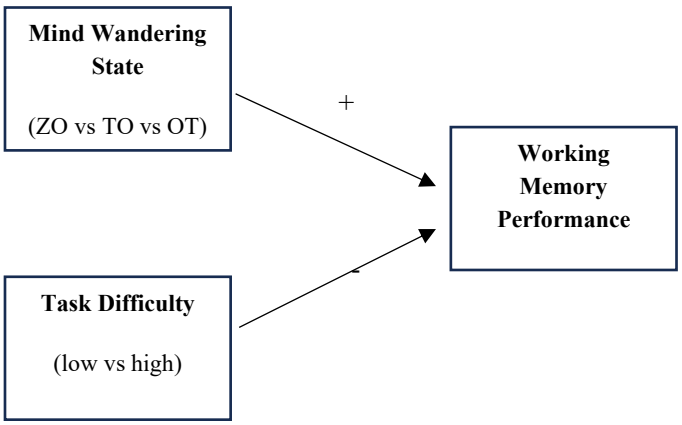
Finally, task demands play a significant role in performance outcomes. Prior studies have demonstrated that performance declines more steeply over time when individuals are exposed to high difficulty tasks compared to low difficulty tasks (Krimsky et al., 2017). This suggests that more difficult tasks tax cognitive resources more heavily, exacerbating the effects of mind wandering. Consequently, it is hypothesized that:

Hypothesis 2: *Working memory performance is better under low task difficulty than under high task difficulty.*

Figure 1 presents the causal relationship between the proposed variables, describing how as meta-awareness in mind wandering increases, so does working memory performance and as task difficulty decreases, working memory performance increases.

Figure 1

Schematic Model of the Relationship between Mind Wandering State, Task Difficulty & Working Memory Performance.



As a measure of working memory performance, participants completed an n-back task (Gilmour et al., 2018), with the task difficulty being manipulated through the match or non-match trial types within the task. Throughout the task, mind wandering state was measured using an experience sampling technique that intermittently prompts participants to report their current mental state. As this study was part of a larger bachelor thesis project, alongside the n-back task, participants also completed a visual detection task. However, this will not be analyzed in this report.

Methods

Participants

Participants were recruited through a purposive sampling strategy, primarily utilizing the University of Amsterdam student body. All 34 participants had normal or corrected-to-normal vision and a sufficient command of the English language. Of the 34 participants, 80% were female, and 20% were male. The ages of participants varied from 20 to 24, with an average age of 21,26 and a standard deviation of .91. Most participants were right-handed, with only 5.98% reporting being left-handed. Data collection was conducted over eight weeks during in-person lab sessions at the Roeterseiland University Campus Behavioral Sciences Lab. This study was approved by the Ethics Committee overseeing the research conducted at the University of Amsterdam.

Design

The first independent variable of this study was the presence or absence of mind wandering with or without meta-awareness, as defined by Smallwood & Schooler (2007). This variable was operationalized using experience sampling (ES) (Christoff et al., 2009), intermittently prompting participants to report their current mental state. For this study, the ES method was adapted to not only probe for the absence or presence (on task or off task) of mind wandering but also for whether the participant was tuning out (TO) or zoning out (ZO) (Smallwood et al., 2007) to detect meta-awareness.

The second independent variable, task difficulty, was operationalized using different trial types in the n-back, which was used to measure the dependent variable. The trial types were either match or non-match (Kam & Handy, 2014). In a match condition, the current letter would match the previous one. This represents a low cognitive load, as these did not require participants to update the stimulus letter in their minds. In a non-match condition, the letter shown currently does not match the one shown previously; since this requires an updating of the letter, this represents a high cognitive load.

The dependent variable was working memory performance, operationalized using the n-back task. This task is a reliable and well-validated measure of working memory in cognitive neuroscience and takes accuracy and reaction time as its primary measures (Gilmour et al., 2018). A schematic overview of the n-back including experience sampling and a visualized explanation of the distinction between match and non-match can be found in Appendix B. This study focused on accuracy, with higher accuracy indicating better working memory performance. In this within-subjects task, participants had to determine if the currently displayed stimulus matched the one presented one step earlier. To counterbalance the order of experiments, half of the participants were randomly assigned to first complete the n-back task, while the other half were randomly assigned to first complete the visual detection task.

Materials

Participants were asked to provide demographic information, including age, gender, and handedness. The experiments were conducted on full-screen computer displays in a well lit laboratory room. The n-back was programmed in Python using the PsychoPy toolbox developed by Peirce (2007). Participants were first presented with two instructional slides: the first provided a general overview of the task, while the second offered detailed instructions regarding key responses for each trial type, mind wandering classification, and the procedure to exit the experiment. . The exact introductory and instruction slides are provided in Appendix B. The stimuli consisted of a subset of consonant letters (*C, B, D, F, G, H, J, L*, and *M*) randomly presented one at a time, centred on the screen in white text (50-pixel height) against a black background. A white fixation cross (5 pixels) was displayed for one second between stimuli presentations at the centre of the screen. Each letter was displayed for 0.7 seconds, followed by a fixation cross shown for a randomized duration between 1.9 and 2.1 seconds, in which the participants should respond. They were asked to respond to each stimulus using the specified keys, with a left key indicating a match and the right key indicating a non-match. Participants completed 12 practice trials with feedback ("*Wrong!"* or "*Correct!"* shown for one second) to familiarize themselves with the task. Apart from the feedback, the practice trials were identical to the main task trials. The main task consisted of 720 trials, divided into blocks, with Experience Sampling probes appearing randomly every 15 to 20 trials. An equal proportion of match and

non-match trials were included. Participants were shown a "*Thank you"* screen to signal the end after completing the experiment. The experience sampling probes asked participants to indicate their mental state immediately before the probe with the question, "*Where was your attention just now?"* Participants had to respond using a keypress to indicate whether they were "on-task" ("*d"*), "off-task (aware)" ("*g"*), or "off-task (unaware)" ("*j"*).

Procedure

Every participant was asked to come in for two sessions, each lasting about 45 minutes up to an hour. There had to be one day between the sessions to avoid effects of fatigue. Before beginning an experiment, participants were informed about the general content of the procedure. They were also asked to provide informed consent for their responses to be used in subsequent analyses. During the n-back task, pupil dilation was measured for a related research project. Therefore, participants were instructed to sit upright and focus on the centre of the screen to ensure the eye tracker functioned optimally. They received verbal instructions on how to perform the tasks and a description of the different mind wandering states and asked whether these were clearly understood. Participants were also informed of their right to stop participation at any time and of the right to revoke their permission for their data to be used. The experiment then consisted of either the n-back task or a visual detection task. There was always one experimenter present to supervise the sessions. After completing both of the tasks, participants were debriefed about the purpose and aim of the study.

Data Analysis

Performance on the n-back task was assessed by comparing accuracy across match and non-match trials and across mind wandering states. Average accuracy scores were calculated for each trial type and each participant. These scores were further categorized based on the attentional states reported in the ES probes (on task, TO, ZO). Only the eight trials preceding each ES probe were analyzed, based on the temporal dynamics of attentional states, as reported by Sonuga-Barke and Castellanos (2007), who suggested that attentional states fluctuate at a rate of 10–15 seconds.

The primary analysis consisted of a repeated measures ANOVA examining the effects of mind wandering state and trial type on accuracy, including Bonferroni corrected pairwise comparisons. These were conducted using JASP, with the significance threshold set at $p < .05$ and effect sizes reported. In order to ensure that the ANOVA assumptions were met, Shapiro-Wilk tests and Q-Q plots were used to assess normality violations (Muhammad, 2023). Missing data were removed during preprocessing under the assumption that the data were missing completely randomly (MCAR; Glas, 2010) and participants with missing data were subsequently removed. Moreover, to ensure proper task compliance and to ultimately reduce noise, participants with an accuracy of below 0.6 were excluded (Pedersen et al., 2022).

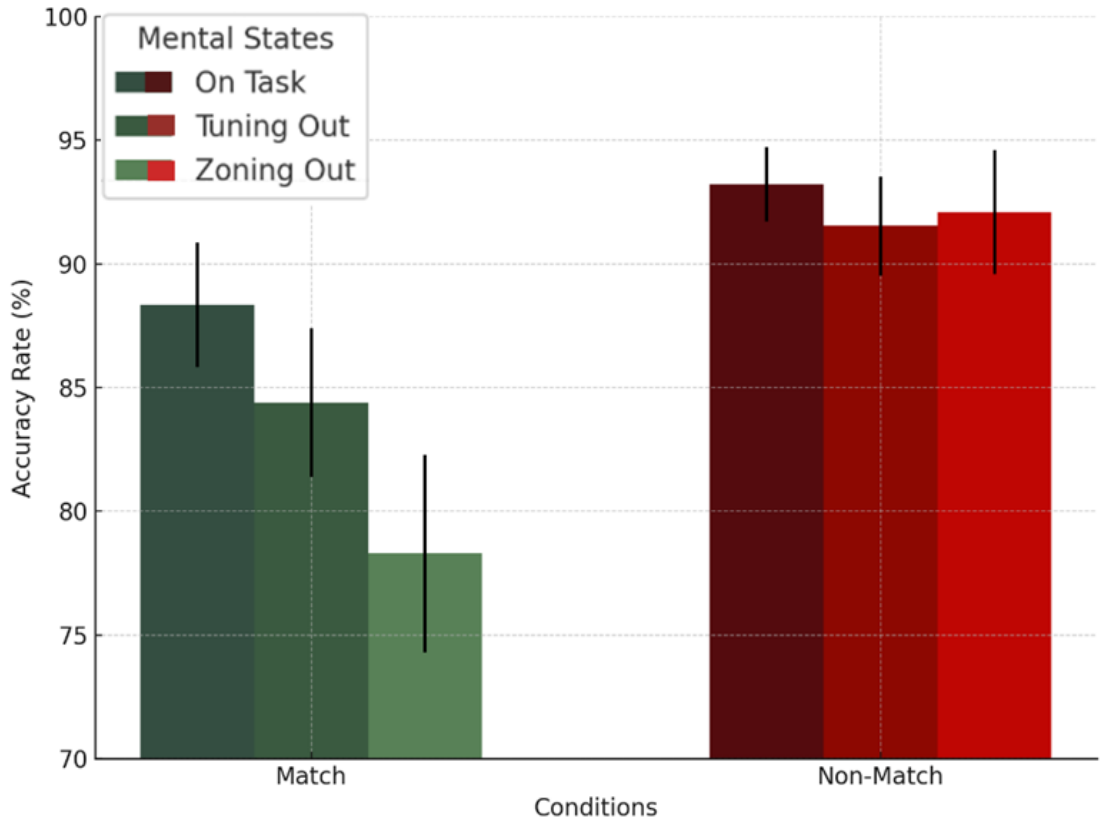
Results

Descriptive Statistics

Across the dataset, there were an almost equal amount of match (50,85%) and non-match (49,15%) trials present. For the mind wandering reports, the most selected state was on task (51,26%), followed by tuning out (34,46%) and then zoning out (14,28%). The average accuracy rates across trial types and mental states, including error bars displaying the standard deviation, are displayed in Figure 2.

Figure 2

Average Accuracy Rates across Trial Types and Mental States, with SD



Confirmatory Analysis

A repeated measures ANOVA on the effects of trial type (match vs. non-match) and mind wandering state (OT vs. TO vs. ZO) on accuracy was conducted using JASP. After preprocessing the dataset in Python as outlined in the data analysis plan, the data were imported into Excel for further inspection. Participants were screened for missing values and for overall accuracy below 0.6, which led to the exclusion of eight participants. The final sample for analysis consisted of 25 participants from the original 34. After preprocessing the file as described in the data analysis plan utilizing Python, the data was loaded into Excel and participants were inspected for missing values and an overall accuracy of below 0.6. This led to an exclusion of eight participants, leaving 25 of the original 34 for data analysis.

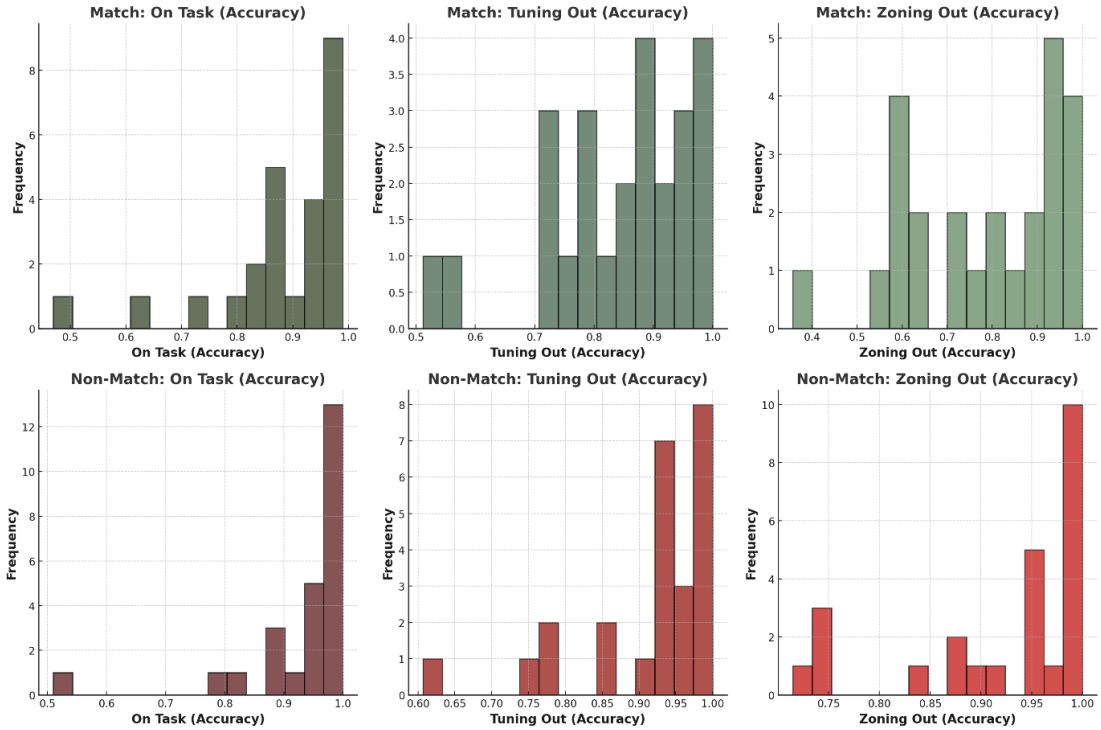
The analysis revealed that the main effect of trial type was significant ($F(1, 24) = 17.71$, $p < .001$, $np^2 = .184$) as was the main effect of mind wandering state ($F(2, 48) = 4.03$, $p = .024$, $np^2 = .052$). This indicates that both

performance on match and non-match trials as well as in different mental states significantly differed. Moreover, the interaction between trial type and mind wandering state was also significant ($F(2, 48) = 4.928$, $p = .011$, $np^2 = .036$), meaning that the effect of trial type depends on the mind wandering state.

Bonferroni corrected pairwise comparisons inspecting trial type showed that participants performed better in non-match compared to match trials ($t(24) = -4.209$, $p < .001$). The comparisons between mental states revealed a significant difference between on task and zoning out ($t(24) = 2.840$, $p = .020$) for both match and non-match. However, no significant difference was found between tuning out and zoning out ($t(24) = 1.4$, $p = .498$), or between on task and tuning out ($t(24) = 1.43$, $p = .475$). Furthermore, the analysis for the interaction effect suggests that performance in match trials was significantly higher in on task than it was compared to zoning out ($t(24) = 4.08$, $p < .001$), but not significantly different from tuning out ($t(24) = -1.07$, $p = 1.000$). For the non-match trials, no significant differences in accuracy were found between the mind wandering states. Specifically, performance did not differ between on task and tuning out ($t(24) = 0.684$, $p = 1.000$), on task and zoning out ($t(24) = 0.455$, $p = 1.000$), or tuning out and zoning out ($t(24) = 0.229$, $p = 1.000$). However, all p - values for the Shapiro -Wilk tests were significant for all conditions, indicating that the data violates the normality assumption. This was supported by visual analysis of the Q - Q plots, showing deviations in all conditions, especially for ZO. The histograms (Figure 3) further illustrate this variability and skewness of accuracy within each condition.

Figure 3

Distributions of Accuracy Scores across Conditions, organized by Trial type and Mind Wandering State



Exploratory Analysis

In light of the assumption test results, an additional nonparametric analysis using the Friedman test was run using Python. The test inspected the same relationship as the confirmatory analysis. The results also indicated that there was a significant difference between the conditions (X^2 (6) = 38.52, $p < .001$, $W = 0.26$).

Post hoc pairwise comparisons for match trials revealed a significant difference between on task and zoning out ($p < .001$), with accuracy being significantly higher when on task compared to zoning out. Moreover, this test found a significant difference between on task and tuning out ($p < .05$) with performance being better in on task compared to tuning out. These results support Hypothesis 1a and Hypothesis 1b, which predicted that working memory performance would be higher during on-task focus than during episodes of tuning out or zoning out, respectively. A significant difference was also found between tuning out and zoning out ($p < .05$), indicating that accuracy is higher when tuning out compared to zoning out, supporting Hypothesis 1c.

In the non-match conditions accuracy was again significantly higher for on-task compared to zoning out ($p < .001$), and tuning out was significantly better than zoning out ($p < .001$), lending further support to Hypothesis 1b and Hypothesis 1c in the context of lower task difficulty. However, no significant difference was found between on-task and tuning out ($p > .05$), indicating that Hypothesis 1a was not supported in the non-match (lower difficulty) condition.

To summarize, for match conditions (lower difficulty), we see a significant difference between on task, tuning out and zoning out, with on task having the highest accuracy, followed by tuning out and then zoning out supporting Hypothesis 1a, Hypothesis 1b, and Hypothesis 1c . In the non-match conditions (lower difficulty), zoning out remained the lowest-performing state, while on-task and tuning out did not significantly differ, thus only Hypothesis 1b and Hypothesis 1c were supported. Lastly, this pattern of results does not support Hypothesis 2, which predicted better performance under lower task difficulty, as the actual overall accuracy of participants was higher in non-match trials (higher difficulty). A summary of the Nemenyi test post hoc pairwise comparisons are to be found in Table 1.

Table 1

Summary of Post Hoc Comparisons of the Nemenyi Test Across Conditions

Pairwise Comparison	***p*-value**	**Direction of Effect**
Match: On task vs. zoning out	**< .001**	On task > zoning out
Match: On task vs. tuning out	**< .05**	On task > tuning out
Match: Tuning out vs. zoning out	**< .05**	Tuning out > zoning out
Non-match: On task vs. zoning out	**< .001**	On task > zoning out
Non-match: On task vs. tuning out	> .05	-
Non-match: Tuning out vs. zoning out	**< .001**	Tuning out > zoning out

Note. Significant *p* – values are bolded, no correction applied

Although both a Friedman test and a repeated-measures ANOVA were conducted, the repeated-measures ANOVA results were not considered for interpretations, due to the severe violations of the normality assumption. Therefore, all conclusions and interpretations are based on the Friedman test and its post hoc comparisons.

Discussion

To assess how the presence or absence of meta-awareness in mind wandering can differently influence working memory under varying task difficulties, the present study had participants perform an n-back task while measuring their mind wandering with experience sampling probes. The results overall support previous findings, the Executive Resource hypothesis and the Control x Concerns hypothesis, positing better working memory performance in a focused compared to a mind wandering state. However, although not present in the high task difficulty condition, we also see the predicted interaction between mind wandering state and performance (TO > ZO) in the low cognitive demand condition. Interestingly, though performance was predicted to be higher in the low cognitive demand condition, the opposite was seen in the results.

Although the initial hypothesis concerning mind wandering states could only be partially supported, the low task difficulty condition findings still suggest that working memory performance is differentially effective depending on the presence of meta-awareness. Importantly, this illustrates the effect of better working memory performance with increased meta-awareness. This pattern aligns with Smallwood et al., 2007, whose findings suggest a difference in executive functioning as a function of meta-awareness being present in mind wandering. However, the results of this study suggest that this distinct pattern may depend on task difficulty. According to the Attentional Resources Theory (Kahneman, 1973, as cited in Bruya & Tang, 2018) and prior research on related cognitive functions (Vannucci et al., 2018), high cognitive load likely diminishes the attentional resources available for monitoring processes. With more cognitive resources allocated to the demanding task, there might be less capacity for meta-awareness, resulting in fewer instances of mind wandering with meta-awareness. This reduction in resources may blur the distinction between tuning out and zoning out.

The current study further provides evidence challenging the findings by Krimsky et al. (2017) which showed more errors under higher cognitive load compared to a low cognitive load. One possible explanation for the pattern observed in this study is that higher task difficulty may promote increased cognitive engagement, as suggested by Dong et al. (2015). When tasks are more challenging, they may demand greater focus and mental effort, enhancing performance despite the higher cognitive load. These findings however also demonstrate the importance of investigating task difficulties across different mind wandering states, as its effects may vary depending on the type of mind wandering.

A key strength of this study is its multidimensional approach to understanding mind wandering. Although the field is gradually evolving, many studies continue to treat mind wandering as a simple binary construct, classifying states along the lines of on-task or off-task. The diverse classification system employed here (on-task, tuning out, zoning out) revealed meaningful differences that would have been overlooked by traditional approaches. Additionally, this study employed a methodologically robust and valid measurement to study the variables at hand. The n-back measure is a gold standard for measuring working memory in cognitive neuroscience (Gilmour et al., 2018), which, unlike subjective measures, provides precise outcome measures of working memory performance.

While this study contributes valuable findings to the field of mind wandering and working memory, it is essential to consider certain limitations that may influence the interpretation and generalizability of the presented results. Firstly, it is important to stress that the reliability and generalizability of this study's results are limited due to various factors, including the sample size and the population used (the majority being young female university students, recruited through purposive sampling).

Secondly, it is quite possible that not all participants optimally or accurately reported their mental state. According to verbal reports following the experimental sessions, they often either a) defaulted to on task or tuning out or b) reported that it was hard to tell what their preceding mental state had been, therefore maybe answering incorrectly. Even though all participants were instructed on how to distinguish the different terms and asked if they needed clarification, a short experiment period simply might not have given everyone enough time to adequately familiarize themselves with the terms. To account for this, the experience sampling probes could include reminders, short explanations or concrete examples to reinforce the distinctions periodically. Another way to address this issue could be to include reaction times as a measure of mind wandering state (Smallwood et al., 2007). This additional measure would make it possible to compare the reported state with the reaction times and validate the self-report. For example, if someone repeatedly reports being on task, while their reaction times become slower, this might be an indication that the self-report was not accurate. This would result in a design that balances reliance on self-reports and objective data. For now, including this measurement was outside of the scope of this study, however it is strongly advised to explore this further.

Thirdly, another shortcoming of this study is the way task difficulty was operationalized using match and non-match conditions in the n-back. The two conditions were used to represent either high or low cognitive load, ensuring they were presented at random and in equal proportions. However, this still leaves room for repeated trials within the experiment, potentially encouraging more mind wandering due to prolonged cognitive demands of one kind. To address this limitation, a more structured randomization approach could be used, where match and non-match trials are still distributed randomly and equally but within predefined blocks (e.g. preceding an experience sampling probe). This would minimize the likelihood of sustained periods dominated by either match or non-match trials.

A critical consideration for future research concerns the ceiling effect observed in the current task, as illustrated in Figure 3 of the results section. Participants performed very well on the task, with most accuracy rates exceeding 0.8-0.9 (which ultimately also resulted in a lack of a normal distribution). However, tasks that measure mind wandering must be sufficiently easy to allow for intrusions to happen, but there is a strong need to find a better balance between task difficulty and mind wandering opportunity. According to the Attentional Resource theory (Smallwood & Schooler, 2006) and the Control x Concerns hypothesis (McVay & Kane, 2010), a task that is too difficult will demand excessive cognitive control, reducing opportunities for mind wandering. Conversely, a task that is too easy may not effectively engage working memory. While significant differences were observed between conditions, they were, in some cases, relatively marginal (shown by the effect sizes of the RM ANOVA and Friedman test). To account for this, future studies could test working memory with different measurements or variations. One obvious one would be to test an n-back again, but to increase *n* to two or three. Other tasks, like a complex span task (Foster et al., 2015), could also be tested to gain a more comprehensive understanding. Mainly

and most importantly, the task needs to be challenging enough to engage working memory while still allowing for sufficient mind wandering.

Research has demonstrated that mindfulness interventions, such as breathing exercises (Turkelson & Mano, 2021), can enhance individuals' ability to monitor their mental state (Wong et al., 2018) and improve working memory capacity (Mrazek et al., 2013). A potential avenue for further studies would be to explore how meta-awareness can be directly manipulated within task designs without requiring prior mindfulness training. In practice, this could look like, for instance, developing in-task reminders that will prompt more frequent monitoring to stop people from drifting off without being aware of it. In a further step, a simple yet effective method like this could be implemented in tests which take working memory as a measure (such as standardized IQ tests). If a simple reminder could reduce episodes of zoning out, such findings could have immensely useful implications for enhancing working memory performance in a competitive environment.

Examining an abstract cognitive concept like mind wandering has always and will always involve a plethora of pitfalls and difficulties. However, this should not deter one from making them the subject of their investigations. Discovering new ways of unravelling these covert mental states is imperative to gain a more comprehensive understanding of cognition. By exploring nuanced distinctions, researchers can refine traditional theoretical models and better explain how different aspects of mind wandering, such as meta-awareness and task difficulty, interact with and influence executive functioning.

Positionality Statement

As a bachelor student of Psychology with a focus on cognitive sciences, my education has immersed me in an academic environment which prioritizes scientific reasoning and empirical research. This background has shaped my understanding of knowledge as being objective and measurable. My personal ontological perspective is rooted in realism, viewing reality as ultimately existing independently of human perception. While engaging with research and theoretical frameworks I allow myself to approach psychological phenomena with both academic rigor and personal insight. I acknowledge that my immersion in academics may introduce certain biases, potentially limiting my capacity to consider alternative perspectives. In order to prevent this, I aim to reflect on my work, carefully and critically examining how my education and personal experiences might have influenced my research approach and subsequent interpretations.

Conflict of Interests

There is no conflict of interest.

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Appendix A

Task Introduction and Instructions

Hello and welcome to this experiment!

Thank you for participating!

Before we start with the experiment, you will receive instructions about the experiment. Please read them carefully!

After reading the instructions, practice trials will be presented to check if you understand what you need to do.

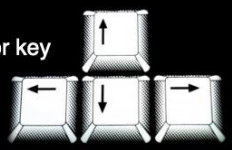
Press the spacebar to continue.

Instructions

You are presented a continuous string of letters (BCDFGHJLM) in the centre of the screen, in random order. Between every stimulus presentation, a cross appears on the screen, during which you can still respond to the stimulus.

You are required to determine whether the letter shown does or does not match the previous one.

- If the letter presented, **matches** the previous letter: press the **left** cursor key
- If the letter presented, **does not match** the previous letter: press the **right** cursor key



Try to respond as fast and accurate as possible!

Press the spacebar to continue. But only when you completely understand these instructions!

Appendix B

Schematic n – back and experience sampling overview

