**Evaluating the Wandering Mind’s Role in Learning:**

**An Extension Study**

Molly Rooyakkers, Filip van Opstal, & Lucia Talamini

Brain & Cognition Program Group

Faculty of Social and Behavioural Sciences, University of Amsterdam

**Author Note**

Molly Rooyakkers (12750824), Brain and Cognition (Major), Research Master’s Psychology, University of Amsterdam

Dr. Filip van Opstal, Brain and Cognition Program Group, University of Amsterdam

Dr. Lucia Talamini, Brain and Cognition Program Group, University of Amsterdam

We have no conflicts of interest to disclose.

Correspondence concerning this article should be addressed to Molly Rooyakkers. Email: molly.rooyakkers@student.uva.nl

**Abstract**

Previous research has suggested that mindwandering can be detrimental to learning and attention. However, the attentional resources theory of mindwandering proposes that mindwandering can run parallel to cognitive processes which do not require attention. A recent study conducted by Brosowsky et al. (2020) supported this theory, finding evidence that mindwandering interfered with explicit, but not implicit, motor sequence learning during a serial reaction time task. To test if the finding generalizes to other types of learning, the current study used a perceptual sequence learning serial reaction time task with a similar paradigm to Browsosky et al. (2020). Bayesian linear models indicated that mindwandering interfered when participants were explicitly, but not implicitly practicing the perceptual training sequence. Additionally, this study found no evidence to support perceptual sequence learning occurring implicitly, nor mindwandering having a detrimental effect on explicit learning. Implications for a nuanced approach to mindwandering and learning are discussed, as mindwandering may have differential effects on different learning tasks.

*Keywords:* mindwandering, attention, implicit learning, serial reaction time, perception

**Evaluating the Wandering Mind’s Role in Learning:**

**An Extension Study**

When the mind wanders, it switches from the current task to internally generated thoughts (Christoff et al., 2016; Smallwood & Schooler, 2015). The process of mindwandering cannot be activated by the external environment or directly observed, making it an elusive process to study (O’Callaghan et al., 2020). Previous research has found that mindwandering can be detrimental to performance during specific tasks, such as reading, driving, or retaining information (for a review, see Mooneyham & Schooler, 2013). The attentional resources theory of mindwandering suggests that mindwandering and performing a task compete for attentional resources (Smallwood & Schooler, 2006). As a task becomes easier, autotomized, or unengaging, participants are more likely to mindwander as the task no longer requires extensive attentional resources (Schooler et al., 2011; Smallwood & Schooler, 2006). Further, it has been found that mindwandering is less detrimental for tasks that require low attention (Andrews‐Hanna et al., 2014; Hutt et al., 2016; Smallwood & Andrews-Hanna, 2013). Therefore, if mindwandering and performing a task do not compete for attentional resources, then mindwandering should not impair task performance (Brosowsky et al., 2020b).

**Implicit and Explicit Learning**

Implicit learning is the process of obtaining complex information or solving a problem without awareness or intention (Shanks, 2005). Implicit learning has been investigated across numerous disciplines (for a review, see Cleeremans et al., 1998), but has been most commonly investigated using a serial reaction time (SRT) task (for a review, see Schwarb & Schumacher, 2012). Moreover, implicit learning has frequently been tested by having participants learn sequences without intention (e.g., Boyer et al., 2005; Gheysen et al., 2010; Gheysen et al., 2011; Wilkinson & Shanks, 2004). Implicit learning is able to occur during periods of low attention (e.g., Baker et al., 2004; Turk-Browne et al., 2005), and therefore, mindwandering should not interfere if the attentional resources theory holds true (Brosowsky et al., 2020b). On the other hand, explicit learning is the process of acquiring information with intention and is implicated when we consciously attempt to solve a problem (e.g., Sosnik, 2009; Unsworth & Engle, 2005). Because explicit learning requires attention (Kruschke, 2003), mindwandering has been found to interfere with this process (Brosowsky et al., 2020b).

Based on our understanding of implicit learning and the attentional resources theory of mindwandering, it should be the case that implicit learning, but not explicit learning, can occur without interference from mindwandering. Brosowsky et al. (2020b) found evidence for this theory. The authors separated participants into an implicit and explicit learning group, who then completed a motor sequence learning SRT task. In the implicit learning group, a sequence of motor responses repeated without the participants being aware, but in the explicit learning group, participants were told to learn the repeating sequences. The authors found that mindwandering did not interfere with learning in the implicit learning condition, suggesting that implicit motor learning could occur without awareness or interference from mindwandering.

**Perceptual and Motor Learning**

Perceptual learning is a broad term for acquiring perception skills, such as visual discrimination or categorizing spatial patterns (e.g., Goldstone, 1998). Motor and perceptual learning share many things, such as fast within-session learning, stabilization of memories during offline periods, and the role of sleep in consolidation (for a review, see Censor et al., 2012). However, it is unclear if an effect found for implicit motor learning would generalize to implicit perceptual learning, due to the increased difficulty of perceptual learning (Shmuelof & Kraauer, 2014) and the mixed findings found in previous literature. For instance, Hallgató et al. (2013) found that participants retained an implicitly learned motor sequence, but did not retain an implicitly learned perceptual sequence. Additionally, attention is often cited as enabling perceptual learning (e.g., Szpiro & Carrasco, 2015; Yotsumoto & Watanabe, 2008), and the occurrence of perceptual learning may be more reliant on attention than motor learning (Deroost & Soetens, 2006). Therefore, it may be the case that implicit perceptual learning is more greatly impacted by low attention than implicit motor learning. However, other results indicate no differences between implicit motor and perceptual learning. For example, Nehmeth et al. (2009) showed no difference in offline improvements or retention between implicitly learned perceptual and motor sequences. Gheysen et al. (2011) found that implicit perceptual sequence learning was found to be a slower learning process that elicited smaller reaction time (RT) effects than implicit motor sequence learning. Nevertheless, implicit perceptual and motor learning still occurred. Finally, Song et al. (2008) found that both implicit motor and perceptual sequence learning was able to occur, but that perceptual learning was more sensitive to interference by variations in the stimuli or changing task demands than motor sequence learning.

**The Current Study**

Despite some discrepancies in the previous literature, most research favours the hypothesis that both types of learning can occur during periods of inattention. Therefore, the current study expects to fully replicate the effects found by Brosowsky et al. (2020b). Specifically, it is expected that mindwandering will significantly impact the practice and learning affects in an explicit learning task, but not an implicit learning task. To test this, the current study will extend the finding of Brosowsky et al. (2020b) by utilizing the original author’s paradigm, but replacing the motor learning task with a perceptual learning task. Additionally, in line with the previous literature, it is expected that mindwandering will increase and reaction times will decrease throughout the experiment.

**Methods**

**Participants**

An a-priori power analysis was conducted in *R* version 4.0.3 (R Core Team, 2020) using the *SimR* package (Green & MacLeod, 2016). Using the open-source data provided by Brosowsky et al. (2020b), the simulation estimated that 45 participants per condition could reliably detect an interaction effect size (*d*) of 0.30 between mindwandering, condition, and reaction time with 80% power.

120 students from the University of Amsterdam were recruited to completed a 75-minute online experiment for course credits. Ethical approval for this experiment was obtained from the Faculty Ethics Review Board at the University of Amsterdam. Participants were informed that they would be completing a task that investigated the impact of mindwandering on perceptual information processing, but were not informed of how many trials would be presented or the underlying purpose of the experiment. Participants were removed if they did not complete all of the trials (*n* = 10) or responded incorrectly to more than 15% of the trials (*n* = 18). This left 92 participants for analysis.

**Task Administration**

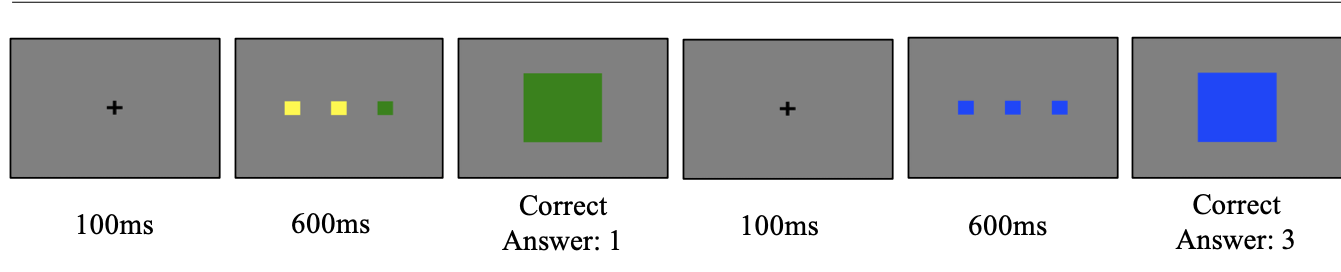
Participants who were seeking research credits could choose to participate in this experiment through the University of Amsterdam’s Behavioural Science Lab (BSL) website. From the BSL website, participants were redirected to an experiment that was written in PsychoPy version 3.0 (Peirce et al., 2019), and hosted on Pavlovia.org. Prior to completing the experiment, participants were presented with the information letter, consent form, instructions for completing the task, an in-depth description of mindwandering, instructions for how they should respond to the mindwandering probes (adapted from Brosowsky et al., 2020b), instructions specific to the condition that they had been randomly assigned to, and perceptual training sequence trials where they received feedback on the correctness of their response. To read the consent form, information letter, or within-experiment instructions, see Appendix A.

**Perceptual Learning Task**

The perceptual learning SRT task was adapted from Gheysen et al. (2010; 2011). In this task, participants observed three coloured squares for three seconds, and then a larger coloured square. The participants had to respond as quickly and accurately as possible to the large square, indicating how many of the smaller squares matched the larger square by selecting 0, 1, 2, or 3 on their keyboard (Figure 1). The learning component came from the colours of the large square repeating in a five-element sequence (red, green, blue, yellow, green). After the 5-element sequence had repeated eight times, participants were probed on their depth of mindwandering. These events made up one “block” of trials, and the entire experiment was composed of 15 blocks.

**Figure 1**

***Example of Task and Stimuli in the Perceptual Learning Task***



Note. Participants first view the three coloured squares, then the large square. Participants have to indicate how many colours from the three squares match the colour of the large square (0, 1, 2, or 3.

*Practice effects* are the gradual reduction of RTs that reflect the participants growing expertise in performing the task. This was measured by the reduction in reaction times that are expected to occur over the course of the experiment. In this study, participants practiced the same perceptual training sequence across 13 blocks of trials, and each participant’s practice effect was calculated by subtracting the median reaction time on block 1 from block 13.

*Transfer effects* are a method of evaluating if learning occurred during the sequence trials. To do this, participants were presented with a new sequence on block 14. If participants were learning the sequence and getting better at the experiment, it would be expected that their RTs to increase in response to the new sequence. Transfer effects were measured by averaging the participant’s median reaction time to the perceptual training sequence on block 13 and block 15, and comparing this to their reaction time to the random sequence on block 14.

As suggested by Seli et al. (2018), we state that the current study conceptualized mindwandering as “task unrelated thoughts” (Seli et al., 2016), which is a frequently used definition of mindwandering in both empirical (e.g., Allen et al., 2013; Brokaw et al., 2016; Brosowsky et al., 2020b) and review (e.g., Smallwood, 2013; Seli et al., 2015; Seli et al., 2016) papers, and is a way for participants to subjectively categorize any of their thoughts that do not relate to the perceptual learning task.Participants received an in-depth description of what mindwandering is and how they should respond to the probe prior to starting the experiment. When the probe was presented, the task was temporarily paused and the participant was asked: *“To what extent were you mindwandering?”.* Participants were presented a sliding scale from “Not at all mindwandering” corresponding to a value of 0, to “Fully mindwandering” corresponding to a value of 100. This probe is the same as what was used by Brosowsky et al. (2020b).

**Awareness Check**

After the SRT task, participant’s awareness of the perceptual training sequence was assessed. Participants were asked to reproduce the perceptual training sequence across 30 key presses, and then to produce a random sequence across 30 key presses. Participants were asked to create a random sequence to evaluate the percentage of triplets produced at chance level. Participant’s awareness was measured by comparing the number of triplets they produced (i.e., three sequential key presses) to the actual perceptual training sequence. Then, participants answered five yes or no questions to evaluate their subjective awareness of the experiment, which can be viewed in Appendix B and was adapted from Gheysen et al. (2011).

**Data Analysis & Manuscript Preparation**

All data exclusions, measures, and analyses have been reported for this study. For full the results of all analyses conducted for this project, see Appendix B through Appendix H. All data, experiment scripts, manuscript preparation code, and preregistration can be found on the [Open Science Foundation](https://osf.io/m4p68) (OSF). Frequentist statistics were conducted with R (R Core Team, 2020), with a number of important packages such as *nlme* (Pinheiro et al., 2021), *ggplot* (Wickham, 2016), and *dplyr* (Wickham et al., 2021). Bayesian statistics were conducted in JASP (JASP Team, 2021).

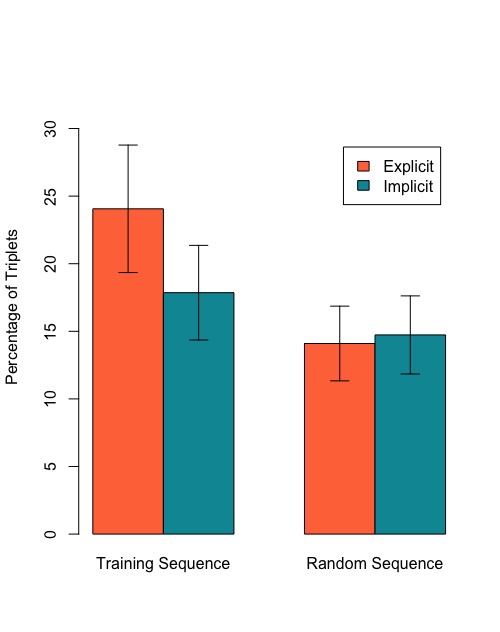
**Results**

**Awareness Check**

To evaluate participant’s explicit knowledge of the sequence, participants were told after the experiment that the colors of the large squares repeated itself and that they should do their best to (1) recreate the training sequence, and (2) create a random sequence. Their accuracy was measured by calculating the percentage of triplets (i.e., three sequential key presses) that matched the actual perceptual training sequence. For the explicit condition, accuracy significantly differed from chance *ΔM* = 0.10, 95% CI [0.02, 0.18], *t*(56) = 2.26, *p* = 0.02. This was followed up by a one-sided Bayesian paired-samples t-test, which suggested moderate evidence for the perceptual training sequence to have higher accuracy than the random sequence (*Med =* 0.31*,* 95% CI [0.07, 0.57], BF10 = 4.50, BF01 = 0.22). For the implicit condition, accuracy was not significantly different from random sequence generation *ΔM* = 0.03, 95% CI [-0.04, 0.10], *t*(39) = 0.94, *p* = 0.35 and obtained weak support in favor of the null hypothesis, where the data was 2.39 times more likely to occur under the null hypothesis *Med =* 0.17*,* 95% CI [0.01, 0.45], BF10 = 0.42, BF01 = 2.39. These results were in line with expectations.

**Figure 2**

***Awareness Check Results***



Note. The percentage of triplets (i.e., three sequential key presses) that matched the actual perceptual training sequence when asked to recreate the perceptual training sequence and to create a random sequence. Participants in the explicit condition recreated the perceptual training sequence above chance, suggesting that implicit learning occurred. On the other hand, participants in the implicit condition did not recreate the perceptual training sequence above chance, which suggests that they were not explicitly aware of the sequence and were completing the task implicitly.

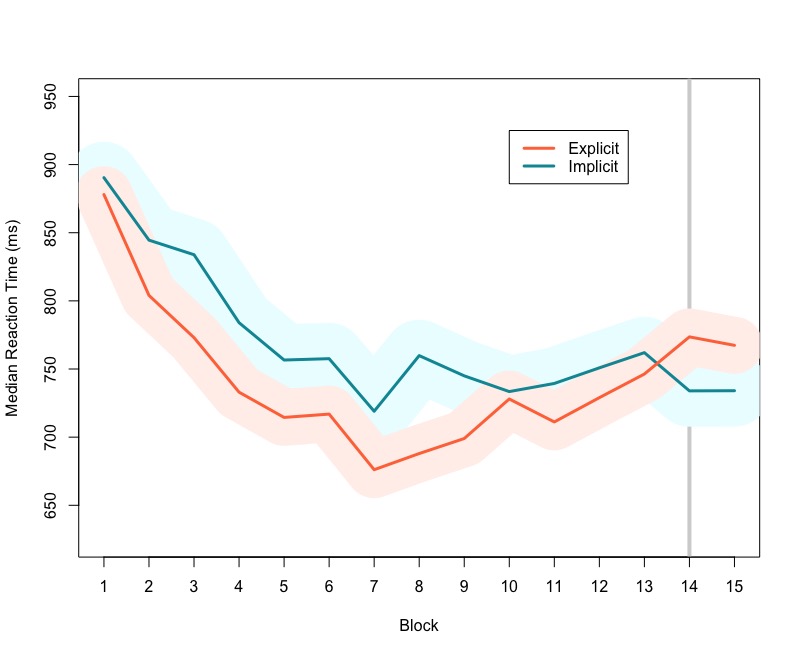
In the second test of awareness, participants completed a series of multiple-choice questions that assessed their explicit knowledge of the color sequence. The explicit condition demonstrated more awareness of the sequence than the implicit condition. The results of this questionnaire can be seen in Appendix B.

**SRT Task**

Prior to analysis of the SRT task, responses longer than 3000ms were removed (0.8% of trials), before applying an inter-quartile range outlier removal procedure (Tukey, 1977 as cited in Bakker & Wicherts, 2014), which removed 3.31% of the remaining trials.

**Figure 3**

***Reaction Time Results***



Note. Median RTs are plotted against block, and the shaded area represents the standard error. Results indicate that both conditions got better at the task as they practiced the perceptual training sequence. Only the explicit condition indicates an increase in RTs when presented with a novel sequence on block 14. This suggests that the explicit condition, but not the implicit condition, learned the perceptual training sequence.

*Practice effects* describe the change in participants performance throughout the experiment, and can be evaluated by comparing participant’s median RTs in block 1 to block 13. Both the explicit (*ΔM* = 148.99, 95% CI [79.33, 218.65], *t*(56) = 4.28, *p* < 0.001) and the implicit (*ΔM* = 102.18, 95% CI [35.73, 168.64], *t*(39)= 3.11, *p* = 0.003) condition demonstrated significant improvements to RT-based performance throughout the experiment (Figure 2). An independent samples t-test was conducted to compare practice effects between conditions. There was no significant difference between the explicit (*M* = -148.99, *SD* = 262.52) and implicit (*M* = 102.18, *SD* = 207.80) condition (95% CI [-141.80, 48.19], *t*(95) = -0.98, *p* = 0.33). To substantiate this finding, a one-sided Bayesian t-test was conducted, where it would be expected the explicit condition to have a greater decrease in RTs across the experimental blocks. A weak Bayes factor indicates that the data is 2.70 times more likely under the null hypothesis (*Med* = -0.15, 95% CI [-0.29, -0.01], BF10 = 0.37, B01- = 2.70), suggesting no difference in practice effects between the conditions.

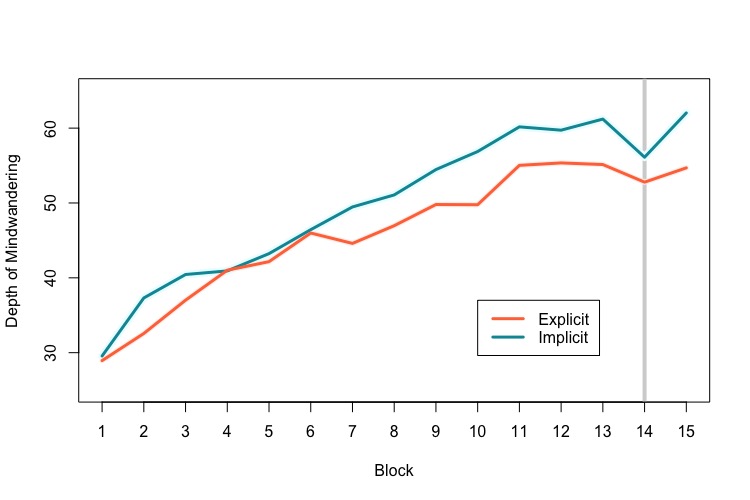
*Transfer effects* are a method of evaluating if participants learned the sequence during the practice session. This can be done by comparing the median RTs on block 13 and block 15 (where participants generating the perceptual training sequence) to their performance in block 14 (where they were generating a random sequence). If the participant’s RTs significantly increase and have a higher RT value during the random sequence, then it can be proposed that participants have learned the perceptual training sequence throughout the experiment. The explicit condition had significant transfer effects (*ΔM* = 39.05, 95% CI [0.50, 77.60], *t*(56) = 2.03, *p* = 0.05), and a follow-up Bayesian t-test indicated weak evidence for the finding (*Med* = 0.26, 95% CI [0.04, 0.52], BF10 = 1.89, BF01 = 0.53). The implicit condition did not demonstrate significant transfer effects (*ΔM* = -3.60, 95% CI [-37.26, 30.05], *t*(39) = -0.22, *p* = 0.83), which was substantiated by a Bayesian t-test which provided strong evidence in favor of the null hypothesis (*Med* = 0.09, 95% CI [0.00, 0.32], BF10 = 0.146, BF01 = 6.87). However, the explicit (*M* = 39.05, *SD* = 145.30) and implicit (*M =* -3.61, *SD* = 105.24)condition did not significantly differ (95% CI [-7.86, 93.16], *t*(95) = 21.68, *p* = 0.10) in their transfer effects. This analysis was followed up with a Bayesian one-sided t-test where it was expected that the explicit condition to have larger transfer effects than the implicit condition. There was unsubstantial evidence for both the alternative and null hypotheses (*Med* = 0.20, 95% CI [0.02, 0.46], BF10 = 0.85, BF01 = 1.18).

**Mindwandering**

A mixed ANOVA with block as a within-subjects factor and condition as a between-subjects factor was used to evaluate if there are differences in mindwandering between groups and across blocks. There was a significant main effect of block *F*(1, 1451) = 180.61, *p* < 0.001. and condition *F*(1, 1451) = 9.18, *p* < 0.001, but no interaction *F*(1, 757) = 1.35, *p* = 0.25.

**Figure 4**

***Mindwandering Probe Results***

****

Note. Participant’s responses to the mindwandering probe are plotted against block, and the shaded area represents the standard error. Results indicate that both conditions reported more mindwandering as the experiment continued. Interestingly, both conditions graphically demonstrate a reduction in mindwandering when they are presented a novel sequence on block 14. However, this was not statistically significant.

To evaluate how mindwandering changed throughout the experiment, mindwandering on block 1 and block 13 was compared. Both the explicit (*ΔM* = 26.20, 95% CI [18.57, 33.82], *t*(56) = 6.88, *p* < 0.001) and the implicit (*ΔM* = 31.65, 95% CI [20.94, 42.36], *t*(39) = 5.98, *p* < 0.001) condition demonstrated significant changes in mindwandering throughout the experiment. However, there was no significant difference between the explicit (*M* = 26.19, *SD* = 28.73) and implicit (*M* = 31.65, *SD* = 33.49) conditions (95% CI [-7.53, 18.44], *t*(95) = 0.83, *p* = 0.41). A follow-up Bayesian t-test suggested that the data is 2.41 times more likely under the null hypothesis (*Med* = 0.20, CI [-0.06, 0.46], BF10 = 0.47, BF01 = 2.14).

To determine if the depth of mindwandering changed when participants were given a new sequence, mindwandering “transfer effects” were evaluated, which is the difference in mindwandering on block 13 and 15 (averaged), compared to when participants are presented with a new sequence block 14. Both the explicit (*ΔM* = -2.13, 95% CI -6.22, 1.95], *t*(56) = -1.04, *p* = 0.30) and the implicit (*ΔM* = -5.51, 95% CI [-12.05, 1.05], *t*(39) = -1.69, *p* = 0.10) condition demonstrated non-significant mindwandering transfer effects. Further, there were no differences between the explicit and the implicit (CI [-4.27, 11.01], *t*(95) = 0.88, *p* = 0.38) conditions. A follow-up Bayesian two-sided independent samples t-test provided moderate evidence in favor of the null hypothesis (*Med* = 0.17, CI [-0.08, 0.43], BF10 = 0.45, BF01 = 2.83).

**Mindwandering, Reaction Time, and Condition Interactions**

To evaluate the relationship between mindwandering, block, and condition, and their impact on RT, participant’s median RT in each block was analyzed using a hierarchical linear model with condition, depth of mindwandering, and the block as the fixed effect, and the subjects as the random effect. As can be seen in Table 1, block had a significant impact on median RT. However, the impact of mindwandering on RT and the critical interaction between mindwandering and condition was insignificant. This suggests that mindwandering did not impact RTs across the entire experiment, let alone demonstrate differential effects on RTs between conditions. These effects were substantiated by a follow-up Bayesian hierarchical linear model, which can be viewed in Appendix E.

**Table 1**

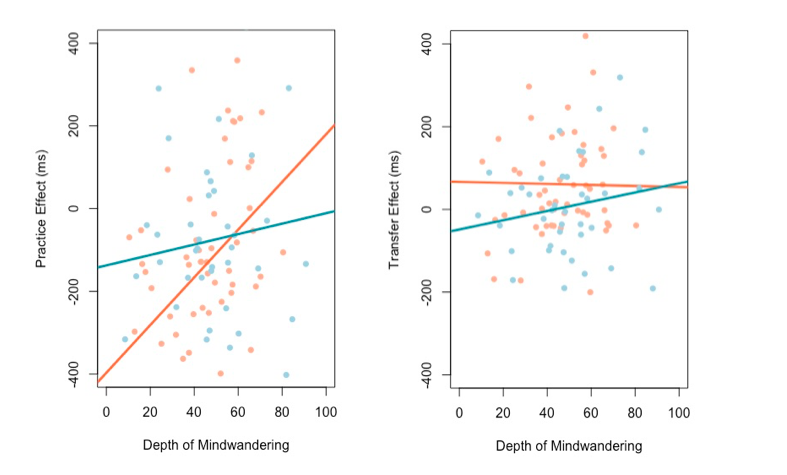
***Frequentist Hierarchical Linear Model Results***

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
|  | Reaction Times (ms) | | | |
| Predictors | Estimates | SE | t | p |
| (Intercept) | 876.92 | 36.68 | 23.91 | 0.01 |
| MW | -0.55 | 0.46 | -1.19 | 0.23 |
| Block | -14.43 | 2.21 | -6.54 | 0.00 |
| Condition | 41.95 | 54.38 | 0.77 | 0.44 |
| MW x Block | 0.19 | 0.04 | 4.27 | 0.00 |
| MW x Condition | 0.27 | 0.67 | 0.40 | 0.69 |
| Block x Condition | 4.34 | 3.42 | 1.27 | 0.21 |
| MW x Block x Condition | -0.10 | 0.06 | -1.50 | 0.13 |

Two follow-up linear models indicated that mindwandering had an impact on RT-based practice effects in the explicit condition (*β*  = 5.77, *F*(1,55) = 8.28, *p <* 0.001), but not in the implicit condition (*β*  = 1.26, *F*(1, 38) = 0.53, *p =* 0.47). As can be seen in Figure 3, as when overall mindwandering increased, participants did not have a large reduction of RTs throughout the experiment, suggesting that mindwandering may have been related to participants practice effects within the task. These results are substantiated by follow-up Bayesian linear models, which can be seen in Appendix F.

**Figure 5**

***The Impact of Mindwandering on Participant’s Practice and Transfer Effects***

******

Note. Participant’s practice effects (panel A) and transfer effects (panel B) are plotted against the participant’s average mindwandering throughout the experiment. In panel A, depth of mindwandering was significantly related to the depth of practice effects in the explicit condition, but not the implicit condition. This suggests that lower levels of mindwandering related to better performance throughout the experiment in only the explicit condition. In panel B, mindwandering did not have a significant relationship with the transfer effects in either condition, suggesting that learning in either condition was not affected by mindwandering.

Finally, two additional linear models were used to evaluate if mindwandering had differential effects on transfer effects in each condition. Mindwandering did not have an impact on RT-based transfer effects in the explicit condition (*β*  = -0.13, *F*(1,55) = 0.01, *p* = 0.92) or the implicit condition (*β*  = 1.15, *F*(1, 38) = 1.46, *p =* 0. 24). When followed up with Bayesian linear models, the results express weak evidence in favour of the null hypothesis for both conditions. These results can be found in Appendix E.

**Discussion**

The attentional resources theory of mindwandering suggest that mindwandering and performing a task compete for attentional resources. Therefore, in most circumstances, mindwandering interferes with task performance and learning. However, studies have found that implicit learning requires low or no attentional resources, suggesting that implicit learning could theoretically occur while mindwandering. The current study tests this theory to see if implicit perceptual sequence learning could occur while mindwandering. Participants who engaged in both an implicit and an explicit perceptual sequence SRT task demonstrated a steady decrease in their RT responses to the stimuli throughout the experiment, indicating that participants became better acquainted with the task as the experiment progressed. Further, as would be expected from the previous literature, participant’s reported depth of mindwandering increased throughout the experiment (Thomson et al., 2014). On the 14th block, participants were given a new sequence, and their slowing of reaction times would indicate that the participants had learned the perceptual training sequence (Pasquali et al., 2019; Brosowsky et al., 2020b). Participants in the explicit condition, but not the implicit condition, demonstrated that they had learned the perceptual training sequence. This finding goes against previous literature that has found evidence for the occurrence of implicit perceptual sequence learning (Gheysen et al., 2011), and ensures that the motor learning findings by Brosowsky et al. (2020b) cannot be extended to perceptual sequence learning in this experiment.

Our failure to replicate an implicit learning effect may have occurred for three reasons. First, when pilot testing the experiment, it became quite obvious to participants in both conditions that the sequence always began with a red square after the probe. Since we did not want the implicit condition to explicitly realize the repeating sequence, each new block began the sequence at a random color. This may have interfered with the implicit learning of the sequence, as previous research has found that perceptual sequence learning can be susceptible to interruption by variations in the experimental procedure (Song et al., 2008). Further, previous research has found that during implicit learning, the brain’s perceptual system is still sensitive to deviant or unexpected sensory (Kam et al., 2013). In our experiment, it may have been the case that the new sequence at block 14 may not have been novel enough as compared to blocks 1 through 13, because the sequence had started on a new color each time during the perceptual training sequence trials.

Second, this may have happened because people lost interest in the experiment. The Brosowsky et al. (2020b) experiment was 30 minutes, while ours was 75 minutes. This was because we implemented the same number of repetitions of the sequence and blocks as Brosowsky et al. (2020b). However, due to the longer time it required to complete the perceptual learning task from Gheysen et al. (2011), it may have been the case that people became too bored and inattentive to engage in any type of implicit perceptual learning. This assumption can be substantiated by the implicit condition having deeper mindwandering episodes but having plateaued RTs after block 6, which is graphically depicted in Figure 2 and Figure 3, and was statistically substantiated by follow-up t-tests (Appendix G). Further, it has been found that decreased motivation is related to increased mindwandering and poorer task performance (Brosowsky et al., 2020a), which may have been the case for this experiment.

Third, it may be the case that perceptual learning requires attention. As discussed earlier, perceptual sequence learning is more difficult than motor learning (Shmuelof & Kraauer, 2014), and there are mixed findings for the robustness of implicit perceptual learning (e.g., Hallogato et al., 2013; Song et al., 2008). Further, attention is often cited as enabling perceptual learning (e.g., Szpiro & Carrasco, 2015; Yotsumoto & Watanabe, 2008), and the occurrence of perceptual learning may be more reliant attention than motor learning (Deroost & Soetens, 2006). Taken together, it may be the case that implicit perceptual learning is more greatly impacted by low attention than implicit motor learning, and could therefore explain why we did not find evidence for implicit perceptual learning in this experiment.

Our study found that that practice effects were impacted by mindwandering in the explicit condition, but not the implicit condition, which extends some of the findings by Brosowsky et al. (2020b). This may indicate that a task as simple as responding quickly to a stimulus is affected by mindwandering when it is conducted explicitly, but is unaffected by mindwandering when it is conducted implicitly. Brosowsky et al. (2020b) found that explicit, but not implicit, transfer effects were impacted by mindwandering, and used this evidence to suggest that implicit learning could run parallel to mindwandering. We did not extend this finding to perceptual learning, and instead found that transfer effects in either condition were not affected by mindwandering. Upon initial interpretation, it may be suggested that both the implicit and explicit learning were unaffected by mindwandering. However, this is likely incorrect. First, it is difficult to interpret the linear regression on the implicit condition because there was no overall transfer effects or learning occurring in the implicit condition (Figure 3). Second, the explicit condition not demonstrating a negative relationship between mindwandering and learning goes against previous research (for a review, see Mooneyham & Schooler, 2013). In an effort to check the robustness of this finding, we also tested if mindwandering impacted the participant’s ability to recreate the sequence. Again, there was no relationship between mindwandering and learning the sequence in either condition (Appendix H). Instead of concluding that mindwandering does not impact learning, it may be that mindwandering affects separate tasks differently. For example, in our study, participants learned a 5-element color-based sequence across nearly 75 minutes. In hindsight, this is quite a simple task and it may be the case that mindwandering and learning the 5-element sequence could have occurred at different times throughout the experiment. It is possible that participants learned the sequence within the first few blocks, and then proceeded to mindwandering for the rest of the experiment, thus, allowing for both an increased frequency of mindwandering while still demonstrating that they had learned the sequence. This finding may have implications for future researchers who are looking to test the attentional resources theory of mindwandering, as we should more or less make participants mindwander and learn simultaneously to appropriately interpret the relationship between mindwandering and learning.

**Conclusion**

Returning to our original research question, we asked: *Can we implicitly learn a perceptual sequence while mindwandering?* And unfortunately, the results of this study do not allow us to properly answer this question. Learning occurred in the explicit, but not implicit, condition suggesting that implicit perceptual sequence learning requires awareness. However, because implicit learning did not occur, we are unable to properly evaluate the relationship between implicit perceptual learning and mindwandering.

**References**

Allen, M., Smallwood, J., Christensen, J., Gramm, D., Rasmussen, B., Gaden Jensen, C., & Lutz,

A. (2013). The balanced mind: the variability of task-unrelated thoughts predicts error-

monitoring. *Frontiers in Human Neuroscience*, *7*, 743.

https://doi.org/10.3389/fnhum.2013.00743

Andrews-Hanna, J. R., Smallwood, J., & Spreng, R. N. (2014). The default network and self-

generated thought: component processes, dynamic control, and clinical relevance. *Annals*

*of the New York Academy of Sciences, 1316*(1), 29. https://doi.org/10.1111/nyas.12360

Andrillon, T., Windt, J. M., Silk, T., Drummond, S., Bellgrove, M., & Tsuchiya, N. (2019). Does

the mindwander when the brain takes a break? Local sleep in wakefulness, attentional

lapses and mind-wandering. *Frontiers in Neuroscience, 13*, 949.

https://doi.org/10.3389/fnins.2019.00949

Baker, C. I., Olson, C. R., & Behrmann, M. (2004). Role of attention and perceptual grouping in

visual statistical learning. *Psychological Science, 15*(7), 460-466. https://doi.org/10.1111/j.0956-7976.2004.00702.x

Bönstrup, M., Iturrate, I., Thompson, R., Cruciani, G., Censor, N., & Cohen, L. G. (2019). A

rapid form of offline consolidation in skill learning. *Current Biology, 29*(8), 1346-1351.

https://doi.org/10.1016/j.cub.2019.02.049

Boyer, M., Destrebecqz, A., & Cleeremans, A. (2005). Processing abstract sequence structure:

learning without knowing, or knowing without learning? *Psychological Research, 69*(5),

383-398. https://doi.org/10.1007/s00426-004-0207-4

Brokaw, K., Tishler, W., Manceor, S., Hamilton, K., Gaulden, A., Parr, E., & Wamsley, E. J.

(2016). Resting state EEG correlates of memory consolidation. *Neurobiology of Learning*

*and Memory, 130,* 17-25. https://doi.org/10.1016/j.nlm.2016.01.008

Brosowsky, N. P., DeGutis, J., Esterman, M., Smilek, D., & Seli, P. (2020). Mind wandering,

motivation, and task performance over time: Evidence that motivation insulates people

from the negative effects of mind wandering. *Psychology of Consciousness: Theory,*

*Research, and Practice.* Advance online publication. https://doi.org/10.1037/cns0000263

Brosowsky, N. P., Murray, S., Schooler, J. W., & Seli, P. (2020). Attention need not always

apply: Mindwandering impedes explicit but not implicit sequence learning. *Cognition,*

*209,* 104530. https://doi.org/10.1016/j.cognition.2020.104530

Bridges, D., Pitiot, A., MacAskill, M. R., & Peirce, J. W. (2020). The timing mega-study:

comparing a range of experiment generators, both lab-based and online. *PeerJ, 8,* e9414.

https://doi.org/10.7717/peerj.9414

Buckner, R. L. (2010). The role of the hippocampus in prediction and imagination. *Annual*

*Review of Psychology, 61*, 27-48. https://doi.org/10.7717/peerj.9414

Censor, N., Sagi, D., & Cohen, L. G. (2012). Common mechanisms of human perceptual and

motor learning. *Nature Reviews Neuroscience,* 13(9), 658-664.

https://doi.org/10.1038/nrn3315

Christoff, K., Irving, Z. C., Fox, K. C., Spreng, R. N., & Andrews-Hanna, J. R. (2016). Mind-

wandering as spontaneous thought: a dynamic framework. *Nature Reviews*

*Neuroscience, 17*(11), 718-731. https://doi.org/10.1038/nrn.2016.113

Cleeremans, A., Destrebecqz, A., & Boyer, M. (1998). Implicit learning: News from the front.

*Trends in Cognitive Sciences, 2*(10), 406-416. https://doi.org/10.1016/S1364-

6613(98)01232-7

Deroost, N., & Soetens, E. (2006). Perceptual or motor learning in SRT tasks with complex

sequence structures. *Psychological Research, 70*(2), 88-102.

https://doi.org/10.1007/s00426-004-0196-3

Gabrys, R. L., Tabri, N., Anisman, H., & Matheson, K. (2018). Cognitive control and flexibility

in the context of stress and depressive symptoms: The cognitive control and flexibility

questionnaire. *Frontiers in Psychology, 9,* 2219.

https://doi.org/10.3389/fpsyg.2018.02219

Gheysen, F., Van Opstal, F., Roggeman, C., Van Waelvelde, H., & Fias, W. (2010).

Hippocampal contribution to early and later stages of implicit motor sequence learning.

*Experimental Brain Research,* 202(4), 795-807. https://doi.org/10.1007/s00221-010-

2186-6

Gheysen, F., Van Opstal, F., Roggeman, C., Van Waelvelde, H., & Fias, W. (2011). The neural

basis of implicit perceptual sequence learning. *Frontiers in Human Neuroscience, 5,* 137.

https://doi.org/10.3389/fnhum.2011.00137

Goldstone, R. L. (1998). Perceptual learning. *Annual Review of Psychology*, *49*(1), 585-612.

https://doi.org/10.1146/annurev.psych.49.1.585

Green, P., & MacLeod, C. J. (2016). SIMR: a R package for power analysis of generalized

linear mixed models by simulation. *Methods in Ecology and Evolution, 7*(4), 493-498.

https://doi.org/10.1111/2041-210X.12504

Grootswagers, T., (2020), A primer on running human behavioural experiments online.

*Behavioural Research 52,* 2283–2286. https://doi.org/10.3758/s13428-020-01395-3

Hallgató, E., Győri-Dani, D., Pekar, J., Janacsek, K., & Nemeth, D. (2013). The differential

consolidation of perceptual and motor learning in skill acquisition. *Cortex*, 49(4), 1073-

1081. https://doi.org/10.1016/j.cortex.2012.01.002

Humiston, G. B., Tucker, M. A., Summer, T., & Wamsley, E. J. (2019). Resting states and

memory consolidation: A preregistered replication and meta-analysis. *Scientific Reports, 9*(1), 1-9. https://doi.org/10.1038/s41598-019-56033-6

Hung, C. S., Sarasso, S., Ferrarelli, F., Riedner, B., Ghilardi, M. F., Cirelli, C., & Tononi, G.

(2013). Local experience-dependent changes in the wake EEG after prolonged

wakefulness. *Sleep*, 36(1), 59-72. https://doi.org/10.5665/sleep.2302

Hutt, S., Mills, C., White, S., Donnelly, P. J., & D'Mello, S. K. (2016). The Eyes Have It: Gaze-

Based Detection of Mindwandering during Learning with an Intelligent Tutoring System. *International Educational Data Mining Society*.

JASP Team (2020). JASP (Version 0.14.1) [Computer software].

Kane, M. J., Brown, L. H., McVay, J. C., Silvia, P. J., Myin-Germeys, I., & Kwapil, T. R.

(2007). For whom the mind wanders, and when: An experience-sampling study of working memory and executive control in daily life. *Psychological Science, 18*(7), 614-621. https://doi.org/10.1111%2Fj.1467-9280.2007.01948.x

Killingsworth, M. A., & Gilbert, D. T. (2010). A wandering mind is an unhappy

mind. *Science, 330*(6006), 932-932. https://doi.org/10.1126/science.1192439

Kruschke, J. K. (2003). Attention in learning. *Current Directions in Psychological Science,*

*12*(5), 171-175. https://doi.org/10.1111%2F1467-8721.01254

Mooneyham, B. W., & Schooler, J. W. (2013). The costs and benefits of mind-wandering: a

review. *Canadian Journal of Experimental Psychology, 67*(1), 11. https://doi.org/10.1037/a0031569

Nemeth, D., Hallgató, E., Janacsek, K., Sándor, T., & Londe, Z. (2009). Perceptual and motor

factors of implicit skill learning. *Neuroreport, 20*(18), 1654-1658. doi: https://doi.org/10.1097/WNR.0b013e328333ba08

O'Callaghan, C., Walpola, I. C., & Shine, J. M. (2020). Neuromodulation of the mind-wandering

brain state: the interaction between neuromodulatory tone, sharp wave-ripples and spontaneous thought. *Philosophical Transactions of the Royal Society B*, 376(1817), 20190699. https://doi.org/10.1098/rstb.2019.0699

Pasquali, A., Cleeremans, A., & Gaillard, V. (2019). Reversible second-order conditional

sequences in incidental sequence learning tasks. *Quarterly Journal of Experimental*

*Psychology, 72*(5), 1164-1175. https://doi.org/10.1177%2F1747021818780690

Peirce, J. W., Gray, J. R., Simpson, S., MacAskill, M. R., Höchenberger, R., Sogo, H., Kastman,

E., Lindeløv, J. (2019). PsychoPy2: experiments in behavior made easy. *Behavior Research Methods.* https://doi.org/1010.3758/s13428-018-01193-y

Pinheiro J, Bates D, DebRoy S, Sarkar D, R Core Team (2021). *nlme: Linear and Nonlinear*

*Mixed Effects Models*. R package version 3.1-152, https://CRAN.R-

project.org/package=nlme.

R Core Team (2020). R: A language and environment for statistical computing. R Foundation for

Statistical Computing, Vienna, Austria. URL https://www.R-project.org/.

Ruby, F. J., Smallwood, J., Engen, H., & Singer, T. (2013). How self-generated thought shapes

mood—the relation between mind-wandering and mood depends on the socio-temporal content of thoughts. *PloS one, 8*(10), e77554. https://doi.org/10.1371/journal.pone.0077554

Seli, P., Cheyne, J. A., Xu, M., Purdon, C., & Smilek, D. (2015). Motivation, intentionality, and

mindwandering: Implications for assessments of task-unrelated thought. Journal of Experimental Psychology: *Learning, Memory, and Cognition, 41*(5), 1417. https://doi.org/10.1037/xlm0000116

Seli, P., Kane, M. J., Smallwood, J., Schacter, D. L., Maillet, D., Schooler, J. W., & Smilek, D.

(2018). Mind-wandering as a natural kind: A family-resemblances view. *Trends in Cognitive Sciences, 22*(6), 479-490. https://doi.org/10.1016/j.tics.2018.03.010

Seli, P., Risko, E. F., Smilek, D., & Schacter, D. L. (2016). Mind-wandering with and without

intention. *Trends in Cognitive Sciences, 20*(8), 605-617. https://doi.org/10.1016/j.tics.2016.05.010

Schooler, J. W., Smallwood, J., Christoff, K., Handy, T. C., Reichle, E. D., & Sayette, M. A.

(2011). Meta-awareness, perceptual decoupling and the wandering mind. *Trends in Cognitive Sciences, 15*(7), 319-326. https://doi.org/10.1016/j.tics.2011.05.006

Schwarb, H., & Schumacher, E. H. (2012). Generalized lessons about sequence learning from the

study of the serial reaction time task. *Advances in Cognitive Psychology, 8*(2), 165.

https://doi.org/10.2478/v10053-008-0113-1

Shmuelof, L., & Krakauer, J. W. (2014). Recent insights into perceptual and motor skill

learning. *Frontiers in Human Neuroscience*, *8*, 683.

https://doi.org/10.3389/fnhum.2014.00683

Smallwood, J. (2011). Mind‐wandering while reading: Attentional decoupling, mindless reading

and the cascade model of inattention. *Language and Linguistics Compass, 5(*2), 63-77. https://doi.org/10.1111/j.1749-818X.2010.00263.x

Smallwood, J. (2013). Distinguishing how from why the mind wanders: a process–occurrence

framework for self-generated mental activity. *Psychological Bulletin, 139*(3), 519. https://psycnet.apa.org/doi/10.1037/a0030010

Smallwood, J., & Andrews-Hanna, J. (2013). Not all minds that wander are lost: the importance

of a balanced perspective on the mind-wandering state. *Frontiers in Psychology, 4,* 441.

https://doi.org/10.3389/fpsyg.2013.00441

Smallwood, J., & Schooler, J. W. (2006). The restless mind. *Psychological Bulletin*, *132*(6), 946.

https://psycnet.apa.org/doi/10.1037/0033-2909.132.6.946

Smallwood, J., & Schooler, J. W. (2015). The science of mindwandering: empirically navigating

the stream of consciousness. *Annual Review of Psychology, 66*, 487-518. https://doi.org/10.1146/annurev-psych-010814-015331

Song, S., Howard, J. H., & Howard, D. V. (2008). Perceptual sequence learning in a serial

reaction time task. *Experimental Brain Research, 189*(2), 145-158.

https://doi.org/10.1007/s00221-008-1411-z

Sosnik, R. (2009). Motor sequences. *Cognitive Psychology, 19,* 1-32.

Szpiro, S. F., & Carrasco, M. (2015). Exogenous attention enables perceptual learning.

*Psychological Science, 26*(12), 1854-1862. https://doi.org/10.1177%2F0956797615598976

Thomson, D. R., Seli, P., Besner, D., & Smilek, D. (2014). On the link between mind wandering

and task performance over time. *Consciousness and Cognition, 27*, 14-26. https://doi.org/10.1016/j.concog.2014.04.001

Turk-Browne, N. B., Jungé, J. A., & Scholl, B. J. (2005). The automaticity of visual statistical

learning. *Journal of Experimental Psychology: General, 134*(4), 552.

https://psycnet.apa.org/doi/10.1037/0096-3445.134.4.552

Unsworth, N., & Engle, R. W. (2005). Individual differences in working memory capacity and

learning: Evidence from the serial reaction time task. *Memory & Cognition, 33*(2), 213-

220. https://doi.org/10.3758/BF03195310

Van Selst, M., & Jolicoeur, P. (1994). A solution to the effect of sample size on outlier

elimination. *The Quarterly Journal of Experimental Psychology Section A, 47*(3), 631-650. https://doi.org/10.1080%2F14640749408401131

Walker, M. P., & Stickgold, R. (2004). Sleep-dependent learning and memory consolidation.

*Neuron, 44*(1), 121-133. https://doi.org/10.1016/j.neuron.2004.08.031

Wickham, H., (2016). *ggplot2: Elegant Graphics for Data Analysis.* Springer-Verlag New York.

ISBN 978-3-319-24277-4, https://ggplot2.tidyverse.org.

Wickham, H., François, R., Henry, L., and Müller, K., (2021). *dplyr: A Grammar of Data*

*Manipulation*. R package version 1.0.6. https://CRAN.R-project.org/package=dplyr

Wilkinson, L., & Shanks, D. R. (2004). Intentional control and implicit sequence learning.

*Journal of Experimental Psychology: Learning, Memory, and Cognition, 30*(2), 354.

https://doi.org/10.1037/0278-7393.30.2.354

Yotsumoto, Y., & Watanabe, T. (2008). Defining a link between perceptual learning and

attention. *PLoS Biol, 6*(8), e221. https://doi.org/10.1371/journal.pbio.0060221

**Appendix A**

**Form A1**

*Consent Form*

In this letter, we refer to the information letter describing the research in which you participate. By pressing ‘c’ to continue with the experiment, you declare that you understand the nature and methods of this study as described in the information letter.

Should you have questions about this study at any given moment, please contact the responsible researcher; dr. Filip van Opstal. Formal complaints about this study can be addressed to the Ethics Review Board; dr. G.H. Valk, G.H.Valk@uva.nl, 0205256850, Nieuwe Achtergracht 129, 1018 WS Amsterdam.

By continuing with the experiment, you confirm that:

* *You are 16 or older;*
* *You have read and understood the information letter;*
* *You agree to participate in this study and agree with the use of the data that are collected;*
* *You reserve the right to withdraw your participation from the study at any moment without providing any reason.*

Press ‘c’ to continue, or ‘esc’ to leave the experiment.

**Form A2**

*Information Letter*

Dear participant,

First, thank you for your interest in our study! Before the experiment starts, it is important that you are informed about the procedures. Therefore, we would like you to read this information letter carefully.

Goal of the study

The goal of this study is to investigate mindwandering through different stages of attention.

Procedure

In this study, you will first see three colored squares on the screen for 6 seconds. Then, one large colored square will appear on the screen. Your job is to remember the previous three squares and indicate how many were the same color as the large colored square. For example, if you are presented with the following three colored squares: blue, yellow, blue. Then, you are presented with a large yellow square, the correct answer would be 1. Use the 0, 1, 2, 3 keys on your keyboard to indicate if none of the squares match (0), one of the squares matches (1), two of the squares matches (2), or all of the squares matched (3). You should try to respond as fast and correct as possible! You will complete 15 blocks, each containing 80 trials.

Voluntary participation

There are no consequences if you decide now not to participate in this study. During the experiment, press ‘esc’ to stop participating at any moment. Within seven days after participation, you are allowed to withdraw your data from this research and your data will be deleted permanently.

Discomfort, risks and insurance

As with any research at the University of Amsterdam, a standard liability insurance applies. Press esc at any point to exit the experiment.

Your privacy is guaranteed

Your personal information (about who you are) remains confidential and will not be shared without your explicit consent. Your research data will be analyzed by the researchers that collected the information. Research data published in scientific journals will be anonymous and cannot be traced back to you as an individual. Completely anonymized data can be shared with other researchers.

Compensation

As compensation for your participation, you receive 1 research credit for participating in this experiment that takes about 60 minutes.

**Form A3**

*Within Experiment Instructions*

Dear participant,

First, thank you for your interest in our study! Before the experiment starts, it is important that you are informed about the procedures. Therefore, we would like you to read this information letter carefully.

Press ’c’ to continue.

The goal of this study is to investigate mindwandering through different stages of attention.

Press ‘c’ to continue.

In this study, you will first see three colored squares on the screen for 6 seconds. Then, one large colored square will appear on the screen. Your job is to remember the previous three squares and indicate how many were the same color as the large colored square. For example, if you are presented with the following three colored squares: blue, yellow, blue. Then, you are presented with a large yellow square, the correct answer would be 1. Use the 0, 1, 2, 3 keys on your keyboard to indicate if none of the squares match (0), one of the squares matches (1), two of the squares matches (2), or all of the squares matched (3). You will complete 15 blocks, each containing 80 trials.

Press ‘c’ to continue.

While you are completing this task, you may find yourself thinking about things other than the task. These thoughts are referred to as “task unrelated thoughts” or “mindwandering”. Having task-unrelated thoughts is perfectly normal, especially when one must do the same thing for a long period of time. We would like to determine how frequently you were thinking about the task versus how frequently you are thinking about something unrelated to the task (mindwandering). To do this, every once in a while, the task will temporarily stop and you will be presented with a thought sampling screen that will ask you to indicate to what extent you have been focused on the task (not at all mindwandering) or focused on task unrelated thoughts (fully mindwandering).

Press ‘c’ to continue.

Being focused on the task means that you were focused on some aspect of the task at hand. For example, if you have been thinking about your performance on the task, or about when you should make a button press, these thoughts would count as being on-task. On the other hand, experiencing task-unrelated thoughts means that you were thinking about something completely unrelated to the task. For example, thinking about what to eat for dinner, about an upcoming event, or about something that happened to you earlier in the day. Any thoughts that you have that are not related to the task you are completing count as task unrelated. When the thought-sampling screen is presented, we will ask you to indicate the extent to which you have been mindwandering. You will indicate the extent you have been mindwandering on a scale from 0 to 100 (0 being not at all mindwandering, 100 being fully mindwandering).

Press ‘c’ to continue.

There are no consequences if you decide now not to participate in this study. During the experiment, press ‘esc’ to stop participating at any moment. Within seven days after participation, you are allowed to withdraw your data from this research and your data will be deleted permanently. As with any research at the University of Amsterdam, a standard liability insurance applies. Your personal information (about who you are) remains confidential and will not be shared without your explicit consent. Your research data will be analyzed by the researchers that collected the information. Research data published in scientific journals will be anonymous and cannot be traced back to you as an individual. Completely anonymized data can be shared with other researchers.

Press ‘c’ to continue.

As compensation for your participation, you receive 1 research credit for participating in this experiment that takes about 1 hour.

Press ‘c’ to continue.

Should you have questions about this study at any given moment, please contact the responsible researcher; dr. Filip Van Opstal, tel. 0615460568, email F.vanOpstal@uva.nl. Formal complaints about this study can be addressed to the Ethics Review Board; dr. G.H. Valk, G.H.Valk@uva.nl, 0205256850, Nieuwe Achtergracht 129, 1018 WS Amsterdam.

Press ‘c’ to continue.

By continuing, you agree that:

You are 16 or older.

You have read and understood the information presented.

You agree to participate in this study and you agree with the use of the data collected.

You reserve the right to withdraw your participation from the study at any moment without providing any reason.

Press ‘c’ to continue with the experiment, or the escape key to leave the experiment.

Would you like to receive a copy of this consent form? If so, enter your email below.

Press the spacebar when you are ready to continue.

[After the participant completes the perceptual training sequence trials]

Now the real experiment will begin.

*Only for the implicit condition:* Please respond to the large square as quickly and accurately as possible!

*Only for the explicit condition:* Important: The color of the large square will repeat throughout the trials, and it is your job to uncover the pattern so that you can respond as quickly as possible.

Press ‘c’ to begin the experiment.

**Appendix B**

**Table B1**

*Questions and answers for the subjective awareness check. Percentages represent the percent of participants that responded “yes” to that question.*

|  |  |  |
| --- | --- | --- |
| Question | Implicit Condition | Explicit Condition |
| Was the sequence of the large square colors random? | 73% | 57% |
| For the large squares, did some colors occur more than others? | 33% | 28% |
| For the large squares, was the succession of colors often predictable? | 38% | 28% |
| For the large squares, did one sequence of colors often occur? | 10% | 32% |
| For the large squares, did one sequence repeat throughout the experiment? | 20% | 32% |

**Appendix C**

**Table C1**

*Mean and stand errors for median reaction times (RT), correct responses (%), and depth of mindwandering as a function of the experiment’s blocks and conditions.*

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
|  | Implicit | | | Explicit | | |
| Block | RT (ms) | Correct | MW | RT | Correct | MW |
| 1 | 890.41 | 95.18 | 29.56 | 963.15 | 96.31 | 28.94 |
| 2 | 844.55 | 94.50 | 37.31 | 950.43 | 95.04 | 32.57 |
| 3 | 833.88 | 93.18 | 40.45 | 930.26 | 93.02 | 37.01 |
| 4 | 783.99 | 95.94 | 40.92 | 951.32 | 95.13 | 41.02 |
| 5 | 756.60 | 96.13 | 43.23 | 958.33 | 95.83 | 42.16 |
| 6 | 719.00 | 92.68 | 46.43 | 932.90 | 93.29 | 45.99 |
| 7 | 757.59 | 95.31 | 49.46 | 952.19 | 95.59 | 44.60 |
| 8 | 719.00 | 94.31 | 51.07 | 950.00 | 95.00 | 46.96 |
| 9 | 759.83 | 93.06 | 54.46 | 934.21 | 93.42 | 49.80 |
| 10 | 744.98 | 87.56 | 56.87 | 882.46 | 88.24 | 49.77 |
| 11 | 733.44 | 92.06 | 60.17 | 919.74 | 91.97 | 55.02 |
| 12 | 739.39 | 94.06 | 59.73 | 942.12 | 94.31 | 55.35 |
| 13 | 762.00 | 94.94 | 61.21 | 948.25 | 94.82 | 55.14 |
| 14 | 733.96 | 93.37 | 56.11 | 940.79 | 94.07 | 52.78 |
| 15 | 734.07 | 93.13 | 62.02 | 940.00 | 94.08 | 54.69 |

**Appendix D**

**Table D1**

*Frequentist hierarchical linear models, with mindwandering, block, and condition as the fixed effect, participant as the random effect, and median reaction times as the dependent variable.*

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
|  | Reaction Times (ms) | | | |
| Predictors | Estimates | SE | t | p |
| (Intercept) | 876.92 | 36.68 | 23.91 | 0.01 |
| MW | -0.55 | 0.46 | -1.19 | 0.23 |
| Block | -14.43 | 2.21 | -6.54 | 0.00 |
| Condition | 41.95 | 54.38 | 0.77 | 0.44 |
| MW x Block | 0.19 | 0.04 | 4.27 | 0.00 |
| MW x Condition | 0.27 | 0.67 | 0.40 | 0.69 |
| Block x Condition | 4.34 | 3.42 | 1.27 | 0.21 |
| MW x Block x Condition | -0.10 | 0.06 | -1.50 | 0.13 |

**Appendix E**

| **Table E1**  *Bayesian Hierarchical Linear Model: Intercept* | | | | | | | | | | | | | |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
|  | | | | 95% CI | | | |  | | | | | |
| Estimate | | SE | | Lower | | Upper | | R-hat | | ESS (bulk) | | ESS (tail) | |
| 869.413 |  | 27.088 |  | 814.054 |  | 924.628 |  | 1.001 |  | 2440.646 |  | 3669.695 |  |
|  | | | | | | | | | | | | | |

| **Table E2**  *Bayesian Hierarchical Linear Model: Awareness* | | | | | | | | | | | | | | | |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
|  | | | | | | 95% CI | | | |  | | | | | |
| Level | | Estimate | | SE | | Lower | | Upper | | R-hat | | ESS (bulk) | | ESS (tail) | |
| explicit |  | -58.008 |  | 34.406 |  | -124.023 |  | 5.497 |  | 1.002 |  | 3063.195 |  | 3996.972 |  |
| implicit |  | -9.537 |  | 35.613 |  | -80.202 |  | 61.037 |  | 1.001 |  | 3188.480 |  | 3890.622 |  |
|  | | | | | | | | | | | | | | | |

| **Table E3**  *Bayesian Hierarchical Linear Model: Mindwandering* | | | | | | | | | | | | | |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
|  | | | | 95% CI | | | |  | | | | | |
| Estimate | | SE | | Lower | | Upper | | R-hat | | ESS (bulk) | | ESS (tail) | |
| 0.016 |  | 0.585 |  | -1.180 |  | 1.159 |  | 1.002 |  | 2895.378 |  | 3641.716 |  |
|  | | | | | | | | | | | | | |

| **Table E4**  *Bayesian Hierarchical Linear Model: Block* | | | | | | | | | | | | | |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
|  | | | | 95% CI | | | |  | | | | | |
| Estimate | | SE | | Lower | | Upper | | R-hat | | ESS (bulk) | | ESS (tail) | |
| -9.104 |  | 2.964 |  | -14.920 |  | -3.280 |  | 1.001 |  | 3085.033 |  | 3984.642 |  |
|  | | | | | | | | | | | | | |

| **Table E5**  *Bayesian Hierarchical Linear Model: Awareness \* Mindwandering* | | | | | | | | | | | | | | | |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
|  | | | | | | 95% CI | | | |  | | | | | |
| Level | | Estimate | | SE | | Lower | | Upper | | R-hat | | ESS (bulk) | | ESS (tail) | |
| explicit |  | 0.647 |  | 0.469 |  | -0.276 |  | 1.572 |  | 1.001 |  | 4246.765 |  | 4645.224 |  |
| implicit |  | 0.991 |  | 0.578 |  | -0.105 |  | 2.136 |  | 1.000 |  | 3834.122 |  | 4781.023 |  |
|  | | | | | | | | | | | | | | | |

| **Table E6**  *Bayesian Hierarchical Linear Model: Awareness \* Block* | | | | | | | | | | | | | | | |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
|  | | | | | | 95% CI | | | |  | | | | | |
| Level | | Estimate | | SE | | Lower | | Upper | | R-hat | | ESS (bulk) | | ESS (tail) | |
| explicit |  | -3.694 |  | 2.790 |  | -9.264 |  | 1.932 |  | 1.002 |  | 3096.268 |  | 1952.182 |  |
| implicit |  | -4.936 |  | 3.401 |  | -11.616 |  | 1.737 |  | 1.000 |  | 3522.867 |  | 4326.533 |  |
|  | | | | | | | | | | | | | | | |

| **Table E7**  *Bayesian Hierarchical Linear Model: Mindwandering \* Block* | | | | | | | | | | | | | | | |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
|  | | | | | | 95% CI | | | |  | | | | | |
| Level | | Estimate | | SE | | Lower | | Upper | | R-hat | | ESS (bulk) | | ESS (tail) | |
| M-SD |  | 0.385 |  | 0.445 |  | -0.559 |  | 1.275 |  | 1.001 |  | 3110.583 |  | 3871.182 |  |
| M |  | 0.819 |  | 0.362 |  | 0.085 |  | 1.568 |  | 1.001 |  | 3732.454 |  | 4198.610 |  |
| M+SD |  | 1.253 |  | 0.416 |  | 0.421 |  | 2.103 |  | 1.000 |  | 4008.826 |  | 4304.387 |  |
|  | | | | | | | | | | | | | | | |

| **Table E8**  *Bayesian Hierarchical Linear Model: Mindwandering \* Block \* Awareness* | | | | | | | | | | | | | | | |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
|  | | | | | | 95% CI | | | |  | | | | | |
| Level | | Estimate | | SE | | Lower | | Upper | | R-hat | | ESS (bulk) | | ESS (tail) | |
| explicit:M-SD |  | 0.124 |  | 0.599 |  | -1.048 |  | 1.262 |  | 1.002 |  | 3580.820 |  | 4004.394 |  |
| implicit:M-SD |  | 0.646 |  | 0.688 |  | -0.725 |  | 2.028 |  | 1.001 |  | 2955.772 |  | 4238.607 |  |
| explicit:M |  | 0.647 |  | 0.469 |  | -0.276 |  | 1.572 |  | 1.001 |  | 4246.765 |  | 4645.224 |  |
| implicit:M |  | 0.991 |  | 0.578 |  | -0.105 |  | 2.136 |  | 1.000 |  | 3834.122 |  | 4781.023 |  |
| explicit:M+SD |  | 1.169 |  | 0.534 |  | 0.125 |  | 2.267 |  | 1.000 |  | 4246.874 |  | 5002.126 |  |
| implicit:M+SD |  | 1.337 |  | 0.651 |  | 0.080 |  | 2.633 |  | 1.000 |  | 4323.371 |  | 4716.804 |  |
|  | | | | | | | | | | | | | | | |

**Appendix F**

**Table F1**

*Bayesian linear model results comparing participant’s depth of mindwandering to their practice and transfer effects.*

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
|  | Estimates | | | |
| Model | M | SD | BF10 | BF01 | |
| [Explicit] Practice Effect ~ MW | 4.476 | 2.41 | 7.44 | 0.13 | |
| [Implicit] Practice Effect ~ MW | 0.27 | 0.92 | 0.38 | 2.68 | |
| [Explicit] Transfer Effect ~ MW | -0.2 | 0.57 | 0.27 | 3.72 | |
| [Implicit] Transfer Effect ~ MW | 0.31 | 0.65 | 0.54 | 1.85 | |

**Appendix G**

**Table G1**

*Exploratory t-test between block 6 and block 13 for mindwandering and reaction times.*

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
|  | Block 6 and Block 13 Differences | | | |
|  | *ΔM* | df | t | p | |
| [Explicit] Mindwandering | -9.15 | 56 | -3.05 | 0.00 | |
| [Implicit] Mindwandering | -14.77 | 39 | -3.20 | 0.00 | |
| [Explicit] Reaction Times | -60.19 | 56 | -0.38 | 0.70 | |
| [Implicit] Reaction Times | -18.48 | 39 | -0.67 | 0.51 | |

**Appendix H**

**Table H1**

*Exploratory linear models for sequence reproduction accuracy and mindwandering.*

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
|  | Reproduction Accuracy | | | |
|  | Estimate | SE | t | p | |
| [Explicit] MW | 0.00 | 0.00 | -0.23 | 0.82 | |
| [Implicit] MW | 0.00 | 0.00 | 1.79 | 0.08 | |