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Is it Possible to Learn Complex Implicit Tasks, Such as Artificial Grammars, While Mind Wandering?

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ABSTRACT

This study examined whether individuals can implicitly acquire rule-based knowledge, such as in artificial grammar learning (AGL), while mind wandering. Implicit learning occurs without conscious awareness, and AGL tasks provide a well-established method for investigating this process. In the current experiment, 116 undergraduate participants memorized 23 grammatical letter strings across 10 training blocks. Between blocks, thought probes assessed the extent of mind wandering. In the subsequent testing phase, participants judged 32 novel strings as grammatical or nongrammatical. Results showed that participants performed significantly above chance in classifying grammatical items, indicating successful implicit learning of the underlying structure. A Bayesian correlation analysis revealed no significant association between self-reported mind wandering and classification accuracy ($r = .04$), with a 95% confidence interval of [-.14, .22] and a Bayes Factor of $B01 = 12.78$, supporting the null hypothesis. These findings suggest that implicit learning is resilient to attentional fluctuations and can occur even when cognitive resources are partially disengaged. While mind wandering often disrupts tasks requiring executive control, it did not impair AGL performance. Instead, the results align with theories emphasizing the automatic, unconscious nature of implicit learning. Overall, the findings highlight the robustness of implicit learning mechanisms and extend understanding of how cognition operates under conditions of reduced attention.

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Introduction

Implicit learning, an important aspect of human cognition, is the process of learning without awareness of an underlying stimulus and without the intention of learning (Gerth, Münte, & Rüsseler, 2006). Implicit learning can be defined as automatically extracting knowledge from the environment without intending to do so and without awareness of what has been learned (Reber, 1967). This phenomenon is a ubiquitous aspect of human cognition, underpinning numerous essential abilities, including language and motor skills.

Importantly, implicit learning may be subject to domain-specific or experience-based constraints or biases which may facilitate or impede the learning of certain kinds of information. For example, implicit learning may be influenced by the complexity of the to-be-learned rule system (Rohrmeier & Cross, 2009), a factor that could be a byproduct of innate predispositions (e.g., Hauser et al, 2002), more general cognitive constraints (e.g., Rey et al, 2012), or the allocation of attention at the time of learning (e.g., Pacton & Perruchet, 2008). This last factor, allocation of attention at the time of learning, is the factor of interest in the current study.

Artificial grammar learning (AGL) has long provided a window into the mechanisms of implicit learning. In a typical AGL paradigm, participants are exposed to letter strings generated by a finite-state grammar and later asked to classify novel strings as grammatical or ungrammatical (Dienes, et al, 1991; Chang & Knowlton, 2004). Despite being unable to articulate the rules of the grammar, participants reliably perform above chance in these classification tasks, indicating sensitivity to structural regularities embedded in the stimulus stream (Pothos, 2007; Seger, 1994). These findings have traditionally been interpreted as evidence that AGL reflects automatic, unconscious learning mechanisms that operate independently of explicit cognitive control. Indirect measures of awareness, or subjective measures of awareness of the rules has also been reported to be evidence for implicit learning (cf. Rebuschat et al, 2015; Sachs et al, 2020; Shanks, 2005).

However, the extent to which AGL is truly impervious to attentional fluctuations remains an open question. While some research suggests that implicit learning is robust under dual-task or divided attention conditions (Frensch et al., 1999; Fu et al., 2010), other studies have reported that reducing attentional resources during learning can impair performance (Leclercq & Seitz, 2012; Jiménez & Méndez, 1999). One factor that has received relatively little empirical attention in the context of AGL is mind wandering—the tendency for attention to drift away from external task demands toward internally generated thoughts (Smallwood & Schooler, 2006). Mind wandering is a pervasive aspect of cognitive life, often occurring without awareness and frequently associated with reduced task performance across a range of domains, including reading comprehension (McVay & Kane, 2012), working memory (Mrazek et al., 2012), and sustained attention (Robertson et al., 1997).

Mind wandering is when thoughts are produced that are unrelated to the goal of completing the current task. Put differently, mind wandering is defined as a shift from an ongoing activity to task-unrelated thoughts (TUTs). These TUTs are extremely common. Extant research suggests that we mind wander 30%-50% of the time (Levison et al, 2012; McVay & Kane, 2012). It is also clear from the extant literature that TUTs typically lead to decrements in performance in the ongoing activity (McVay & Kane, 2009, 2012: Unsworth & McMillan, 2013). Mind wandering is typically measured subjectively in experimental studies. Participants are typically asked to describe or rate their thought content immediately preceding a thought probe briefly interrupts an ongoing primary task (Smallwood & Schooler, 2006; Kane & McVay, 2012).

Smallwood and Schooler (2006) stated that mind wandering demands attentional (executive control) resources. This demand on executive control draws resources away from the task at hand without proper metacognitive monitoring. However, the extant literature has focused on how TUTs impair performance on explicit learning and other tasks in which attentional resources are required.

Given its association with impaired task performance, mind wandering might be expected to interfere with AGL by disrupting the encoding of sequential structure during the exposure phase. However, if AGL reflects an automatic learning mechanism that operates largely outside of conscious awareness, then it may be resilient—even functional—in the face of attentional disengagement. In fact, under some conditions, reduced cognitive control may facilitate implicit learning by minimizing the interference of explicit strategies or hypothesis testing (Cleeremans & Jiménez, 2002). From this perspective, mind wandering may not necessarily be detrimental to learning; rather, it could be orthogonal—or even beneficial—to the acquisition of implicit structure.

The present study tests the hypothesis that participants can learn an artificial grammar even while mind wandering. Using a standard AGL task combined with thought-probe methodology, we measured participants' self-reported attentional states during the exposure phase and examined whether AGL performance (grammaticality classification accuracy) varied as a function of mind wandering frequency. If implicit learning mechanisms operate independently of conscious attention, we should observe above-chance performance even among participants who frequently report mind wandering. Such findings would have implications not only for theories of implicit learning, but also for understanding the boundaries of attention's role in cognitive acquisition.

Method

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116 undergraduates from a large Midwestern University were recruited from the Department of PsychologicaltSciences participant pool. Participants received course credit for their participation.

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Participants completed the experimental task online. The task was programmed using PsychoPy® and administered via Pavlovia.org. Participants were provided the opportunity to compete the research for credits in their course of record and recruitment took place via the department's onlineaparticipant recruitment system. Once the participant chose to complete the study, they followed a link in the participant recruitment system and were directed to Pavlovia.org to complete the task.

After initially starting the task, participants were presented with a screen prompting them to consent to the experiment. Participants were then prompted to enter their name and course for appropriate credit to be assigned by their course instructor. Participants were deidentified after course credit was awarded.

The experimental task consisted of three components: a training phase, mind-wandering probes, and a testing phase. At the beginning of the experimental task participants were provided instructions for the training phase of the experiment. Participants were instructed that they would be presented with several letter strings that would repeat throughout the experiment. They were told that their task was to do their best to memorize each of the letter strings. Participants were also informed that they would periodically be asked if they areI paying attention to the task and to please answer honestly. Participants were not told about the testing phase of the experiment, nor were they informed of the grammatical structure of the letter strings at this point.

Stimuli

The letter strings were constructed using the artificial grammar paradigm from Chang and Knowlton (2004). Following Chang and Knowlton, grammatical strings were generated by starting at the "IN" arrow and picking up a letter while traversing from one state to the next until an "OUT" arrow is reached (see Figure 1). Nongrammatical strings were formed by introducing an error in one position of an otherwise grammatical string. A list of the letter strings used in both training and testing are presented in the Appendix. Letter strings consisted of a minimum of two letters and a maximum of six letters. "XVXJJJ" and "XVT" represent letter sample letter strings.

Training Phase

The training phase stimuli consisted of 23 grammatical strings of letters that were repeatedly presented. A training phase trial began with the presentation of an asterisk in the center of the screen for 500ms. Next, a letter string was presented in the center of the screen and remained for 3000ms before disappearing, followed by a 500ms blank screen. Stimuli were randomly presented in blocks in which each of the 23 stimuli was presented once. Participants were presented 10 blocks for a total of 230 training phase trials. Four mind-wandering probes were pseudo randomly distributed after training phase blocks 3, 4, 6, and 10. Figure 2 represents a block of training phase trials followed by a response probe. These four probes asked the participants where their attention was in that moment on a scale from (1) completely off task to (6) completely on task.

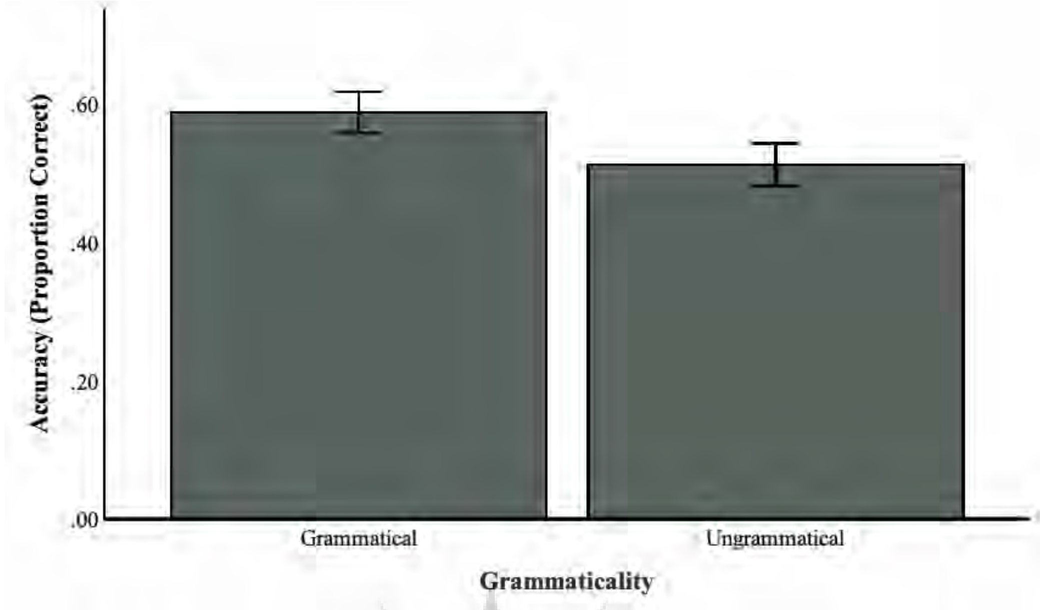
Testing Phase

After the 230 trials and the last mind-wandering probe, participants completed the testing phase of the experiment. During the testing phase, participants were presented 32 new letter strings in random order. One half of the letter strings were constructed to be grammatically correct according to the artificial grammar paradigm and one half were constructed to be ungrammatical. Participants were informed that the sets of letters they were asked to memorize in the training phase were created using a specific set of complex rules and that all previous stimuli followed those rules but, they were not informed about the nature of the rules. Participants were instructed to select 1 for "yes" the new letter string conformed to the rules or 2 for "no" if they believed that the letter string did not match the same set of grammatical rules as the previous 23 strings. Letter strings were preceded by an asterisk for 500ms and again presented in the middle of the screen and remained on the screen until the participant responded. The reminders "1 = Yes" and "2 = No" were presented with the stimuli.

Results

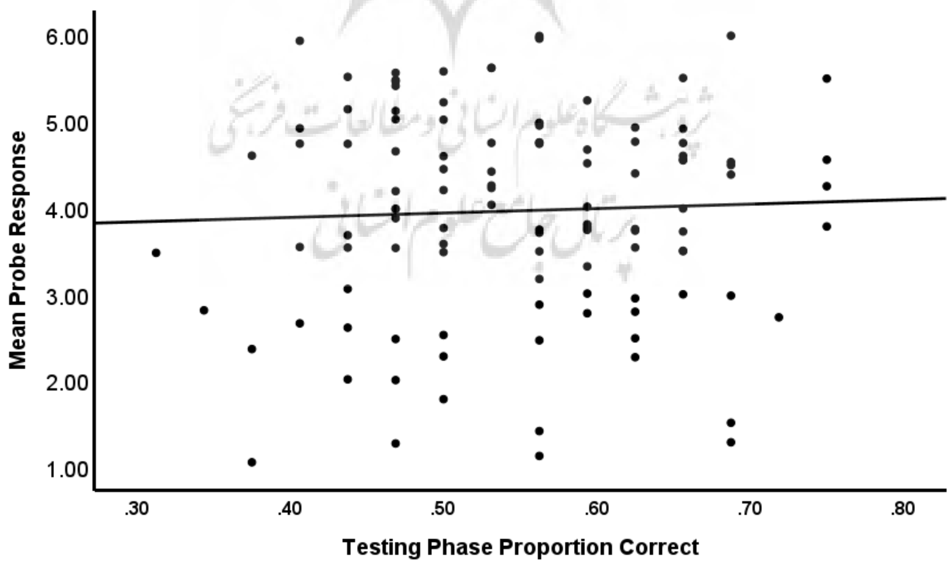
Figure 1 presents the mean proportion correct of testing phase responses by grammaticality (including total mean proportion correct). Mean accuracy for all testing phase items was M = .55 (SD = .10). A two-tailed, single-sample t-test comparing mean accuracy to chance accuracy (.50) indicated that participants were better than chance at determining whether new stimuli in the testing phase were grammatical or ungrammatical, $t(112) = 5.40$, $p < .001$, $M_{Diff} = .05$, 95% CI [.03, .07], d .. 51.

To test our hypothesis that artificial grammars can be learned when participants mind wandered, we first calculated the mean of the four mind wandering probes responses for all participants. Participants' mean responses to mind wandering probes was *M* = 3.96 (*SD* = 1.20).



Fggr e 1. Proportion Correct by Grammaticality

As our hypothesis was that participants would be able to implicitly learn the artificial grammar present in the training phase whether mind wandering or not, we next conducted a Bayesian.null.correlation analysis to determine if there was no correlation between the amount of mind wandering reported and the proportion of items correctly identified in the testing phase. The Pearson correlation coefficient was not significant, $r = .04$, $p = .66$. The Bayesian analysis revealed a small positive correlation between variable mind wandering probes and accuracy ($r = .04$), with a 95% credible interval of [-.14, .22] and a Bayes Factor of B01= 12.78, indicating substantial evidence in favor of the null hypothesis of no correlation (see Figure 2).



Fggr e 2. Scatterplot of Mean Probe Response by Testing Phase Accuracy

Discussion and Conclusion

The present study investigated whether participants could implicitly acquire an artificial grammar despite experiencing attentional lapses in the form of mind wandering during learning. Consistent with prior research on artificial grammar learning (AGL), participants demonstrated above-chance accuracy when classifying novel letter strings as grammatical or ungrammatical, even though they were not informed of the rule system during training. Crucially, participants.'

Self-reported frequency of mind wandering during the exposure phase was not significantly correlated with their grammaticality judgment accuracy. Bayesian analysis provided substantial evidence in favor of the null hypothesis, indicating that mind wandering did not impair learning in this context. These findings support the hypothesis that implicit learning mechanisms involved in AGL are resilient to fluctuations in attentional engagement.

This result aligns with theoretical accounts suggesting that implicit learning operates automatically and independently of conscious cognitive control (Reber, 1967; Cleeremans & Jiménez, 2002). While mind wandering is known to disrupt performance in tasks that rely on deliberate attentional regulation, such as reading comprehension or working memory (McVay & Kane, 2012; Mrazek et al., 2012), the current data indicate that these same disruptions may not extend to implicit structure learning. In fact, it is possible that disengaging from external task demands may reduce the influence of explicit hypothesis testing or strategic rule search, thereby preserving—or even facilitating—implicit learning (see Pothos, 2007).

At the same time, the results temper claims that attentional allocation during encoding is necessary for all forms of learning (Jiménez & Méndez, 1999; Leclercq & Seitz, 2012). Whilea attentionalr resourcesr ares criticalwini many explicitt learningi contexts,FtheirCrole inf implicitm learning may be more nuanced. Our results support the view that implicit learning can occur under conditions of reduced attention, consistent with prior work showing intact learning under divided attention (Frensch et al., 1999; Fu et al., 2010). Extending this literature, the current study is amongt thel first ~~to~~ directly relate trial-by-trial subjective attentional state (i.e., task-unrelated thoughts) to performance on a canonical AGL task.

It is worth noting that while mean performance was significantly above chance, accuracy was relatively modest overall (M = .55). This is typical of AGL paradigms in which participants are unaware of the structure and are not instructed to search for patterns. However, the relatively weak magnitude of learning may also reflect a ceiling imposed by the implicit nature of the training and test, or by the potential interference of metacognitive interpretations during the overt classification phase (Hamrick & Sachs, 2018). Notably, participants were alerted at test that the strings had followed specific rules, which may have introduced some degree of strategic guessing or post hoc rule inference. Future studies could assess whether more covert or indirect testing procedures (e.g., forced-choice familiarity or speeded classification without mention of rules; see Zizak & Reber, 2004) yield stronger or more clearly implicit learning effects.

An additional limitation is that mind wandering was assessed using self-report probes distributed across the training phase. While this method is widely used and has good ecological validity (Smallwood & Schooler, 2006; Kane & McVay, 2012), it relies on introspective access to attentional state and may not capture fluctuations occurring between probes. Future work could incorporate physiological or behavioral indices of attentional lapses (e.g., pupillometry, reaction time variability) to triangulate on the moment-to-moment impact of mind wandering on learning.

In conclusion, the present findings contribute to a growing body of evidence suggesting that implicit learning processes can remain intact under conditions of reduced executive attention. Despite high rates of self-reported mind wandering during learning, participants were able to extract and apply grammatical structure from the stimulus stream at levels significantly greater than chance. These findings have important implications for theories of attention and learning, and suggest that even when the mind wanders, the brain may continue to learni

Declarations

Author Contributions

All authors contributed actively to the conception, design, and execution of the research.

Data Availability Statement

The datasets generated during and/or analysed during the current study are available from the corresponding author on reasonable request.

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Ethical considerations

This study was conducted in accordance with the ethical principles of the Declaration of Helsinki. Informed consent was obtained from all participants prior to their involvement in the study

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Conflict of interest

The authors declare that there are no conflicts of interest regarding the publication of this research.

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