Unaware Yet Reliant on Attention: Experience Sampling Reveals That Mind-Wandering Impedes Implicit Learning

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Word Count:3279

 **Abstract**

Although implicit learning has been widely studied, controversy remains regarding its reliance on attentional resources. A central issue to this controversy is the question of how best to manipulate attention. The usual approach of comparing implicit learning in a sequential reaction time task (SRT) under single-versus dual-task conditions is known to be problematic because the secondary task can not only divert attention away from the primary task but also interfere with the implicit learning process itself. To address this confound, the present study used an experience sampling approach instead of a dual-task approach. We assessed lapses of attention (mind-wandering) with experience sampling thought probes during a standard implicit learning SRT task. Results revealed a significant negative correlation between mind-wandering and implicit learning. Thus, greater task focus was associated with improved implicit sequence learning. This result suggests that, at least in the context of this SRT task, optimal implicit learning relies on attention.

Keywords: implicit learning, mind-wandering, control processes, automatic processing, conscious awareness, sequence learning, serial reaction time

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When conceptualizing the learning process researchers often distinguish between explicit learning, in which a person can describe the learned material, and implicit learning in which a person, although unaware of what has been learned, still shows performance benefits. The dissociation between these two types of learning is most clearly demonstrated in patients suffering damage to the medial temporal lobe. This damage can result in anterograde amnesia in which explicit learning is compromised, yet implicit learning is spared (i.e., a new skill can be acquired, in spite of memory loss of even the learning session itself). Although a large number of studies of implicit learning have been informative regarding its cognitive and neural mechanisms (e.g., Keele, Ivry, et al., 2003; Nissen & Bullemer, 1987; Seger, 1994), there is still a lack of consensus regarding the role of attentional resources in implicit learning. Although some studies suggest that implicit sequence learning can proceed with little or no use attentional resources (Cleeremans & Jimenez, 1998; Frensch, 1998; Frensch et al., 1998), other studies show impaired implicit learning when attention is diverted away from the primary implicit learning task (Shanks & Channon, 2002; Shanks, Rowland & Ranger, 2005). Still other also results support the view that inattention may actually improve implicit learning (Filoteo, Lauritzen, & Maddox, 2010; Nemeth, Janacsek, Polner, & Kovacs, 2013; though see Newell et al., 2013 for re-evaluation of Filoteo et a., 2010

 The question of whether implicit learning requires attentional resources has typically been addressed through the use of a sequential reaction time (SRT) task (Nissen & Bullemer, 1987). In this task, participants identify the location of a target and press a corresponding button depending on the location of the target. For example, if an asterisk appears in the first of four squares arranged from left to right, the participant should press the far left button press (Nissen & Bullemer, 1987). A key aspect of the SRT is that, while some target locations are determined randomly, fixed patterns are embedded into the sequential presentation of targets, and the patterns repeat over the course of the task. By comparing the reaction times from patterned versus random sequences, it is possible to reveal that implicit learning has taken place. That is, it is usually found that, towards the end of the task, participants are faster when responding to patterned than random sequences. Importantly, despite this reaction time advantage, participants are unable to reconstruct the pattern and usually report no awareness of it, ruling out explicit learning.

 To investigate the role of attention on implicit learning, researchers typically compare implicit learning under single- versus dual-task conditions; the assumption being that when a “distractor”-task is performed, attention is relatively more often diverted away from the primary task. Although the findings have been mixed, much of the early work using this approach has come under question. A main argument is that the secondary task may not only divert attention away from the task, but also interfere with the learning process itself (e.g., Frensch, Lin, & Buchner, 1998; Stadler, 1995). For instance, by presenting distractor stimuli in the SRT task, or by introducing additional operations to be performed on the stimuli of the SRT task, the interval between stimuli in the SRT task is filled, which is suggested to limit the simultaneous availability of sequence elements in working memory (Schmidtke & Heuer, 1997). Although recent work has modified the protocol, even the improved methodology does not completely rule out this option (see Shanks, Rowland, & Ranger, 2005). Even on a theoretical level, it remains unclear whether it is possible to design the kind of distractor task that is difficult enough to sufficiently tax attentional resources required for learning yet does not put significant constraints on performing the SRT task in the same manner as under single task conditions.

 The present study takes a novel approach to investigate the impact of attention on implicit learning. Specifically, we use experience sampling during the SRT task to assess the degree to which attention is focused on the task. The idea behind this methodology is derived from the literature on mind-wandering, which is concerned with the occurrence of task unrelated thoughts under single task conditions (Teasdale et al., 1993,1995). Studies have shown that people’s attention becomes disengaged from the task and shifts to task-unrelated personal concerns 30-50% of the time (Kane et al., 2007; Killingsworth & Gilbert, 2010). Task unrelated thoughts measured by thought probes are usually associated with measurable performance deficits across a variety of different tasks (see Mooneyham & Schooler, 2013, Smallwood & Andrews-Hanna, 2013, for reviews) such as reading (Schooler, Reichle, & Halpern, 2004; Smallwood, McSpadden, & Schooler, 2008; Franklin, Smallwood & Schooler, 2011), simple motor tasks (Seli et al., 2014), as well as those requiring sustained attention and executive processing (e.g., the sustained attention to response task, SART- Smallwood et al., 2008; Stroop- Thomson, Besner & Smilek, 2013), as well as learning and memory tasks (Smallwood et al., 2003; Mrazek, Smallwood, Franklin, Baird, & Schooler, 2012). Based on this literature, we expect that, if implicit learning depends on attention, the thought probe approach should be helpful to reveal it.

 In a way, responding to thought probes embedded into the SRT task creates a dual-task context. However, since all participants respond to thought probes, any potential negative (or positive) effect of this secondary task on the implicit learning process should not be specific to the distracted participants.

 The impact of mind-wandering on implicit learning is, as of yet, an open question with each of the three outcomes—interference/no effect /facilitation—theoretically plausible. Given the many previously-documented examples of performance deficits associated with mind-wandering (especially with regard to learning and memory tasks), one might suspect that it would also impair implicit learning. However, since incidental, or implicit learning, occurs outside of conscious awareness, it has been suggested that it may require little or no attentional resources (Cohen, Ivry, &Keele, 1990; Curran, & Keele, 1993). It is therefore possible that mind-wandering may not impact implicit learning at all. There is also evidence to suspect that mind-wandering might even improve implicit learning. For example, the *competition between verbal and implicit systems* theory (COVIS; Ashby, Paul, & Maddox, 2011) was developed in an attempt to recognize that categorization is mediated by multiple learning systems. This theory suggests a competition between verbal and implicit systems. Based on COVIS one might suspect that mind-wandering, by utilizing verbal processing that rely on the phonological loop (Teasdale et al., 1995), may release its interference on the implicit system. If so, this freeing of the implicit system could lead potentially enhance learning. In addition, recent work by Stillman and colleagues (2014) shows that trait mindfulness (i.e., the ability to maintain periods of sustained non-distraction) was negatively associated with implicit learning. This work predicts that mindlessness, or mind-wandering, may be positively related to implicit learning.

**Current Study**

 In order to investigate the role of task focus on implicit learning, the present study utilized a standard serial reaction time (SRT) task, alternating periods of the target sequence (i.e., a pattern) with random sequences. In order to measure the extent of attention directed towards the task, we embedded thought probes in the task, which asked to participants to indicate to what degree their attention was focused on the task or on task-unrelated concerns. In addition, we collected scale measures of mind-wandering that include (a) the Imaginal Processes Inventory (IPI; Singer & Antrobus, 1972), (b) the Attention-Related Cognitive Errors Scale (ARCES; Carriere, Cheyne, &Smilek, 2008), and (c) the Memory Failures Scale (MFS; Cheyne, Carriere, & Smilek, 2006).

Uncovering the relationship between mind-wandering and implicit learning will help establish the role of attention in implicit sequence learning. If implicit learning operates automatically, not requiring attentional resources, then there should be no significant relationship between MW and implicit learning. If, attention is necessary and/or helpful for implicit learning, a negative relationship between MW and implicit learning may emerge. If, however, task focus impairs implicit learning, then we would expect a positive relationship between MW and implicit learning—MW would aid implicit learning.

**Methods**

*Participants*

There were 74 participants in the study (48 female, mean age 18.85, S.D. = 1.48). This study was granted ethical approval by the University of California, Santa Barbara Ethics Committee and written informed consent was acquired from every participant

prior to participation.

*Tasks and Scales*

*(1) Serial Reaction Time (SRT) Task*

Four boxes were presented in a horizontal row at the center of the screen. An asterisk appeared in one of the 4 locations (referred to as 1-4, from the left to right) for 1000 ms. Participants were given instructions to respond using their right hand based on the location of the asterisk as quickly and accurately as possible using the H, J, K, and L keys on the keyboard. The keys were in a "direct" spatial mapping to the target locations (such that an asterisk appearing in location '1' would require the H key-press with index finger, an asterisk appearing in location '2' would require the 'J' key-press with middle finger, etc.). The target sequence consisted of 12 locations (1-2-1-4-2-3-4-1-3-2-4-3) and was created so that each location occurred 3 times and each possible transition (e.g., 1-2, 1-3, etc.) was never repeated (see Shanks & Channon, 2003). Random sequences also consisted of 12 locations that were created based on the same parameters, but importantly these sequences all differed from on another (and the target sequence). There were 624 trials in total. Each half of the experiment contained 312 individual trials (96 Random, 216 Target). Random sequences (R) were interspersed with presentation of the target sequence as follows: R(2) T(6) R(2) T(6) R(2) T(6) R(2).

 Twelve thought probes were administered pseudorandomly (6 during random sequences, 6 during target sequences). At the probes participants were asked: “In the moments prior to the probe, was your attention focused: (1) Completely on the task (2) Mostly on the task (3) On both the task and unrelated concerns (4) Mostly on unrelated concerns (5) Completely on unrelated concerns?”

Although we recognize that there are more target trials than random trials, we opted to choose parameters that have been used and are known to be conducive to implicit learning (i.e., enough target trials to facilitate learning). Given the spaced out pseudorandom nature of the design – that every 12 trials there was a potential for a thought probe – we do not expect this imbalance (especially given low explicit awareness of target trials) to differentially influence thought probe responses and/or implicit learning. Also, we do not expect that interrupting random sequences with probes more often than target sequences could influence the main outcome, which is based on individual differences in mind wandering and implicit learning.

*Explicit memory test*

At the conclusion of the experiment, participants were queried about the presence of a repeating pattern of target locations in the task. Specifically, participants were told, “You may not have noticed, but there was a pattern embedded within some of the trials. Please use the 5 point scale below to rate how confident you are that you discovered the sequence.”. Next, they were asked to try to reproduce the pattern which they were told could be up to 15 items, using the same response keys and mapping as in the main experiment. Accuracy was measured as the probability of generating the correct key response in the correct place in the sequence, chance = .25.

Finally, participants were administered the following scales to measure mind-wandering in everyday life.

 *(a) Imaginal Processes Inventory (IPI):* Participants responded to Part I of the IPI, a 24 item questionnaire used to assess the frequency of daydreams (as an index of mind-wandering) and night dreaming (Singer & Antrobus, 1972). Each question has five alternatives, with responses ranging from infrequent to frequent. A mean was calculated for both daydreaming and night dreaming across items. A higher mean score indicates that the participant experiences a greater number of daydreams/night dreams.

 *(b) Attention-Related Cognitive Errors Scale (ARCES):* The Attention-Related Cognitive Errors Scale (ARCES; Carriere, Cheyne, &Smilek, 2008), measures the frequency of everyday cognitive failures that are most likely caused by a lapse of attention. Participants use a scale of five possible responses, ranging from 1 (*never*) to 5 (*very often*). The mean across items was calculated and a higher mean score indicates more attention-related cognitive errors.

 *(c) Memory Failures Scale (MFS):* Participants completed the 12-item Memory Failures Scale (MFS; Cheyne, Carriere, & Smilek, 2006) to assess everyday memory failures that are minimally explained by attentional errors. The scale includes items such as ‘‘I forget what I went to the supermarket to buy,’’ where participants respond on a five- point scale ranging from 1 (*never*) to 5 (*very often*). The mean score was calculated with a high score indicating that a participant is more prone to everyday memory failures.

**Results**

 Of the 74 participants, 4 were excluded from the analysis for an accuracy 2.5 S.D. below the mean (<46%). Percent-correct SRT performance for the remaining participants was high (M = 92.5,S.D. = 11.09). The mean RT for the target sequence was 419.5 ms (*S.D.* = 60.95) and for the random sequence 435.95 ms (*S.D.* = 58.29). A one-way repeated measures ANOVA revealed a significant effect of sequence type (target/random), *F*(1,69) = 43.16, *p* = <.0001. Mean confidence in learning the sequence was low (*M* = 2.18,*S.D.* =1.15) and accuracy at recreating items from the target sequence was not better than chance (accuracy = 21.43%, S.D. = 13.94) suggesting that explicit knowledge was not responsible for the effect of the faster RTs to target sequences. Moreover, the effect of the faster RTs to target sequences was significant even for those individuals (N = 24) who were least confident in identifying the target sequence (choosing 1, “Not confident at all” from the 5 pt. scale; F (1,22) = 15.30, p< .001).

 The mean response to thought probes across participants was 2.91 (S.D. = .80), corresponding closely to the middle scale item reporting that attention was "On both the task and unrelated concerns". There was no difference between random (mean= 2.94, SD = .83) and target thought probe responses (mean= 2.93, SD = .84; F(1,69) = .08, p=.76;). Assessing the relationship between task focus and implicit learning, there was a significant negative correlation between individual difference-score indices of implicit learning (Random RT – Target RT) and individuals' mean degree of mind-wandering (Figure 1; r = -.31, p = .009). Diminished task focus was associated with a smaller implicit learning effect. This relationship was further investigated using a median split to create high MW and low MW groups (see Figure 2). A mixed model ANOVA with MWgroup (High/Low) x Condition (Random/Target) revealed no main effect of mind-wandering on RT (*F*(1,68) = 0.59, *p* = 0.44), a significant effect of Condition (*F*(1,68) = 55.77, *p*<.0001), and a significant MWgroup x Condition interaction (*F*(1,68) = 9.63, *p* = 0.003). This analysis reveals that the high MW group is particularly slow for the target sequence. Additionally the scale measures of mind-wandering in daily life (DDQ, MFS, and ARCES) were each negatively associated with implicit learning, although these relationships were not statistically significant (r’s = -.15, -.12, -.08, respectively; all p’s >.20).

**Discussion**

The present study used a novel approach to investigate the effect of attention on implicit sequence learning. Previous studies have addressed this question by using a distractor task and comparing single task (implicit) versus dual-task (implicit + distractor) conditions. While this has been the dominant approach when addressing the question, authors have pointed out important limitations with this approach (Cohen, Ivry, & Keele, 1990; Curran & Keele, 1993; Frensch, Lin, & Buchner, 1998; Hsiao & Reber, 2001; Schvaneveldt & Gomez, 1998; Shanks & Channon, 2002; Stadler, 1995). In particular, the major theoretical limitation being that with this procedure it cannot fully be ruled out that the distractor task does more than just distract attention away from the task, and interferes with the learning processes or how the SRT task is executed (see Shanks, 2003 for an extensive discussion of these issues). The aim of the present study was to offer a novel approach to address this question.

The results show evidence of implicit learning, replicating earlier studies. That is, an RT advantage emerged for patterned compared to random sequences, while participants reported low confidence and accuracy levels with regards to reproducing the learned sequence. Secondly, and more importantly, we found that mind-wandering was associated with a diminished RT advantage for patterned vs. random sequences, a finding that suggests that focusing attention on the task facilitates implicit sequence learning. This result is consistent with recent findings using the typical distractor task approach (Shanks & Channon, 2002; Shanks, Rowland & Ranger, 2005). Importantly, the finding is not due to a general interference by thought probes, since all participants received thought probes and learning was associated only with specific *responses* to these probes. Although the results from the questionnaire data were less clear, they were in the same direction and it is possible that weaker results would emerge for such “trait” measures compared to acute mind-wandering episodes assessed during the task.

 Why would mind-wandering interfere with implicit sequence learning? Based on different literatures, one could predict negative effects, no effects, or even positive effects. So, in light of the present findings, it is important to understand the mechanism through which mind-wandering, at least under the present conditions (in the SRT task as it was used here) impairs learning. The mind-wandering state entails at least two processes: a decoupling of attention from perceptual input that affords an internal train of thought and episodic memory processes that contribute the mental contents that is at odds with the task in hand (Smallwood, 2013). Plausibly the intermittent decoupling of attention from perception that occurs during mind-wandering could reduce a participant’s capacity to build up an implicit model of the patterns. Alternatively, it could be that episodic process that occur during mind-wandering also play a role in implicit learning, leading to the decrement we find during mind-wandering. Given that the decrement for mind-wandering was specific to the patterned trials it is possible that, like in other distractor tasks, task-unrelated thoughts “fill up” the interval between task stimuli, thus reducing the number of successive stimuli that can be maintained in working memory. These results are consistent with recent work by Thomson, Smilek, and Besner (2014) revealing mind-wanderings reporting greater effects on mind-wandering with deep vs. shallow encoding. Presumably, the acquisition of these hidden complex sequences requires deep encoding and, as such, are impacted by mind-wandering. Perhaps future work can distinguish different off-task states. For example, “tuning out” vs. “zoning out” (Smallwood, McSpadden, & Schooler, 2007) could further refine our understanding of how mind-wandering impacts implicit learning. It is plausible that “zoning out” would be more detrimental than “tuning out”.

 Is it still possible that mind-wandering could, under some conditions, improve implicit learning? There are findings consistent with this idea, including a recent study showing that trait mindfulness (i.e., the ability to maintain periods of sustained non-distraction) was negatively associated with implicit learning (Stillman et al., 2014). Likewise, it is possible that a different type of implicit learning task, for example one with less of a response component, would have different attentional demands. However, further work will be needed to test these ideas.

 The present results provide strong evidence for the negative relationship between mind-wandering and implicit learning. At least in the context of an SRT task, implicit learning benefits from attention. This study also addressed an important methodological issue associated with earlier work through the use of experience sampling. Other studies investigating the role of attention for implicit learning could benefit from the experience sampling probe approach introduced in the present paper.

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***Acknowledgements***

MSF, JMB, CMZ, MDM, JS and JWS are supported through United States Department of Education grant R305A110277 awarded to JS & JWS. The content of this article does not necessarily reflect the position or policy of the U. S. Government, and no official endorsement should be inferred.

**Figure Captions**

Figure 1.Shows the correlation between implicit learning and mean thought probe score.

Figure 2. Shows RT for target vs. random sequences based on a median split of the MW score.

Error bars representing 95% confidence intervals for the within subjects effect are plotted for

this figure using methods taken from Loftus and Masson (1994).

Figure 1.



r = .31

Figure 2.

