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## Dispositional mindfulness is associated with reduced implicit learning



Chelsea M. Stillman<sup>a,\*</sup>, Halley Feldman<sup>a</sup>, Caroline G. Wambach<sup>a</sup>, James H. Howard Jr.<sup>b,c,d</sup>, Darlene V. Howard<sup>a,b</sup>

<sup>a</sup> Department of Psychology, Georgetown University, Washington, DC 20057, USA

<sup>b</sup> Center for Brain Plasticity and Recovery, Georgetown University, Washington, DC 20057, USA

<sup>c</sup> Department of Psychology, The Catholic University of America, Washington, DC 20064, USA

<sup>d</sup> Department of Neurology, Georgetown University Medical Center, Washington, DC 20057, USA

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### ABSTRACT

Behavioral and neuroimaging evidence suggest that mindfulness exerts its salutary effects by disengaging habitual processes supported by subcortical regions and increasing effortful control processes supported by the frontal lobes. Here we investigated whether individual differences in dispositional mindfulness relate to performance on implicit sequence learning tasks in which optimal learning may in fact be impeded by the engagement of effortful control processes. We report results from two studies where participants completed a widely used questionnaire assessing mindfulness and one of two implicit sequence learning tasks. Learning was quantified using two commonly used measures of sequence learning. In both studies we detected a negative relationship between mindfulness and sequence learning, and the relationship was consistent across both learning measures. Our results, the first to show a negative relationship between mindfulness and implicit sequence learning, suggest that the beneficial effects of mindfulness do not extend to all cognitive functions.

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## 1. Introduction

*Mindfulness* refers to the ability to stay attentive and receptive to events and experiences taking place in the present and thus disengage from habitual actions and thought tendencies. This construct has grown in popularity in recent years because it has been linked to a number of positive psychological and cognitive outcomes (Brown & Ryan, 2003). However, there may be tradeoffs to mindfulness, such that it benefits some domains of functioning but not others. The goal of the present study was to investigate the hypothesis that higher mindfulness is associated with *reduced* implicit learning, the type of learning that can take place without intent to learn or awareness of what has been learned (Reber, 1967).

Individual differences in the propensity, or disposition, for mindfulness, as assessed through self-report, are associated with enhanced psychological wellbeing. For example, people higher in mindfulness tend to have fewer symptoms of anxiety and depression (Brown & Ryan, 2003; Rasmussen & Pidgeon, 2011; Salmoirago-Blotcher, Crawford, Carmody, Rosenthal, & Ockene, 2011), lower levels of self-consciousness (Brown & Ryan, 2003; Evans, Baer, & Segerstrom, 2009), and lower levels of negative affect (Brown & Ryan, 2003). Dispositional mindfulness is also associated with better performance on a wide

\* Corresponding author. Address: 303 White-Gravenor Hall, Georgetown University, Washington, DC 20057, USA.

E-mail address: [cms264@georgetown.edu](mailto:cms264@georgetown.edu) (C.M. Stillman).

range of cognitive tasks that have implications for maintaining psychological health. For example, higher mindfulness is associated with better performance on sustained attention (Mrazek, Smallwood, & Schooler, 2012; Schmertz, Anderson, & Robins, 2009) and inhibitory control (Oberle, Schonert-Reichl, Lawlor, & Thomson, 2011) tasks, and with increased persistence on challenging tasks, reflecting an enhanced ability of more mindful people to regulate their emotions and attentional resources in the face of frustration (Evans et al., 2009). Studies measuring dispositional mindfulness therefore suggest that being mindful can benefit cognitive and mental health.

Mindfulness can also be cultivated through practice. Studies comparing the outcomes of mindfulness-based training groups to various matched control groups provide evidence for a causal link between mindfulness and improved psychological wellbeing and cognitive functioning. In healthy adults, mindfulness training increases performance on cognitive tasks assessing executive functions, including working memory (Jha, Stanley, Kiyonaga, Wong, & Gelfand, 2010; Mrazek, Franklin, Phillips, Baird, & Schooler, 2013), attention (Jha, Krompinger, & Baime, 2007) and inhibitory control (Allen et al., 2012). In the clinical realm, mindfulness-based therapies are effective at reducing symptoms and relapses of a wide range of psychiatric disorders, including depression and anxiety, chronic pain, addictions, and disordered eating (e.g., Barnhofer et al., 2009; Kabat-Zinn, 1982; Kristeller & Hallett, 1999; Rosenzweig et al., 2010; Shahar, Britton, Sbarra, Figueredo, & Bootzin, 2010; Tang, Tang, & Posner, 2013; Teasdale et al., 2000).

These effects of mindfulness training provide clues about its underlying neural bases. Many of the disorders shown to be ameliorated by mindfulness training have been linked with abnormal functioning and/or structure in brain regions supporting emotional control and processing, especially regions in the prefrontal cortex, including anterior cingulate and dorsolateral prefrontal cortices (Beauregard, Paquette, & Lévesque, 2006; Bishop, Duncan, Brett, & Lawrence, 2004; Luerding, Weigand, Bogdahn, & Schmidt-Wilcke, 2008; Phillips, Drevets, Rauch, & Lane, 2003; Uher et al., 2004).

The same prefrontal regions shown to have abnormalities in patient populations are consistent with those implicated in cognitive control and executive functioning in healthy populations (Cabeza & Nyberg, 2000; Miller & Cohen, 2001). Therefore, the mechanism by which mindfulness is hypothesized to exert its many salutary effects is by disengaging individuals from habitual response tendencies supported by subcortical neural systems (e.g., the striatum) and promoting engagement of executive control functions mediated by the frontal lobes (Holzel et al., 2013; Hölzel et al., 2011; Teper, Segal, & Inzlicht, 2013). Supporting this mechanistic hypothesis, higher mindfulness is associated with smaller caudate (a region in the striatum) and amygdala volumes (Taren, Creswell, & Gianaros, 2013), and with increases in both volume and functioning of prefrontal regions implicated in cognitive control (Grant, Courtemanche, Duerden, Duncan, & Rainville, 2010; Hölzel et al., 2007; Modinos, Ormel, & Aleman, 2010; Tang et al., 2010, 2013). For example, Tang et al. (2013) demonstrated that the resting state activity of several regions in the prefrontal cortex (i.e., brain activity during non-goal directed tasks) increased following mindfulness training. The changes in resting brain activity coincided with decreases in subjective craving and objective smoking behavior in a subset of participants who were smokers with no prior intent to quit. The authors interpreted the results as suggesting that mindfulness-induced changes in the underlying structure and function of frontal regions may have lasting, tonic influences on self-control capacity and, consequently, smoking behavior. Together, these findings raise the possibility that mindfulness may exert its salutary effects on human behavior by strengthening one of two competing neural systems, increasing the relative involvement of frontal control in cognitive functioning. For example, greater mindfulness may strengthen reliance on cognitive functions driven by frontal control processes, resulting in improved performance on cognitive functions relying on frontal brain regions but not those relying on subcortical structures.

If, as the evidence presented above supports, mindfulness is associated with greater engagement and altered structure of frontal control regions, then people higher in mindfulness might be worse at implicit cognitive processes in which reduced frontal involvement has been shown to benefit performance. Findings from a recent study by Whitmarsh, Uddén, Barendregt, and Petersson (2013) support this hypothesis; they found that individuals higher in dispositional mindfulness displayed poorer learning of artificial grammar, a cognitive task thought to depend on subcortical structures and to be impaired by explicit task instructions (Reber, 1976). The authors propose that greater mindfulness reduces habitual responding to unconsciously acquired preferences in the task, perhaps by promoting a non-reactive and non-judgmental disposition. The findings from this study demonstrate the potential relevance and importance of dispositional tendencies like mindfulness on implicit types of learning and retrieval.

In the present study, we examined how mindfulness relates to implicit sequence learning, hereafter referred to as *sequence learning*. This is the process by which people acquire complex regularities occurring in sequences of events without intending to learn them and without subsequent awareness of what has been learned. The ability to learn sequential relationships is important because it underlies essential functions of daily life; it contributes to our ability to perceive the world efficiently, to learn and use language, and even to engage in social interactions (Kuhl, 2004; Lieberman, 2000; Saffran, Newport, & Aslin, 1996).

Experimental studies of sequence learning, including those using neuroimaging, highlight the role of subcortical structures, especially the striatum, for this type of learning (Bennett, Madden, Vaidya, Howard, & Howard, 2011; Howard & Howard, 2013; Rauch et al., 1997; Rieckmann, Fischer, & Bäckman, 2010; Simon, Vaidya, Howard, & Howard, 2012; Simon et al., 2011). Crucially, there is also intriguing evidence that sequence learning is *impaired* by engagement of frontal control processes (Filoteo, Lauritzen, & Maddox, 2010; Foerde, Knowlton, & Poldrack, 2006; Howard & Howard, 2001; Nemeth, Janacsek, Polner, & Kovacs, 2012). For example, sequence learning improves following inhibitory theta burst stimulation (TBS) to the dorsolateral prefrontal cortex (Galea, Albert, Ditye, & Miall, 2009), and following hypnosis, a practice thought to temporarily disconnect frontal areas, such as the anterior cingulate, from other brain areas, such as the striatum

(Nemeth et al., 2012). It has been argued that hypnosis therefore disrupts neural communication underlying executive and attentional control (e.g., Egner, Jamieson, & Gruzelier, 2005). Given the growing evidence that prefrontal engagement does not benefit (and in many cases hurts) implicit sequence learning, we chose to focus on this essential cognitive process to test our hypothesis regarding mindfulness.

Participants completed a widely used measure of dispositional mindfulness to assess their tendency to attend to experiences in the present without distraction. They then completed an implicit sequence learning task. Given that mindfulness and implicit learning may rely on opposing neural systems, we hypothesized that people with higher levels of mindfulness would have a lower tendency to engage in habitual types of responding. We therefore predicted a negative relationship between mindfulness and sequence learning. We tested this prediction in two different samples and using two different sequence learning tasks.

## 2. Study 1

### 2.1. Method

#### 2.1.1. Subjects

Sixteen college-aged adults (12 female) ages 18–26 years ( $M \pm SD = 20.9 \pm 2.6$ ) were recruited from the Georgetown University Research Volunteer Pool. Characteristics of these participants are presented in Table 1. All experimental procedures were approved by Georgetown University's Institutional Review Board.

#### 2.1.2. Procedure

Participants completed the Mindful Attention Awareness Scale (MAAS) (Brown & Ryan, 2003), on the first day of a larger, 3-day study. They then completed 3 sessions of an implicit sequence learning task, the Triplets Learning Task (TLT) (Howard, Howard, Dennis, & Kelly, 2008). Both the MAAS and TLT are described in more detail below.

#### 2.1.3. The Triplets Learning Task (TLT)

Participants completed three abbreviated sessions (720 trials total) of the TLT (Howard et al., 2008) while in an fMRI scanner. A schematic of the TLT is shown in Fig. 1. In this task, participants view a row of four open circles centered on a computer screen. These circles fill in sequentially, red, then green in sequences of three events referred to as “triplets”. Each triplet constitutes a trial. Participants are instructed to observe the first two red cues (appearing for 120 ms each, with a 150 ms ISI) and to respond only to the location of the green “target” by pressing a spatially corresponding response button as quickly as possible. In the present version of the TLT, the target remains on the screen for a set amount of time after a response is made, and the next trial begins 1–3 s later. Short breaks were provided after every block of 50 trials, during which the subject's mean reaction time (RT) was displayed along with instructions to “focus more on speed”, “focus more on accuracy”, or “speed and accuracy are about right”. The instructions were based on the subject's mean accuracy for the preceding block of trials and were intended to drive all subjects to a similar level of response accuracy (92%). The TLT took approximately 45 min to complete.

Unbeknownst to participants, the TLT contains a probabilistic pattern, such that an arbitrarily chosen set of 8 triplets occurs with high probability (HP), while another 40 triplets occur with low probability (LP) throughout the task. LP and HP triplets are presented in a 1:5 ratio in the present version of the TLT so that the frequencies of HP and LP trials are balanced, a characteristic that equates power in the two task conditions.

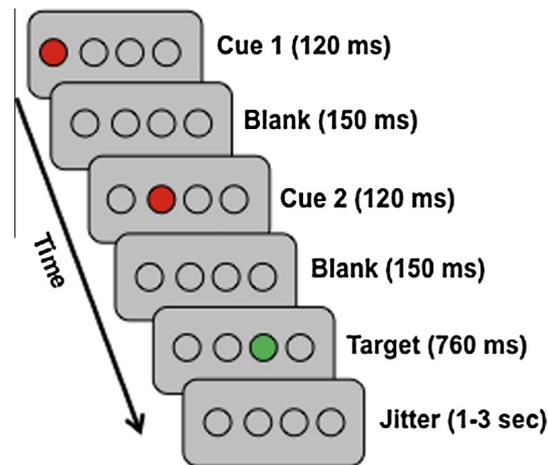
#### 2.1.4. Measures of sequence learning

Sequence learning in the TLT is assessed by comparing reaction time to HP vs. LP triplets (Howard et al., 2008) and can be quantified by one of two measures, both of which were examined in the present study.

**Table 1**  
Characteristics and neuropsychological test scores of participants.

Measure	Study 1 Mean(SD)	Study 2 Mean(SD)
Age	20.9(2.6)	80.5(9.0)
Education	14.2(1.7)	15.4(2.4)
MAAS	4.1(.88)	4.4(.88)
MMSE	–	28.7(1.8)
NAART	14.5(6.0)	11.8(9.6)
GDS	–	3.9(.73)
BDS	8.7(2.7)	6.6(2.1)

Note: For the NAART and GDS, higher scores reflect worse performance and higher levels of depression, respectively. For the other measures, higher scores reflect better performance. MAAS = Mindful Attention Awareness Scale, MMSE = Mini Mental State Examination; NAART = North American Adult Reading Test; GDS = Geriatric Depression Scale; BDS = Backwards Digit Span.



**Fig. 1.** The Triplets Learning Task (TLT). On each trial, participants observe the first two red cues and then respond to the location of the green target. These discrete, 3-event sequences are called “triplets”. Unbeknownst to participants, certain triplets occur with high frequency and others with low frequency in the task. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

**2.1.4.1. Difference scores.** Difference scores, or the size of the triplet type effect, are calculated by subtracting a participant’s mean reaction time to HP from that to LP triplets. Larger difference scores reflect more learning.

**2.1.4.2. Associative learning scores.** Because individual differences in the mean and/or standard deviation of overall response time could possibly influence the Difference Score measure of learning, we also examined Associative Learning Scores. Associative Learning Scores are computed by correlating for each subject, the number of times each unique triplet occurred with that participant’s mean reaction time to that triplet (Howard et al., 2008). More negative correlations indicate more learning, in that the participant is responding faster to triplets occurring with higher frequency. These correlation values are then multiplied by  $-1$  so that higher Associative Learning Scores reflect more learning.

### 2.1.5. Assessing implicitness

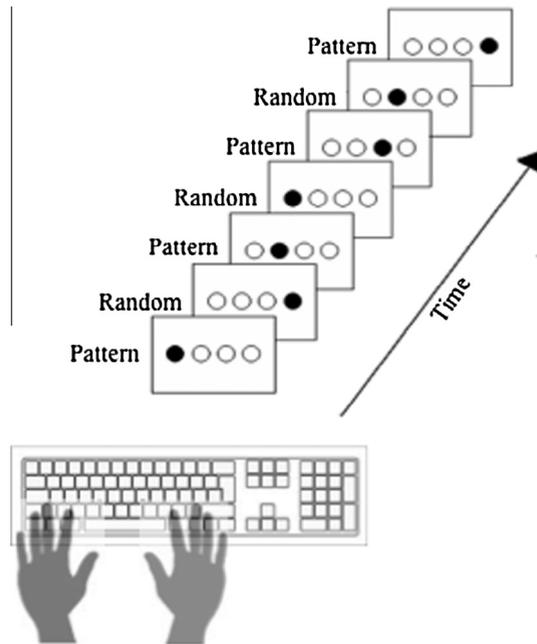
In order to assess whether learning in the TLT was implicit, participants completed a computer based recognition task immediately following the TLT. Participants were shown each possible triplet once. Thus, they saw the 8 high frequency and 40 low frequency triplets, as well as the 16 triplets that had never occurred during training. They then rated how often they thought each triplet occurred (1 = infrequently and 2 = frequently). The presentation timing of the two red cues and target are the same as in the TLT. This task is described in detail elsewhere (e.g., Howard et al., 2008; Simon et al., 2012).

### 2.1.6. The Mindful Attention Awareness Scale (MAAS)

Participants completed the MAAS to assess their trait level of mindfulness disposition. The MAAS is a single factor, self-report questionnaire designed to assess the ability to focus on experiences taking place in the present and to disengage from habitual, automatic modes of functioning. The questionnaire contains 15 items, and participants rate on a 6-point Likert scale (1 = almost always to 6 = almost never) how often they experience each item on a day-to-day basis (e.g., “I break or spill things because of carelessness, not paying attention, or thinking of something else,” “I do jobs or tasks automatically, without being aware of what I’m doing,” “I find it difficult to stay focused on what’s happening in the present”). The questionnaire is scored by averaging the participant’s responses across all items. Higher scores indicate higher mindfulness. The MAAS has been validated using a variety of subject populations, including healthy younger and older adults (e.g., Brown & Ryan, 2003; Shaurya Prakash, De Leon, Klatt, Malarkey, & Patterson, 2012), and has been shown to have good psychometric properties (Brown & Ryan, 2003; Carlson & Brown, 2005; Evans et al., 2008).

## 2.2. Results

Overall accuracy on the TLT was high ( $M \pm SD = .94 \pm .02$ ). A one sample  $t$ -test confirmed that participants learned in the TLT, in that both difference scores ( $M \pm SD = 10.47 \pm 10.9$ ;  $t(15) = 3.8$ ,  $p = .002$ ) and Associative Learning Scores ( $M \pm SD = .13 \pm .12$ ;  $t(15) = 4.3$ ,  $p = .001$ ) were significantly above zero. Results from the computer-based recognition test revealed no evidence of explicit awareness. Participants’ ratings to HP ( $M \pm SD = 1.61 \pm .24$ ) and LP ( $M \pm SD = 1.60 \pm .18$ ) triplets did not differ from one another ( $t(15) = .52$ ,  $p = .61$ ), suggesting that they could not successfully identify which triplets had occurred more than others during the TLT. However, participants’ ratings to triplets that had *never* occurred during training were consistently lower than their ratings to both LP and HP triplets (all  $t$ s  $> 1.9$ ,  $p$ s  $< .08$ ), indicating that participants understood and were complying with the instructions of the recognition task.



**Fig. 2.** Correlation between dispositional mindfulness and TLT difference scores (a) and TLT Associative Learning Scores (b) in Study 1.

Consistent with our predictions and as shown in Fig. 2, there was a negative correlation between mindfulness and both Associative Learning Scores and Difference Scores in this sample. This correlation was significant for Associative Learning Scores ( $r(16) = -.55, p = .02$ ) and marginal for Difference Scores ( $r(16) = -.48, p = .06$ ).

Participants' overall mean reaction time and accuracy in the task were not correlated with their mindfulness or learning scores (all  $p$ 's  $> .31$ ), suggesting the mindfulness-learning relationships we detected are not attributable to individual differences in overall task performance.

### 3. Study 2

Next, we sought to replicate the correlation we detected in Study 1 between mindfulness and sequence learning. A second sample of adults was tested to examine whether this relationship would occur in a different, older, sample of adults. In addition, we used a different implicit sequence learning task (the ASRT) and administered this task under different circumstances (i.e., in a behavioral testing room, rather than in the scanner).

#### 3.1. Method

##### 3.1.1. Subjects

Eighteen healthy older adults (15 female) ages 63–98 years ( $M \pm SD = 80.5 \pm 9.0$ ) participated in the study for payment. They were residents of a senior living community located in Northwest, DC and were recruited through advertisements placed in community common areas, or by word of mouth. Participants' neuropsychological test scores confirmed that they were cognitively healthy (Table 1). All experimental procedures were approved by Georgetown University's Institutional Review Board.

##### 3.1.2. Procedure

Participants completed 2 days of testing (in sessions separated by 1 day). All testing took place on-site in a quiet room centrally located to all participants. On the first day, participants completed a series of self-report questionnaires, including the MAAS and biographical and health questionnaires, and the Geriatric Depression Scale–Short Form (GDS) (Sheikh & Yesavage, 1986). They also completed an implicit sequence learning task, the Alternating Serial Response Time Task (ASRT) (Howard & Howard, 1997). The ASRT is described in more detail below. On the second day, participants completed the neuropsychological test battery and the Brief Test of Adult Cognition by Telephone (BTACT) (Tun & Lachman, 2006). The BTACT is a collection of cognitive measures assessing verbal episodic memory, working memory, executive functioning, processing speed, and reasoning. These measures are modified versions of validated psychometric tests that have been adapted to be suitable for quick administration, even when testing in person is not possible. All adults in the present study, however, were tested in person.

### 3.1.3. The Alternating Serial Response Time Task (ASRT)

A schematic of the ASRT is shown in Fig. 3. In this task, participants view a horizontal row of four open circles (outlined in black) centered on a computer screen. On each trial, one of the open circles fills in black. Participants are instructed to indicate the location of the black “target” by pressing a spatially corresponding response button as quickly as possible. If the first response is incorrect, the target remains on the screen until the correct response is made. After an accurate response is logged, the target is cleared and the next trial begins 120 ms later.

Unbeknownst to participants, the version of the ASRT task used here contained a second-order probabilistic pattern, such that the location of the target on every other trial was determined by a repeating sequence, and the intervening trials were randomly determined. Therefore, there were 6 possible repeating sequences: 1r2r3r4r, 1r2r4r3r, 1r3r2r4r, 1r3r4r2r, 1r4r2r3r, and 1r4r3r2r. The numbers in these sequences refer to the location of the target from left to right, and the “r’s” refer to a random trial in which the target could occur at any of the four possible locations. The result of this sequence structure is that some triplets (e.g., 132 for sequence 1) occur with high probability (HP) and others (e.g., 231 for sequence 1) with low probability (LP) for a given participant. Each participant was randomly assigned one of these repeating sequences.

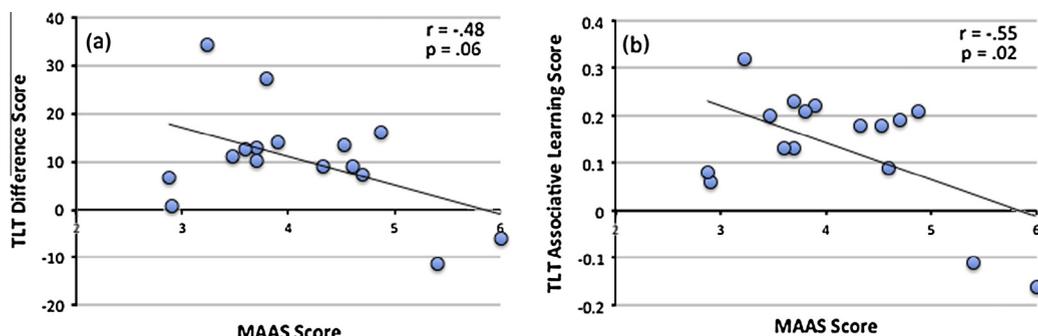
Participants completed 3960 trials of the ASRT, which corresponded to 30 repetitions of the 8-element sequence. The task was broken up into 45 88-trial blocks, with each block containing 8 practice trials and 10 repetitions of the 8-element sequence. Short breaks were provided after every block, during which the subject’s mean reaction time (RT) was displayed along with instructions to “focus more on speed”, “focus more on accuracy”, or “speed and accuracy are about right”. The instructions were based on the subject’s mean accuracy for the preceding block of trials and were intended to drive all subjects to a similar level of response accuracy (92%). Participants were given the option to take a longer break after every 15 blocks. The task took approximately 60 min to complete. As in the TLT, sequence learning in the ASRT is quantified by comparing responses to HP vs. LP triplets (Howard & Howard, 1997), thus we again calculated Difference Scores and Associative Scores.

**3.1.3.1. Assessing implicitness.** To assess whether learning was implicit on the ASRT, participants were asked a series of increasingly leading interview questions. These questions were administered on Day 2 of the protocol (rather than at the end of Day 1), and we did not administer the recognition task from Study 1 at all. This is because some of the tasks administered after the ASRT on the second day were incidental or implicit and so we did not want to compromise their implicit nature by drawing their attention to the structure of the ASRT.

## 3.2. Results

Overall accuracy in the ASRT was high ( $M \pm SD = .95 \pm .04$ ). A one sample t-test revealed that participants became sensitive to the regularity in the ASRT; learning scores were significantly above zero for both difference scores ( $M \pm SD = 12.39 \pm 14.31$ ;  $t(17) = 3.68$ ,  $p = .002$ ) and Associative Learning Scores ( $M \pm SD = .08 \pm .15$ ;  $t(17) = 2.17$ ,  $p = .04$ ). Although awareness was not assessed immediately following training, none of our participants reported having gained knowledge of the regularity in the ASRT. Furthermore, previous studies using the ASRT show that virtually no one becomes aware in this task, even when training is extended (Howard et al., 2004), and when the sensitive recognition tests included in Study 1 are used (e.g., Bennett et al., 2011; Howard & Howard, 1997; Howard et al., 2004). Moreover, when participants of a similar age to those tested here are explicitly told of the nature of the regularity in the ASRT and are instructed to look for it, they are still unable to do so (Howard & Howard, 2001). This previous evidence (coupled with the results of our interview) suggests that learning in the present study was implicit.

Most important, as in Study 1, there was a negative correlation between mindfulness and both ASRT Difference Scores and Associative Learning Scores (Fig. 4); This correlation was significant for Difference Scores ( $r(18) = -.58$ ,  $p = .01$ ), and marginal for Associative Learning Scores, ( $r(18) = -.44$ ,  $p = .06$ ).



**Fig. 3.** The Alternating Serial Response Time Task (ASRT). Participants respond to the location of sequentially presented targets using response buttons that spatially correspond to the target’s location. Unbeknownst to participants, the location of the target on every other trial is determined by a repeating sequence.

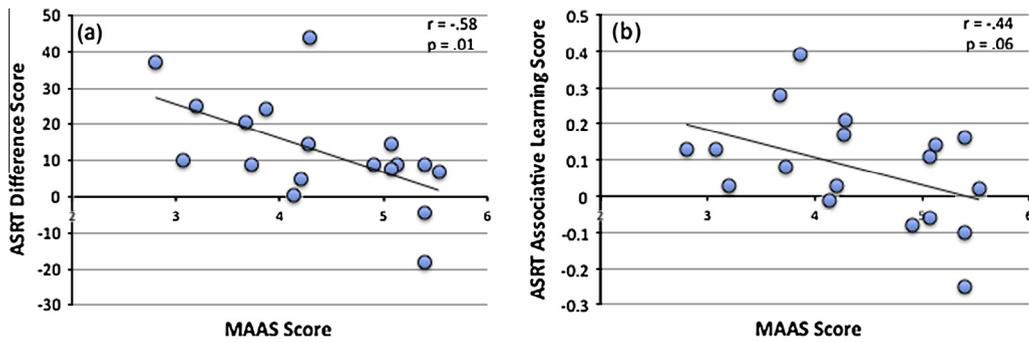


Fig. 4. Correlations between dispositional mindfulness and ASRT difference scores (a) and ASRT Associative Learning Scores (b) in Study 2.

As in Study 1, there was no correlation between mean accuracy and mindfulness or learning scores ( $ps > .84$ ). However, unlike in Study 1 there was a significant negative correlation between mindfulness and mean reaction time ( $r(18) = -.53$ ,  $p = .02$ ), as well as a non-significant positive correlation between mean reaction time and Difference Scores ( $r(18) = .44$ ,  $p = .08$ ). We therefore tested whether the relationship between mindfulness and Difference Scores was accounted for by individual differences in mean reaction time. Controlling mean reaction time did not eliminate the relationship between mindfulness and learning ( $r(18) = -.46$ ,  $p = .06$ ), but controlling for mindfulness did eliminate the relationship between mean reaction time and Difference Scores ( $r(18) = .21$ ,  $p = .41$ ). This pattern of results suggests that the correlation between mindfulness and learning we report in Study 2 is not solely due to mean speed in the task.

In addition to our primary goal of replicating the relationship between mindfulness and sequence learning, in Study 2 we also examined how mindfulness related to other measures with well-established associations with mindfulness. Higher dispositional mindfulness, for example, has been associated with fewer symptoms of depression and anxiety (e.g., [Brown & Ryan, 2003](#); [Cash & Whittingham, 2010](#); [Rasmussen & Pidgeon, 2011](#)), as well as increased subjective (and objective) physical well-being ([Brown & Ryan, 2003](#)). We therefore used participants' scores on the GDS and their self-reported overall health (recorded as a score ranging from 1 = "poor" to 5 = "excellent") in the health questionnaire) to examine whether our results would be consistent with the previously established relationships between mindfulness and these measures. Because mindfulness has been associated with better executive functioning ([Mrzcek et al., 2012, 2013](#); [Oberle et al., 2011](#)), we also examined correlations between mindfulness and participants' performance on various BTACT subcomponents tapping aspects of executive or explicit cognitive functioning. Consistent with the literature, mindfulness was negatively associated with scores on the GDS,  $r(18) = -.51$ ,  $p = .03$ , and positively associated with self-reported health,  $r(18) = .47$ ,  $p = .05$ . In addition, mindfulness was positively associated with higher accuracy on the experimental portion of the Stop and Go Test,  $r(18) = .57$ ,  $p = .01$ , a measure of inhibitory control, as well as with better episodic recall on the delayed recall subcomponent of the BTACT,  $r(18) = .46$ ,  $p = .05$ .

#### 4. General discussion

In two studies, we investigated the relationship between mindfulness and sequence learning. Supporting our hypothesis, both studies revealed negative relationships between participants' scores on a self-report mindfulness scale and sequence learning scores. In Study 1, this relationship emerged in a sample of healthy young adults who completed the learning task (the TLT) in a scanning environment. In Study 2, a similar negative mindfulness-learning relationship occurred in a sample of healthy older adults who completed a different learning task (the ASRT) in a more traditional testing environment (behavioral testing room). These key differences between the studies provide support that the novel relationship between mindfulness and sequence learning is not limited to a specific age group, learning task, or testing context.

The correlations between mindfulness and other cognitive and wellbeing measures found in Study 2 were all in directions consistent with those previously reported in the literature. That is, we found that mindfulness was significantly correlated with two measures of wellbeing (negatively with depression scores and positively with self-rated health), as well as positively with performance on executive functioning and verbal episodic memory subcomponents of the BTACT. The fact that these correlations are consistent with earlier research helps to rule out other possible explanations for the negative correlation we observed between mindfulness and implicit learning, such as the possibility that unique characteristics of the participants (and not sequence learning per se) were responsible for the effect.

The present results expand upon findings from studies examining relationships between individual differences in personality and sequence learning performance. For example, [Kaufman et al. \(2010\)](#) found that people higher in Openness (assessed via the NEO five-factor questionnaire), higher in intuition (assessed via the Myers-Briggs Type Indicator), and lower in premeditation (assessed via the UPPS impulsivity scale) scored higher on the Serial Reaction Time task, a task very similar to the ASRT used in Study 2. The authors posit that people higher in Openness and who deliberate less are better at sequence learning because they have a wider focus of attention and focus on a wider variety of stimuli, which makes them more likely to

capture relevant associations in complex tasks. Our results are consistent with this explanation: Having less of a tendency to focus on events and experiences taking place in the present (i.e., being less mindful), might ultimately make people more sensitive to the complex probabilistic patterns embedded in the TLT and ASRT. Thus, mindfulness may be another trait/disposition associated with one's aptitude for sequence learning. It is not possible to say from the present results whether participants lower in mindfulness also tended to be higher in openness, intuition, and impulsivity because we did not include additional personality measures in our studies. However, elucidating specific combinations of traits associated with sequence learning ability would be a direction for future research.

Our results are also broadly consistent with findings from neuroscience, which suggest that mindfulness exerts its salutary effects by increasing structure (e.g., regional brain volume) and functioning (e.g., mean regional BOLD signal and resting activity) of frontal brain regions implicated in cognitive control (Grant et al., 2010; Modinos et al., 2010; Tang et al., 2010, 2013). The additional positive correlations of mindfulness with executive functioning we observed in Study 2 support this mechanistic hypothesis and replicate the results of previous studies. However, our results join other findings in suggesting that increased involvement of frontal brain regions may not be beneficial for *all* domains of cognitive functioning. Indeed, there is evidence of a competitive relationship between frontal and subcortical brain regions. In the case of sequence learning, for example, experimental manipulations that *decrease* functional activation and/or connectivity of frontal brain regions to the rest of the brain (e.g., TBS and hypnosis) *increase* learning performance (Galea et al., 2009; Nemeth et al., 2012). In fact, the Nemeth et al. study described in the introduction, which showed that hypnosis improved sequence learning, did so using the same task (the ASRT) as used in our Study 2. Thus, one interpretation of the present results is that people lower in mindfulness engage frontal regions to a lesser degree during sequence learning tasks compared to people higher in mindfulness, thereby enabling the task-optimal striatal system to dominate during training. Future work could combine behavioral with functional neuroimaging techniques to further explore this interpretation.

A recent behavioral study by Janacsek, Fiser, and Nemeth (2012) offers a similar competition-related explanation, but in their case to explain why sequence learning is better in early childhood than in older age groups in the ASRT task. Janacsek and colleagues differentiate between learning based on internal models vs. that based on detection of raw probabilities. They posit that prior to adolescence learning of statistical regularities is not heavily influenced by previous experience and interpretations, i.e., by "internal models". This is because the cortical regions that support the development and use of internal models, including the frontal and medial temporal lobes, are underdeveloped. Children instead rely on a basal ganglia-dependent system that enables them to readily detect raw statistical probabilities in environmental input, a strategy optimal for sequence learning. In contrast, adolescents and adults have well-developed internal models that influence their interpretations of the raw probabilities in environmental input. While beneficial for efficiently adapting to more complex aspects of the world, this strategy impairs sensitivity to raw statistical input and sequence learning therefore declines. The idea that competition between the neural systems supporting internal models vs. the detection of raw probabilities provides an additional description, at a different level of analysis, for why mindfulness is negatively related to sequence learning in the present studies. It is possible, for example, that sensitivity to raw probabilities is modulated not only by group differences in frontal/medial temporal cortical development, but also by individual differences in the propensity for mindfulness.

The present findings should be interpreted in light of some limitations. First, the present findings are correlational in nature. We therefore cannot determine whether mindfulness *causes* people to learn less on implicit sequence learning tasks or whether there is a confounding factor driving this negative relationship. Training studies in which participants are tested both before and after mindfulness training would address this issue.

Second, our sample sizes are small. Since the chance of Type 1 error increases in small samples, replicating the present results with a larger sample is desirable. However, the fact that we detected the same negative mindfulness-learning relationship in two studies using participants of different ages, two different implicit sequence learning tasks, and across two different measures of learning, makes it less likely that these results are due to chance.

Third, the majority of participants in both study samples were female. This fact may limit the generalizability of these findings. However, it seems unlikely that the present results would be limited to females given that (to our knowledge) there are no studies reporting that mindfulness is associated with improved executive functioning in one gender, but not the other.

Finally, a fourth limitation of the present studies is that they investigated the relationship between mindfulness and one type of implicit learning (sequence learning). It is therefore not possible to determine whether mindfulness would also be negatively associated with other forms of implicit learning (e.g., implicit context learning). We also cannot tell whether mindfulness impairs sequence learning performance across both beneficial and harmful domains (e.g., implicitly acquiring a good vs. bad habit). The laboratory-based tasks used in the present study were not designed to assess any specific real-life domain in which implicit sequence learning applies so we cannot draw any conclusions on this issue here. The fact that we used different implicit sequence learning tasks across our studies is a step in the right direction, but determining whether these results occur for different forms of implicit learning in the lab—and perhaps in both adaptive and maladaptive real-life contexts—would be informative.

#### 4.1. Conclusions

Our results show a negative relationship between mindfulness and implicit sequence learning, suggesting that the beneficial effects of mindfulness do not extend to all domains of cognitive functioning. Cognitive functions, such as sequence learning, which underlie habit formation may therefore be impeded by mindfulness. The fact that there may be tradeoffs

to predominately adaptive traits such as mindfulness is not surprising. At the same time, however, being a poor sequence learner could sometimes be advantageous for cognitive and emotional wellbeing. For example, to the extent that this type of learning is involved in forming addictions and maladaptive habits, being higher in mindfulness may ultimately be protective against certain adverse health outcomes based on sequence learning.

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