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Brief communication

Mindfulness training disrupts Pavlovian conditioning

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ABSTRACT

Classical conditioning is a quintessential learning process; however, maladaptive forms of conditioning sustain many unhealthy behaviors (e.g., addiction). Mindfulness training is theorized to de-automatize conditioned behavior by decoupling stimulus and response. This study assessed the effect of mindfulness training on conditioned behavior during a classical conditioning task. Findings indicated mindfulness training decreased classically conditioned behavior relative to an active control condition, delaying the onset of first conditioned response and decreasing conditioned response frequency. Thus, mindfulness training may be one method of increasing volitional control over maladaptive conditioned behaviors that contribute to the development and maintenance of clinical disorders.

1. Introduction

In the early 1900s, Ivan Pavlov delineated the quintessential learning process of classical conditioning [1]. Classical conditioning involves pairing two stimuli, an unconditioned stimulus (e.g., appetizing food) that naturally elicits a response (e.g., salivation) with a conditioned stimulus (e.g., bell), to create a new, learned response (e.g., salivation when hearing the bell). Many adaptive behaviors are learned through conditioning; however, maladaptive forms of conditioning are also common. Maladaptive conditioning contributes to the development and maintenance of “bad habits” and psychiatric conditions, including addiction [2,3], phobias [4,5], and post-traumatic stress disorder [6,7]. Since Pavlov, extensive research has examined the neuroanatomical regions implicated in conditioning [8,9], and translated conditioning processes [10,11] into efficacious behavioral therapies designed to extinguish maladaptive conditioned behaviors [12,13]. However, no behavioral therapy has been found to disrupt the *acquisition* of classically conditioned responses. The current study provides novel empirical evidence that mindfulness meditation training, a common behavioral therapy technique, disrupts learning of classically conditioned behavior.

Mindfulness is a mental state in which one non-reactively attends to present-moment experience with an attitude of acceptance [14]. Traditionally construed as a means of de-automatizing conditioned behavior [15], mindfulness is theorized to decouple stimulus and response [16]. Mindfulness may ameliorate unhealthy cognitive and behavioral habits [17] by increasing sensitivity to currently operative contingencies and relaxing the control of previously established contingencies [18]. In this manner, mindfulness meditation de-automatizes behavior by cultivating a “fresh awareness” [19] of present moment experience unconstrained by old, conditioned habits. Evidence indicates that a propensity toward mindfulness in everyday life impedes conditioned learning of complex, probabilistic visual [20] and grammatical [21] patterns, that long-term mindfulness meditators more quickly relinquish conditioned reward expectations associated with learned cues [22], and that a mindfulness-based treatment for addictive behaviors reduces attentional reactivity to conditioned drug cues [23]. Yet, to date no study has investigated the effect of mindfulness meditation training on the acquisition of conditioned behavioral responses.

This study assessed the effect of mindfulness training on conditioned behavior during a canonical classical conditioning task, delay eyeblink conditioning, in a sample of healthy, young adults. This methodology allowed for investigation of whether mindfulness disrupts classical conditioning through the process of de-automatization [15]. Conditioned learning rates, quantified by conditioned blink frequency during the delay eyeblink conditioning task, was the primary outcome of interest. We hypothesized that relative to an attention control condition, mindfulness training would be associated with significantly lower conditioned blink frequency. Secondarily, we hypothesized that mindfulness training would be associated with significantly longer time to acquire the first conditioned response. Finally, we hypothesized that the effect of mindfulness training on conditioned blink responses would be mediated by increases in state mindfulness and independent of the effects of mindfulness on parasympathetic regulation of startle

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responses induced by the task.

2. Method

A sample size of 48 was determined to provide sufficient power (1–β = 0.90) to observe a small effect size (η^2 = 0.04) in conditioned response frequency. Oversampling by 10% to account for potential screen failures, we recruited 53 participants for an attention training study at a large university in the Western United States. Recruitment materials did not mention mindfulness. Four participants were excluded from the study following screening due to hearing impairment that would have prevented acquisition of conditioned responses by auditory stimuli. The final data set consisted of 49 healthy participants (36 females) between 18 and 43 years of age ($\overline{x}$ = 27.17, *SD* = 6.46) without memory disorders or learning disability diagnoses. The local Institutional Review Board approved all study procedures and all participants provided written informed consent.

Study procedures took place over the course of six, individually scheduled study sessions, completed over three weeks. In the first session, consent and demographic information were obtained before participants completed a five-minute resting baseline assessment in which they remained still, with their eyes open and did not speak. Following this rest period, participants completed a self-report measure of state mindfulness [24]. The next four study sessions lasted 15 min each and included an 11-minute experimental induction – either mindfulness training or active listening. Immediately following the induction, the same state mindfulness measure completed during the first session was used as a manipulation check to characterize the extent of state mindfulness produced by the induction. Participants randomized to the mindfulness condition (n = 24) received scripted instruction in basic mindful breathing and body scanning techniques [14]. Participants randomized to the active listening control condition (n = 25) listened to time-matched selections from *The Natural History of Selborne* [25] – an attention control condition validated by Zeidan et al. [26] for use in experimental studies of mindfulness inductions. In the sixth session, the delay eyeblink conditioning task was performed after participants completed their respective experimental induction and self-report measures. Electrocardiogram (ECG) sensors were affixed to participants' pectoral muscles and ECG was recorded during experimental induction and the eyeblink conditioning task.

An empirically-validated delay eyeblink conditioning procedure was used [27,28]. Participants completed six conditioning blocks followed by one extinction block. Each block consisted of 10 trials. The conditioning blocks were comprised of seven reinforced and three unreinforced trials (70% reinforcement schedule), presented in random order (Fig. 1a). The extinction block consisted only of unreinforced trials. For each reinforced trial, an 800 ms tone (70db SPL; *CS*) was coupled with a 80 ms airpuff administered to the cornea (200 mmHg; *US*). The tone was presented first, with the airpuff beginning 720 ms after the tone so that both stimuli co-terminated (Fig. 1b). In unreinforced trials, only the tone was presented. Inter-trial intervals fluctuated randomly between 10 and 14 s. The tone was presented through noise canceling headphones. The airpuff was delivered toward the eye's medial canthus through tubing affixed to a headband. During the delay eyeblink conditioning task, participants were instructed to fixate on a cross in the center of a computer screen and refrain from deliberate eye or body movement. Participants were informed that their attention would be measured at the experiment's conclusion, that they would hear some tones, and intermittently feel a puff of air in the eye that would not be painful or harmful.

Eyeblinks were recorded using an electrooculogram (EOG) amplifier (Gain = 2000, 0.05 Hz) from a MP150 system (Biopac Systems, Inc.). Analysis of eyeblink data was performed offline with AcqKnowledge 5.0 (Biopac Systems Inc.). Using established conventions [27,28], a blink was defined as a change in the EOG waveform's curve exceeding an amplitude of 25 A/D units for 25 ms and a peak amplitude exceeding 75 A/D units. A conditioned response was defined as a closing movement of the eyelid occurring between 450 ms and 720 ms after tone onset. The first conditioned response and conditioned response frequency in each of the seven task blocks was determined for all participants.

With respect to the HRV analyses, R-R intervals were detected in the ECG data using automated routines in Acqknowledge 4.1 software (BIOPAC, Inc.). The R-wave file was then visually inspected to correct misidentified or omitted R-waves. Kubios 2.0 (Biosignal Analysis and Medical Imaging Group, University of Finland) was used to calculate beats-per-minute (BPM) and for spectral analysis of R-waves. R-R interval data were divided into two segments, one spanning the experimental manipulation period and the other spanning the eyeblink condition. HRV analyses were conducted on the entire segment length for each of these two conditions: a fast Fourier transform was applied separately to R-R interval data to extract normalized HF-HRV from a detrended, end-tapered interbeat interval time series. The spectrum for the selected R-R interval segment was calculated via Welch's periodgram method, in which R-R interval data were reduced using Kubios 2.0 default settings of a window width of 128 s (with a window overlap of 50%). The HF-HRV ratio was selected as the primary focus for statistical analysis. Following Berntson [29] and Malliani et al. [30], we calculated HRV in normalized units to elucidate shifts in this frequency component that might otherwise be obscured by use of absolute units which are dependent on total HRV power. HF-HRV was averaged separately for the experimental manipulation and the eyeblink conditioning task periods.

3. Results

Repeated-measures ANOVA was used to examine the impact of Group (mindfulness vs. active listening) and Time (study sessions 1–6) on state mindfulness. A significant Group x Time interaction was observed ($F_{5,235}$ = 3.77, p = .003, η^2 = 0.07), indicating that mindfulness training increased state mindfulness across the six study sessions (Fig. 2).

The mean trial number of first conditioned response, a measure of conditioning onset, is presented in Fig. 3. Given that sex differences in eyeblink conditioning are well-documented [28], a one-way ANCOVA was conducted to examine the impact of mindfulness training on first conditioned response, controlling for sex. There was a significant mean

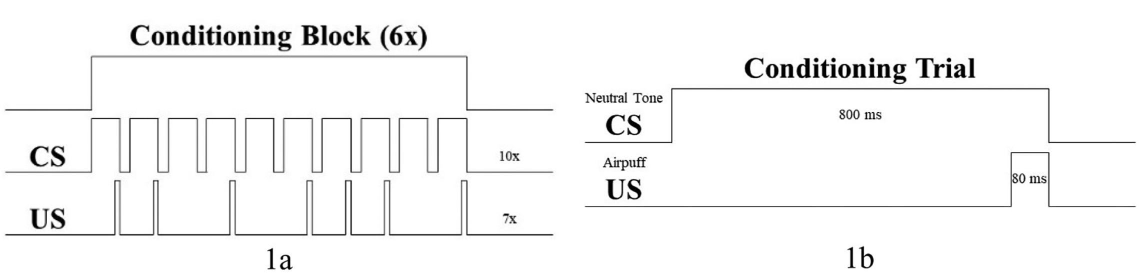

Fig. 1. Visual representation of the experimental schedule depicting a conditioning block with 70% reinforcement schedule (1a) and timing of unconditioned stimulus (US) and conditioned stimulus (CS) presentation for an individual conditioning trial (1b).

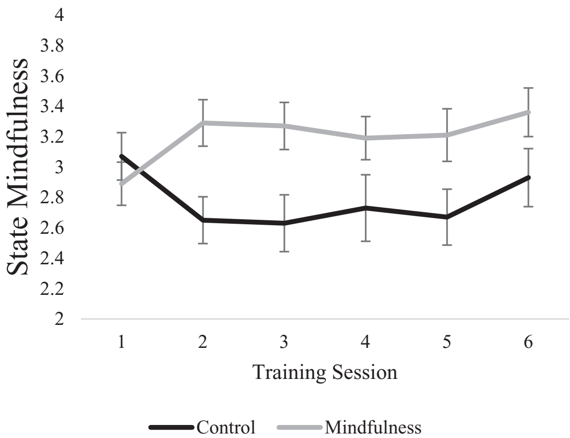

Fig. 2. Mean state mindfulness (± 1 standard error) over the course of six study sessions. Participants in the mindfulness condition displayed higher state mindfulness in response to experimental induction than participants in the active listening control condition. Delay eyeblink conditioning took place during the sixth study session.

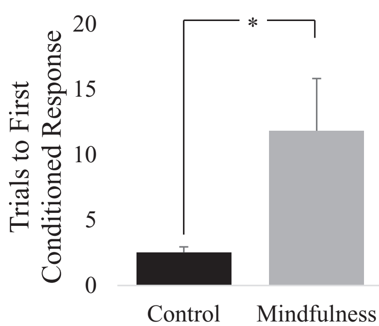

Fig. 3. Effect of mindfulness training on the number of trials needed to acquire the first conditioned response (± 1 standard error). Participants in the mindfulness condition needed significantly more trials before demonstrating an initial conditioned response.

difference in the number of trials to first conditioned response ($F_{1,46} = 6.12$, p = .017, $\eta^2 = 0.12$), indicating that mindfulness training delayed ($M = 11.8$, $SD = 19.57$) conditioned response acquisition relative to the active listening ($M = 2.5$, $SD = 2.16$).

The development of conditioned response frequency across the six acquisition blocks and the extinction block is presented in Fig. 4. Prior to testing the hypothesis that mindfulness could impact acquisition, we

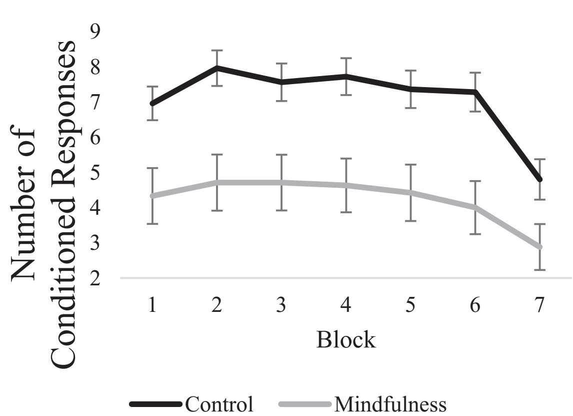

Fig. 4. Effect of mindfulness training on acquisition and extinction of delay eyeblink conditioned responses (± 1 standard error). Mindfulness training resulted in less conditioned responding.

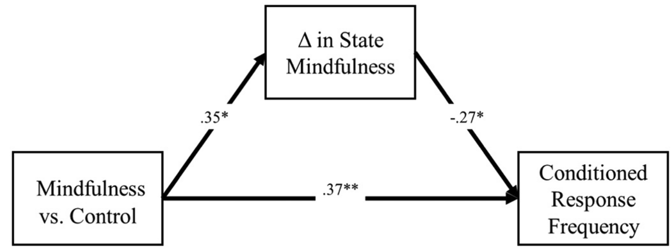

Fig. 5. Path analytic test of mindfulness training on changes in conditioned response frequency mediated by changes in state mindfulness from study session 1 to study session 6. (* $p < .05$, ** $p < .01$. Note. Standardized betas are reported.)

first sought to demonstrate whether the tone-airpuff association had been acquired. In that regard, an acquisition curve was observed in the first block, with a significant main effect of time across the 10 trials indicating participants learned to associate the tone with the aripuff ($F_{9,40} = 4.43$, $p < .001$, $\eta^2 = 0.50$). For the six acquisition blocks, repeated measures ANCOVA with factors Group (mindfulness versus active listening) and Block (blocks 1–6) yielded a significant main effect of Group ($F_{1,46} = 16.95$, $p < .001$, $\eta^2 = 0.27$), controlling for sex ($F_{1,46} = 5.57$, $p = .023$, $\eta^2 = 0.11$). A non-significant independent samples T-test revealed that this effect was not simply the result of mindfulness decreasing eyeblinks generally (i.e., during and in-between tones: $t_{46} = 0.12$, $p = .91$) nor during the inter-trial interval ($t_{46} = 0.20$, $p = .85$). Thus, significantly higher conditioned response frequency was observed in the active listening condition compared with the mindfulness condition.

Path analysis was used to examine whether training-dependent changes in state mindfulness explained reductions in conditioned responding (Fig. 5). Experimental group was a significant predictor of change in state mindfulness from study session one to study session six, and change in state mindfulness was a significant predictor of conditioned response frequency. Experimental condition demonstrated a significant indirect effect ($B = 4.13$, $SE = 1.87$, 95% CI: 0.48, 6.69) on conditioned response frequency via change in state mindfulness. Because sex along with stress and autonomic regulation are known to influence delay eyeblink response (e.g., Wolf et al., 2009), a sensitivity analysis was performed to determine whether HF-HRV, a marker of vagal tone, could also serve as a mediator while controlling for sex. A significant Group (mindfulness vs. active listening) X Condition (induction vs. eyeblink conditioning) interaction on HF-HRV was observed ($F_{1,44} = 6.09$, $p = .018$, $\eta^2 = 0.12$), controlling for sex ($F_{1,45} = 0.16$, $p = .69$, $\eta^2 = 0.004$). Participants in the active listening condition experienced decreased vagal tone from induction to eyeblink conditioning whereas participants in the mindfulness condition experienced no change in vagal tone. In a sensitivity analysis conducted with a multivariate path model, change in state mindfulness remained a significant mediator ($B = 4.34$, $SE = 1.94$, 95% CI: 0.37, 7.14), whereas HF-HRV did not mediate the observed effect when controlling for sex.

4. Discussion

This study assessed the effect of mindfulness training on Pavlovian (classical) conditioning. Findings indicate that mindfulness decreased classically conditioned behavior. Mindfulness training delayed the onset of first conditioned response (i.e., first blink) and decreased conditioned response frequency. To our knowledge, this is the first study to demonstrate effects of mindfulness training on the acquisition of conditioned responses. Furthermore, although mindfulness training buffered against decreases in vagal tone during startle responses to the task, training-dependent increases in state mindfulness mediated the effect of mindfulness training on conditioned response frequency, even after accounting for changes in HRV at the time of conditioning. This mechanistic finding suggests that mindfulness training disrupts classical conditioning via the cognitive aspects of state mindfulness and not through mere parasympathetic regulation. However, neuroimaging is indicated to more fully elucidate the mechanisms by which mindfulness modulates conditioned responding. Thus, mindfulness training may be one method of increasing volitional control over habitual, automatized responding. Our results, in conjunction with prevailing theories of mindfulness [15,17,31] and associated empirical evidence, indicate that mindfulness meditation training disrupts conditioning, impeding the acquisition of classically conditioned behaviors and facilitating extinction [18,20–22]. It may be that the non-reactive, present moment orientation characterizing mindfulness increases the likelihood that each moment is experienced as a novel, discrete event, unconditioned by prior experience. In this way previously conditioned cues may be less likely to activate conditioned behaviors when those cue are encountered. On the other hand, it is possible that mindfulness may impair extinction, as the extinction process involves the acquisition of a new association between cue and outcome, and our findings suggest mindfulness impairs acquisition. Continued research is needed to more comprehensively test whether and how mindfulness impacts acquisition, extinction, or both.

Conditioned behaviors underlie some of the most vexing public health threats confronting society today. For instance, addiction is thought to arise in part through a process of classical conditioning in which drug-related contextual cues come to reflexively elicit drug use – a conditioned response that can operate out of habit and against one's will. Results from the present study further justify the use of mindfulness as a clinical intervention and may have far-reaching implications. In fact, findings from this study suggest that mindfulness training may have the potential to inoculate individuals against the development of maladaptive conditioned behaviors. In the general population, relaxing conditioned behavioral contingencies through mindfulness training may allow individuals to act with greater intentionality and purpose. In the context of psychopathology, pairing mindfulness training with established extinction therapy techniques might enhance treatment outcomes. However, continued examination is needed to better characterize how mindfulness meditation discourages the formation of maladaptive habits and how these findings can be more directly translated into clinical intervention approaches.

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Conflict of interest

The authors declare no conflict of interest.

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