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MINDFUL AWARENESS RELATED TO WORKING MEMORY CAPACITY AND RESPONSE INHIBITION

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Abstract

Objectives: This study investigated the associations among trait mindfulness, working memory capacity (WMC), and response inhibition. Mindfulness and WMC are thought to involve goal maintenance while resolving competing responses (inhibition), and studies have indeed found associations among mindfulness, WMC, and response inhibition. However, previous studies focused primarily on behavioral inhibition and many failed to differentiate components of mindfulness (awareness and acceptance). This study examined how self-reported mindfulness (awareness and acceptance) related to performance on tasks of WMC and multiple types of response inhibition (i.e., behavioral inhibition, interference control, and cognitive inhibition).

Methods: Sixty-seven undergraduate students (75% female) received extra credit for participation. Measures included the Philadelphia Mindfulness Scale (measuring awareness and acceptance), Hayling Task (cognitive inhibition), go/nogo task (behavioral inhibition), Attention Network Test (interference control), n-back task (WMC), and Automated Reading Span Task (WMC).

Results: Higher self-reported awareness was related to stronger performance on two measures of WMC (r =.29; r =.32) and multiple measures of response inhibition, including behavioral inhibition (r = -.25), interference control (r = -.25), and cognitive inhibition (r = -.28); response inhibition and WMC accounted for 22% and 16% of the variance in awareness respectively. No relations were found between self-reported acceptance and cognitive performance.

Conclusions: Overall, this study found that the Mindfulness component of higher awareness (but not the component of acceptance) was related to stronger WMC and response inhibition. Because Mindfulness, WMC, and response inhibition are related in unique ways to healthy functioning and wellbeing; learning about how they interact increases scientific understanding, and suggests a direction for potential interventions to target these areas.

Keywords

Mindfulness, Working Memory Capacity, Response Inhibition, Awareness, Acceptance, PHLMS

Mindfulness is described as being actively present in the moment without applying value judgments. There is growing interest in understanding this construct, as a considerable body of literature has demonstrated positive effects of mindfulness on both physical and mental health, as well as quality of life (Keng, Smoski, & Robins, 2011; Michaelsen, 2023; Verhaeghen, 2021). Mindfulness has been examined in relation to many cognitive processes (Chiesa et al., 2011; Whitfield et al., 2022; Zainal & Newman, 2024), with a particular emphasis on the relation with working memory capacity (WMC). WMC and mindfulness both involve maintaining a goal in the presence of competing stimuli, and thus require inhibitory ability to respond to interference (response inhibition). The remainder of the introduction will elaborate each of these constructs (i.e., mindfulness, WMC, and response inhibition), and will also provide a review of initial research into their possible interrelatedness.

Mindfulness

Mindfulness entails a decision to be present in the moment with a nonjudgmental attitude, which disrupts mind wandering or habitual responding and provides space for intentional action. Mindfulness was originally based in Buddhist meditative practices, but clinical interest emanated from the development of a mindfulness-based stress reduction program for management of pain and chronic illness (Kabat-Zinn, 1982). Mindfulness-based therapies have since been used with other clinical and non-clinical populations (e.g., medical students, nurses, educators, leaders), and have been shown to decrease distress and to enhance well-being (Brown et al., 2013; Hathaisaard et al., 2022; Sulosaari et al., 2022; Urrila, 2022). Mindfulness practice is thought to increase emotional and behavioral awareness and regulation, reduce rumination and reactivity, and alter relations toward negative experiences (Bishop et al., 2004). Mindfulness has been looked at as both a state that can be induced or strengthened through training, and a trait, which was the focus of the present research. Bishop and colleagues (2004) proposed an operational definition of mindfulness as "the self-regulation of attention so that it is maintained on immediate experience . . . adopting . . . an orientation . . . characterized by curiosity, openness, and acceptance" (p. 232). Sustained attention to the present moment forms the awareness facet of mindfulness, while the acceptance facet comprises the open attitude toward that experience.

Working Memory Capacity (WMC)

Working memory is the ability to activate, maintain, process, and manipulate information, and contains components for short-term memory storage, rehearsal, and executive attention (Engle & Kane, 2005). WMC is the ability of the executive attention system to keep information relevant to the present goal accessible in the foreground despite competing demands from interfering stimuli. A two-factor model of executive control by Engle and Kane (2005) postulated that maintenance of a goal and resolution of competing responses (response inhibition) are interrelated aspects of WMC.

Consistent with this view, individuals with higher WMC have been found to perform better on tasks involving response inhibition (Kane & Engle, 2003; Long & Prat, 2002; Redick & Engle, 2006; Unsworth et al., 2022) and were less likely to experience unwanted intrusive thoughts (Brewin & Smart, 2005). Response inhibition has also been found to decrease as working memory load task demands are increased (Redick et al., 2011). Mindfulness is similar to WMC in that it also maintains focus on a goal while resolving conflict from competing stimuli (Jha, et al., 2010).

Response Inhibition

The ability to inhibit responding is vital for well-being, as it enables individuals to suppress impulsive or unhealthy actions and to decrease interference from unhelpful thoughts and emotions (Lee & Chao, 2012). Response inhibition is a key component of executive control for resolving conflicts between competing responses (Engle & Kane, 2005). A decision to act can involve both a choice to engage in a response and negation of an alternate response. Withholding or cancelling an action when there is a strong tendency to engage in that action is known as response inhibition. This cognitive flexibility allows suppression of a response that is no longer relevant or applicable to the desired goal. Response inhibition requires individuals to maintain information necessary to determine what is pertinent or irrelevant information and what is an appropriate or inappropriate response. Thus, response inhibition may rely in part on WMC, and WMC may rely in part on response inhibition.

A taxonomy of response inhibition developed by Nigg (2000) delineates multiple dimensions of inhibition, including automatic (orienting of attention), motivational (in response to immediate punishment or novelty), and executive (goal-driven) inhibition. Executive inhibition, which was the focus of the current research, requires intentional effort and is further decomposed into behavioral inhibition (suppressing behavioral responses), interference control (suppressing competing stimuli), cognitive inhibition (suppressing extraneous information from within working memory), and oculomotor inhibition (suppressing reflexive saccades). Deficits in response inhibition have been found to play a role in a number of disorders, such as attention-deficit hyperactivity disorder (ADHD; Wodka, 2007; Senkowski et al., 2024), borderline personality disorder (BPD; Rentrop et al., 2008; Yang et al., 2021), and substance use disorders (Smith et al., 2014), as well as aspects of obsessive-compulsive disorder (OCD; Mar et al., 2022), trichotillomania (Ali et al., 2024), anxiety (Asadi-Rajani, & Sharifi-Daramadi, 2023; Fox et al., 2021), and learning disorders (Crisci et al., 2021)

Mindfulness, WMC, and Response Inhibition

Mindfulness is associated with that aspect of WMC known as executive functioning by "self-regulating the focus of attention while inhibiting the urge to elaborate on thoughts and feelings" (Oberle, Schonert-Reichl, Lawlor, & Thomson, 2011, p. 572). Bishop and colleagues (2004) suggested that the practice of maintaining attention while refraining from elaborating on extraneous stimuli (mindfulness) is associated with cognitive inhibition, which frees resources in working memory. Thus, on these construals, mindfulness and WMC contain shared processes of maintaining a goal while inhibiting interference (Jha et al., 2010). This maintenance requires the ability to identify and resolve irrelevant thoughts (cognitive inhibition) and external distractions (interference control) that impede the goal. The awareness component of mindfulness may help perceive the need to disrupt automated responding to withhold or cancel an undesirable response, while the acceptance component may promote letting go of, rather than struggling with, conflicting stimuli.

Research on the Relation Between Mindfulness and WMC

A limited body of research has provided support for an association between trait mindfulness and WMC. People with higher WMC were less likely to experience unwanted intrusive thoughts (Brewin & Smart, 2005), consistent with the acceptance and letting go of intrusive thoughts in mindfulness. Higher self-reported mindfulness was also associated with increased performance on (Anicha et al., 2012; Ruocco & Direkoglu, 2013), and decreased mind wandering during (Ju & Lien, 2018), WMC tasks. However, Ruocco and Direkoglu (2013) were the only researchers to use the Philadelphia Mindfulness Scale (PHLMS; Cardaciotto et al., 2008) as a measure of trait mindfulness -- a measure developed to assess the two domains (awareness and acceptance) delineated by Bishop and colleagues (2004). Ruocco and Direkoglu's study found that acceptance (but not awareness) was related to improved WMC.

Other researchers examined WMC (and response inhibition or interference control) as related to separate components of mindfulness using the Five Facet Mindfulness Questionnaire (FFMQ; Baer et al., 2006), which contains subscales of Observing, Describing, Nonjudgment, Nonreactivity, and Acting With Awareness. Results were highly variable: some researchers found a positive association between levels on the Observing subscale and WMC (Anicha et al., 2012), interference control (Di Francesco et al., 2017), or behavioral inhibition (Noone et al., 2016); other researchers found positive associations between interference control and Nonreactivity (Anicha et al., 2012), or the Describing and Nonjudgment subscales (Sorensen et al., 2018), or the Acting With Awareness subscale (Lee & Chao, 2012); and surprisingly, Di Francesco and colleagues (2017) found a negative association between the Acting With Awareness subscale and interference control.

Research on the Relation Between Mindfulness and Response Inhibition

A relation between mindfulness and response inhibition has received additional research support. Higher self-reported mindfulness was associated with stronger behavioral inhibition in adolescents (Oberle et al., 2012) and adults (Galla et al., 2012; Mrazek et al., 2012; Ruocco & Direkoglu, 2013; Schmertz et al., 2009), with behavioral inhibition generally measured through performance on go/no-go tasks that require a response to a predominant set of stimuli (go trials) but not to another set of infrequent stimuli (no-go trials). Similarly, higher self-reported mindfulness was associated with stronger interference control (Anicha et al., 2012; Galla et al., 2012; Jaiswal et al., 2018; Lee & Chao, 2012; Teper & Inzlicht, 2013), with interference control typically measured by performance on the Stroop Test (Stroop, 1935). The Stroop Test requires inhibition of the automatized process of word reading in order to attend to the color of ink in which the word is printed. These studies support the idea that higher levels of mindfulness are associated with greater inhibitory control (behavioral and interference control). However, only two of these studies used the PHLMS to examine the primary mindful domains of awareness and acceptance: Teper and Inzlicht (2013) found a positive relation between self-reported mindfulness and increased interference control, with acceptance mediating the relation; but Ruocco and Direkoglu (2013) obtained a contrary result -- that awareness but not acceptance -- was associated with sustained performance of behavioral inhibition.

Mindfulness encourages maintenance of attention on the present, with a continual monitoring of attentional lapses or secondary elaboration of thoughts, and redirection back to the present goal. Given this cognitive nature of mindfulness, it is surprising that cognitive inhibition, the subtype of response inhibition that involves suppression of unnecessary or unhelpful internal information, has been largely ignored in research. There do not appear to be any studies looking at *trait* mindfulness and cognitive inhibition, and only one study by Heeren et al. (2009) examined effects of mindfulness training on cognitive inhibition. Their results demonstrated that mindfulness training enhanced the inhibition of cognitive responses on the Hayling Test (Burgess & Shallice, 1997), which requires subjects to inhibit an alluringly appropriate response to sentence stems by rapidly completing sentences with an unrelated word.

The Present Study

Overall, initial support has been found for a relation between mindfulness and WMC and between mindfulness and response inhibition, but most research has failed to consider the inter-dependent relation between WMC and response inhibition. Existing research has also generally focused on *behavioral* response inhibition. In addition, while initial research suggests that cognitive abilities may relate differentially to mindfulness facets, only two studies (Ruocco & Direkoglu, 2013; Teper & Inzlicht, 2013) used the only bi-dimensional measure reflective of the widely accepted operational definition by Bishop and colleagues (2004), the PHLMS, which includes the subscales of awareness and acceptance. Further, only one of these studies (Ruocco & Direkoglu, 2013) looked at both WMC and response inhibition together.

Thus, the present study partially replicated research by Ruocco and Direkoglu (2013) that found a relation between acceptance and WMC, as well as with awareness and behavioral inhibition. To enable comparison with their results, a similar go/no-go task was used to assess behavioral inhibition and an *n*-back task to assess WMC. *N*-back tasks require a response every time a letter presented matches a letter that occurred *n* items back in the sequence. While some support has been found for the use of *n*-back tasks (e.g., Shelton et al., 2009), others argue that variable reliability renders them less efficient for measurement of individual differences (e.g., Redick & Lindsey, 2013). On the other hand, complex span tasks (e.g., reading-span, operation-span, symmetry-span), which combine recall of items presented with simultaneous processing on a separate task, are an accepted means for assessing individual differences in WMC (Unsworth et al., 2009). Complex span tasks tend to be weakly correlated with *n*-back tasks, likely due to accessing different components of WMC, with the former requiring recall and the latter recognition, and thus these different tasks cannot be used interchangeably to measure WMC (Redick & Lindsey, 2013). To cover both components of WMC, a reading-span task was added here to capture the recall aspect of WMC.

The present study also extended research by Ruocco and Direkoglu (2013) by assessing multiple subtypes of response inhibition: behavioral, interference control, and cognitive. As previously noted, research on trait mindfulness and interference control generally used a Stroop test. However, performance on the Stroop may be variable, as it captures different types of interference (semantic, perceptual, etc.) that could be responded to in a variety of ways (Wager et al., 2005). Mindfulness training research has used the Attention Network Test (ANT; Fan et al., 2002), which requires attending to central stimuli while inhibiting attention to surrounding stimuli. While van den Hurk et al. (2012) failed to find effects using the ANT, others found that mindfulness training improved ANT performance post-intervention (Zylowska et al., 2008) and compared to controls (e.g., Jha et al., 2007; Polak, 2009). Subsequently, the ANT was used to assess interference control in the present study. Finally, the present study sought to corroborate the relation between mindfulness and cognitive inhibition (as measured by the Hayling Test) found by Heeren et al. (2009) in their examination of mindfulness training effects.

Summary

The purpose of this study was to add to the current understanding of trait mindfulness and its underlying cognitive constructs by examining how bi-dimensional levels of self-reported mindfulness (awareness and acceptance) relate to performance on tasks of WMC and response inhibition. To this end, we extended existing findings by administering a bi-directional measure of mindfulness (the PHLMS), along with measures of multiple aspects of WMC and assessed multiple types of response inhibition (behavioral, interference control, and cognitive). The primary question was whether components of mindfulness (awareness and acceptance) and response inhibition (behavioral, interference control, and cognitive) are related to WMC. The secondary question was whether participants with higher self-reported components of mindfulness (awareness and acceptance) would demonstrate a greater ability to inhibit prepotent responses (all three types).

Method

Participants

Sixty-seven undergraduate students recruited from two medium-sized private universities in the Midwest received extra credit for study participation. All participants were adults ages 18 to 25 (M = 19.8, SD = 1.35), with normal or corrected-to-normal vision and hearing, who were able to read and understand English. Exclusion criteria included current pharmacotherapy, active substance use, and known neurological impairments. Participants were predominantly White (75%) females (75%), with 9% Black, 6% Hispanic, 5% Asian, and 6% Bi-racial individuals. All participants completed informed consent forms prior to study initiation.

Measures

Demographic Questionnaire

The participants read, and responded in writing to, a demographics questionnaire about their age, gender, race/ ethnicity, and frequency and duration of any meditative practices.

Mindfulness

The PHLMS (Cardaciotto et al., 2008) assessed components of mindfulness. The participants read, and responded in writing to, a 20-item, self-report measure which includes two distinct subscale scores: awareness and acceptance. The measure contains awareness questions such as “I am aware of what thoughts are passing through my mind” and acceptance questions such as “There are aspects of myself I don’t want to think about” responded to on a 5-point Likert-scale (*never* to *very often*), with higher scores reflecting greater awareness or acceptance. Internal consistency has been found to be very good for the acceptance subscale (α = .82) and adequate for the awareness subscale (α = .75) of the PHLMS (Cardaciotto et al., 2008).

(Executive) Response Inhibition

Behavioral Inhibition. A go/no-go task (Bezdjian et al., 2009) was used to assess behavioral inhibition.

Participants are asked to respond to the letter "P" (go trials) and withhold responding to the letter "R" (no-go trials) in the first block of trials, which has an 80:20 ratio of target to non-target items (reversed ratio in the second block). Practice blocks containing ten trials are issued prior to each test block to ensure task understanding; test blocks contain 160 trials. Commission errors, or incorrect responses to non-target items, reflect disinhibition.

Wöstmann and colleagues (2013) reported that the go/no-go test demonstrated strong reliability, with high test-retest reliability for commission errors (r = .84) and mean reaction times (RT) overall (r = .78). They also found high internal consistency across time points for commission errors (α = .87 – .89) and mean RT (α = .92 – .96). In addition, the go/no-go test was found by Enge and colleagues (2014) to have medium to high correlations with another measure of behavioral inhibition, the Stop Signal Task, for error rates (r = .61) and RT (r = .47).

Interference Control. The Attention Network Test (ANT; Fan et al., 2002) assessed interference control. In this computerized task, participants are instructed to attend to a central arrow and determine whether it points left or right, while ignoring flanking arrows. A practice block with 24 trials is issued to ensure task understanding, followed by three test blocks with 96 trials. Flanking arrows sometimes point in the same direction as the central arrow (congruent) or in different directions (non-congruent); comparing congruent with incongruent trials provides a conflict monitoring score. Overall RT and error rates provide a general measure of attentional control.

Fan and colleagues (2002) found that the ANT had high test-retest reliability for overall RT (r = .87), and adequate stability for conflict monitoring (r = .77). Validity of the ANT is generally accepted, as it is based on well-established tests, adding a cued RT task to a flanker task (Posner, 1980, 2016). In addition, the ANT was found to correlate highly with corresponding subtests of the Test for Attentional Performance (r = .55 – .71) and to correlate highly with deficits reported by staff on the Attention Deficits Questionnaire (r = .62 – .70) for patients with traumatic brain injuries (Beck et al., 2008).

Cognitive Inhibition. The Hayling Task (HT; Burgess & Shallice, 1997) assessed cognitive inhibition. This orally administered test is made up of two parts, each comprising 15 sentence stems read to participants who must rapidly complete the sentences. In the first part, participants complete sentences with a meaningful word and in the second part, they must inhibit this prepotent response to complete sentences with an unrelated word. Two practice sentences are issued prior to each part to ensure task understanding. Response latency is measured in whole seconds by the examiner using a stopwatch, as the time from when the examiner finishes reading the sentence stem to when the participant initiates a response. Error rate is measured in the second part based on the scoring system by Burgess and Shallice (1997), awarding 0 points for unrelated words, 1 point for semantically-related words, and 3 points for words that meaningfully complete the sentence. Response latency and error rate were transformed and combined into an overall scaled score (SS).

The Hayling Test has been found to show adequate test-retest reliability for the overall score (r = .76) and the second part (r = .78) measuring inhibition (Burgess & Shallice, 1997). A moderate negative correlation was found between overall efficiency on the Hayling Test and self-reported dysexecutive impairments on the Dysexecutive Questionnaire for the overall score (r = -.48) and Inhibition factor (r = -.42) of this scale (Odhuba et al., 2005).

Working Memory Capacity Tasks

N-Back Task. An n-back task assessed the recognition component of WMC. In this computerized task, participants are presented with a string of letters and asked to respond each time the current letter matches the previous letter (1-back), or the letter before the previous letter (2-back). Participants completed two practice blocks with ten trials each responding first to 1-back, then 2-back, followed by two test blocks in the same order with 20 trials each. Accuracy during the 2-back trial was used as one of the two primary measures of WMC in this study.

A meta-analysis by Redick and Lindsey (2013) reported that, while some studies found variable reliability, others found the *n*-back to have adequate reliability ($r \geq .70$). An *n*-back task was also reported to correlate moderately (r = .33 – .45) with other measures of WMC, such as complex span tasks and Letter-Number Sequencing, and with measures of fluid intelligence (r = .37 – .40), such as Raven's Matrices and Matrix Reasoning (Shelton et al., 2009).

Automated Reading Span Task. The Automated Reading Span Task (ARST; Unsworth, et al., 2009) assessed the recall component of WMC. This is a complex span task where participants are asked to indicate whether basic sentences make sense. After each sentence, they are presented with a letter for later recall. For example, participants might see a sentence such as "There are 7 days in a week" or "I like to fly bicycles," followed by a screen where they will select true or false to indicate whether the sentence made sense, followed by a screen with a single letter. Approximately half of the sentences in each set make sense. At the end of each set, participants are asked to select the letters that they had seen in their proper order. Participants practice the letter memory portion of the task (four trials of two to three letters), the sentence reading portion (15 trials of one to three sentences), and both parts together (two trials with two sentences and letters), followed by a test block comprised of 25 trials varying from three to seven sentences and letters.

The partial score, which sums items recalled in their proper order (even if some items are incorrect), was used as the other main measure of WMC in this study. Redick and colleagues (2012) reported good internal consistency for the partial score (α = .86 – .88) and good test–retest reliability (*r* = .82). The automated reading span task was reported to correlate highly (*r* = .61 – .68) with other complex span tasks, such as operation and symmetry span (Redick et al., 2012), and with another measure of WMC, Letter-Number Sequencing (Shelton et al., 2009).

Procedure

After informed consent was obtained, the investigator conducted assessments with each participant individually in a private testing room in sessions taking approximately 75 minutes. Computer-based tests were administered on a laptop computer using Psychology Experiment Building Language (PEBL) software (Mueller & Piper, 2014) with pop-up notifications disabled.

Participants completed WMC and response inhibition tasks in a balanced Latin-square design to control for possible order-effects. Participants were offered the opportunity to take one brief (less than 5 minute) break at a time of their choosing between measures, as well as brief (1 minute) breaks between computer-based measures and between test trials within tasks. Participants then completed the PHLMS and the demographic questionnaire.

Results

Data Preparation and Analysis Planning

Data from computer-based measures were exported into SPSS.for analysis. Paper-and-pencil measures were scored by the investigator, with scoring accuracy for the Hayling Test verified by a second reviewer for approximately half of these measures; inter-rater agreement of 95% was obtained. Primary outcome measures were performance on tasks of WMC and response inhibition (all three types)

Preparatory data analysis was conducted to examine distributions for outliers and violations of statistical assumptions. Data from seven participants who had scores that were extreme outliers on one or more measures were removed from analyses. Pearson correlations were calculated for variables that did not violate assumptions of normalcy and linearity. Spearman's rho was calculated for correlations between rates on the Hayling Test that had skewed distributions. Correlations were computed to test for significant associations between components of mindfulness (PHLMS: awareness and acceptance) and performance on the cognitive tasks of WMC and response inhibition. Multiple regression analyses were performed to further examine statistically significant relations.

Descriptive Statistics

Variable	Accept	Aware	*n*-back	Read Span	GNG Err	GNG RT	ANT Err	ANT Con	ANT RT	HT SS	HT Err	HT RT	*M*	*SD*
Mindfulness														
(Accept)ance	1	0.16	0.07	-0.06	0.04	-0.19	-0.07	0	-0.1	0.01	0.03	0.05	38.57	4.5
(Aware)ness	--	1	.29*	.32**	-.25*	-0.03	-0.16	-0.21	-.25*	.34**	-.28*	-0.22	27.49	6.8
WMC														
N-Back	--	--	1	0.13	-0.13	-0.08	0.04	-0.08	-.35**	0.04	-0.12	-0.18	0.71	0.1
(Read)ing Spn	--	--	--	1	-.28*	0.02	-0.02	-.31*	-.29*	0.12	-0.23	-0.02	93.42	21
Behav Inhib														
GNG (Err)or	--	--	--	--	1	--	.30*	0.1	0.07	-0.13	.31*	0.01	16.6	9.6
GNG RT	--	--	--	--	--	1	-.30*	-0.01	.39**	0.02	-0.11	0.07	918	48
Interference														
ANT (Err)or	--	--	--	--	--	--	1	--	--	-0.11	0.08	0.05	6.02	5.8
ANT(Con)flict	--	--	--	--	--	--	--	1	--	0.11	-0.05	-0.14	99.94	38
ANT RT	--	--	--	--	--	--	--	--	1	-0.09	0.08	0.1	564.2	66
Cog Inhib														
HT SS	--	--	--	--	--	--	--	--	--	1	--	--	6.45	1
HT (Err)or	--	--	--	--	--	--	--	--	--	--	1	--	2.16	2.8
HT RT	--	--	--	--	--	--	--	--	--	--	--	1	18.84	10

***p < .05** **** p < .01**

Table 1: Intercorrelations, Means, and Standard Deviations for PHLMS Subscales, Measures of Inhibition (go/no-go task [GNG], Hayling Test [HT]), Attention Network Test [ANT]), and Measures of Working Memory Capacity (N-Back Task, Reading Span Task [ARST])

See Table 1 for means, standard deviations and correlations among study variables. Psychometric properties of the PHLMS self-report measure was examined. As in previous research (Cardaciotto et al., 2008), PHLMS awareness and acceptance subscales of mindfulness were not correlated. However, subscale means varied from the normative student sample, with current awareness means lower than the normative sample and current acceptance means higher. Internal consistency was good for the acceptance subscale (α = .83), but questionable for the awareness subscale (α = .60).

Correlations between performance measures within the same constructs (i.e., WMC and response inhibition) were also examined. Measures of WMC were not correlated, consistent with prior literature suggesting that *n*-back tasks access recognition memory while reading span tasks access recall. Correlations between measures of response inhibition were variable. Total errors on the go/no-go task were correlated with total errors on the ANT and Hayling Test; errors on the ANT and Hayling Test were not correlated. RTs for inhibition tasks requiring a motor response (go/no-go, ANT) were correlated; these RTs were not correlated with RTs on a cognitive inhibition task (Hayling Test) requiring an oral response.

Potential group differences were explored using independent samples *t*-tests and one-way ANOVAs. No significant differences were found based on age, test order, or university. Asian participants scored lower, $F(4, 62) = 3.10$, $p < .05$, on the Reading Span test (M = 60.67, SD = 22.68) than White participants (M = 97.3, SD = 21.08); however, this was influenced by the small number of Asian participants (n = 3). No other significant differences were found based on race/ethnicity.

Females had lower scores, $t(65) = -2.84$, $p < .01$, on the PHLMS awareness subscale (M = 26.18, SD = 6.55) than males (M = 31.35, SD = 6.30) and slower RTs, $t(62) = 2.25$, $p < .05$), on the ANT (M = 574.93, SD = 67.69) than males (M = 534.49, SD = 50.24).

Participants who reported a history of meditative practices (n = 20) scored higher, $t(65) = 2.05$, $p < .05$, on the awareness subscale (M = 30.05, SD = 6.19) than those without experience (M = 26.40, SD = 6.86). No significant difference was found between meditators and non-meditators on the acceptance subscale; however, the majority of meditators (78%) reported practicing for less than one year.

In addition, participants reporting a history of meditation had stronger scaled scores, $t(62) = 2.19$, $p < .05$, on the Hayling Test (M = 6.85, SD = 1.18) than those without experience (M = 6.27, SD = .87).

Hypothesis Testing

The first question was whether components of mindfulness (awareness and acceptance) and response inhibition (behavioral, interference control, and cognitive) are related to working memory capacity. The second question was whether participants with higher self-reported components of mindfulness (awareness and acceptance) would demonstrate a greater ability to inhibit prepotent responses (all three types). Contrary to prior studies finding levels of mindful acceptance related to interference control (e.g., Teper & Inzlicht, 2013) or working memory efficiency (e.g., Ruocco & Direkoglu, 2013), no significant correlations were found between the PHLMS acceptance subscale and performance on any of the cognitive tasks assessed in this study. (See the first row of Table 1.)

Remaining results will focus on relations with the awareness subscale of the PHLMS. Performance on WMC tasks (*n*-back and Reading Span) were positively correlated with self-reported awareness, with medium size correlations (see Table 1; Cohen, 1988). Performance on response inhibition tasks had varying correlations with self-reported awareness. Regarding behavioral inhibition (go/no-go), levels of awareness were negatively correlated with total errors, but were not correlated with RT. Levels of awareness were not correlated with errors or the conflict score on a measure of interference control (ANT), but were negatively correlated with RT. Levels of awareness were positively correlated with overall performance on a measure of cognitive inhibition (Hayling Test), and negatively correlated with error rates, while no correlation was found with RT. Participants with higher self-reported awareness made fewer errors on measures of behavioral and cognitive inhibition, had stronger overall performance on a measure of cognitive inhibition, and had faster response times on a measure of interference control, with medium size correlations (see Table 1; Cohen, 1988).

Associations between measures of WMC and response inhibition were also examined. Performance on the *n*-back was not correlated with a measure of behavioral inhibition (go/no-go), while the Reading Span test was negatively correlated with go/no-go error rates, but not RT. Neither WMC task was related to overall errors on a measure of interference control (ANT), while the Reading Span test was related to conflict-related ANT error rates; participants with stronger performance on the Reading Span test made fewer overall errors on the go/no-go test and fewer conflict-related errors on the ANT, with medium size correlations (see Table 1; Cohen, 1988). A negative correlation was found between accuracy on both WMC tasks and RT on the measure of interference control (ANT); participants with stronger performance on the *n*-back and Reading Span tests had faster RTs on the ANT. Surprisingly, no significant correlations were found between performance on either measure of WMC and a measure of cognitive inhibition (Hayling Test).

Variable	*B*	SE_B	β	*t*	*p*
PHLMS Awareness[a]					
N-back	20.2	9.67	0.23	2.08	0
Reading Span	0.1	0.04	0.31	2.67	0
PHLMS Awareness[b]					
GNG Errors	-0.1	0.08	-0.2	-1.2	0.2
ANT RT	-0.01	0.01	-0.1	-0.6	0.6
HT SS	1.02	1.03	0.16	0.99	0.3
HT Errors	-0.68	0.39	-0.3	-1.8	0.1

aBlock2 ∆R2 = .16, F(5,63) = 5.07, p = .001
.bBlock2 ∆R2 = .22, F(7,56) = 4.05, p = .001

Table 2: Two Sequential Multiple Regression Analyses of Awareness Regressed on Demographic Variables in Block1 and in Block2 a. Measures of WMC and b. Measures of Response Inhibition

Results of multiple regression analyses are presented in Table 2. Awareness was regressed on demographic variables (age, gender, and race) and measures of WMC (*n*-back and reading span) using a sequential multiple regression analysis. After controlling for demographic variables, measures of WMC explained a statistically significant increase in the variance of awareness. WMC overall accounted for 16% of the variance in awareness and each of the two WMC variables also had a statistically significant effect on awareness.

Awareness was also regressed on demographic variables and measures of response inhibition (go/no-go errors, ANT RTs, and Hayling Test overall scores and total errors) using sequential multiple regression analysis. After controlling for demographic variables, measures of response inhibition also explained a significant increase in the variance of awareness, accounting for 22% of the variance in awareness. Hayling Test total errors approached significance; however, none of the individual response inhibition variables were significant. This was likely influenced by insufficient power. Taken together, these findings suggest that both WMC and response inhibition may indeed be important for maintaining awareness.

Discussion

WMC is the executive control system of working memory that holds goal-relevant information in the foreground, and employs inhibition to resolve demands from competing stimuli. Mindfulness parallels WMC in maintaining focus on the present, while also resolving conflicts from competing stimuli. Mindfulness is thought to promote discontinuation of automatic responding, thereby enhancing attention and cognitive control. Thus, it could be anticipated that mindfulness and response inhibition would be related to WMC, and that participants with higher self-reported components of mindfulness, both awareness and acceptance, would show a greater ability to inhibit responses (behavioral inhibition, interference control, and cognitive inhibition).

As it turned out, our results regarding components of mindfulness were mixed: We found associations among awareness, WMC, and aspects of response inhibition, as well as between aspects of WMC and aspects of response inhibition, but we found no associations between acceptance and WMC or any type of response inhibition (behavioral inhibition, interference control, and cognitive inhibition).

Several possible explanations exist for our null findings regarding acceptance in contrast with our expectations and prior positive research findings. While we used an *n*-back task to measure WMC similar to Ruocco and Direkoglu (2013), the particular indicator they found to be related to acceptance (overall efficiency) was not available in the present study. A number of researchers who found relations between acceptance and interference control measured this construct with the Stroop test (e.g., Teper and Inzlicht, 2013 Anicha et al., 2012; Galla et al., 2012; Lee & Chao, 2012). Given that the Stroop test is a less precise measure than our measure (ANT), it is possible that other cognitive constructs in addition to interference control were being captured in previous findings.

On the other hand, the associations we found between awareness, WMC, and the three types of response inhibition were consistent with findings of some previous studies but not others. While Ruocco and Direkoglu (2013) failed to find a relation between awareness and WMC using an *n*-back task, the present study found that participants with higher self-reported awareness had stronger performance on both WMC tasks (*n*-back and reading span tasks).

Regarding awareness and behavioral inhibition, Ruocco and Direkoglu (2013) found a positive relation between performance on these constructs, but not error rates, using their measure of behavioral inhibition (CPT). However, awareness was inversely related to error rates using the measure of behavioral inhibition (go/no-go) of the present study. Our result was similar to findings by Mrazek et al. (2012), whose participants with higher self-reported awareness made fewer errors on a similar (go/no-go) measure of behavioral inhibition. The findings of inverse relations support the role of awareness in effectively inhibiting a behavioral response.

In the present study, which used the ANT as the measure of interference control, awareness was not related to error rates but was inversely related to RT. It is noteworthy that mean RTs included correct responses only, eliminating concern that this relation is reflective of a speed-accuracy trade off, rather than improved performance. Thus, the relation between awareness and RT may be reflective of more efficient responding in the presence of interfering information. Previous research investigating mindfulness and interference control used varied measures of mindfulness and typically measured interference control with the Stroop Test, making direct comparisons of findings difficult.

In looking at our last measure of response inhibition, which is cognitive inhibition measured by the Hayling Test, we found an inverse relation between awareness and error rates. This is an important finding, as this is the first study to link levels of trait mindfulness with cognitive inhibition. Our results are consistent with findings of Heeren and colleagues (2009), who demonstrated that mindfulness training resulted in reduced errors on the Hayling Test. Mindfulness is an internal process that involves monitoring the thoughts that arise in one's mind and redirecting those thoughts back to the present moment when they stray. This is akin to the process of cognitive inhibition, in that one must recognize and suppress extraneous thoughts to promote thoughts relevant to the goal. Therefore, it is not surprising that awareness and cognitive inhibition, or the suppression of arising internal thoughts, showed significant relations.

An unexpected finding of the present study was the mixed relations found between different measures of WMC and different types of response inhibition: Only performance on the reading span task (not the *n*-back task) was related to error rates on measures of behavioral inhibition (go/no-go task) and interference control (ANT); accuracy on both WMC tasks was inversely related to RT on the measure of interference control (ANT); neither measure of WMC was related to cognitive inhibition. It may be that WMC relates more to efficiency in resolving interferences from other stimuli that compete for one's attention (interference control) than to other types of inhibition. An update by Engle (2018) countering his original theory also postulates that WMC more heavily reflects the maintenance of necessary information, rather than inhibition of unnecessary information.

Strengths of this study include use of a mindfulness measure that captures the bi-dimensional model of mindfulness (awareness and acceptance), enabling examination of the associations of these distinct components with other cognitive constructs. Similarly, this study looked at subtypes of response inhibition to see if they related to components of mindfulness differently. Finally, multiple measures of WMC were used to capture both the recognition *(n*-back task) and recall (reading-span task) components. Future researchers are encouraged to continue examining these aspects separately, particularly separate domains of mindfulness, as they clearly interact differently with other constructs.

Possible limitations that should be considered are the sample demographics, which consisted of undergraduates who were predominantly white females with limited meditation experience. Schmertz and colleagues (2009) suggest that a certain level of mindfulness may be required before a relation with cognitive constructs becomes evident. Perhaps our null results regarding acceptance are because acceptance requires a higher level of attainment than does awareness to enter into cognitive relations. Samples including a larger amount of practice could address this issue. Also, the well-grounded decision not to include the Stroop test as a measure of interference control and the use of RT variability as an indicator in other measures made it difficult to compare results across studies. Future research should include samples with more varied demographic characteristics, and use multiple measures to permit replicability, cross-comparisons, and bolster robustness of constructs.

This study added to the understanding of the association between components of mindfulness (awareness and acceptance) and underlying cognitive constructs. In particular, mindful awareness was associated with both WMC and response inhibition. Awareness may be constitutive of the abilities necessary to both identify the need to pay attention in order to potentially alter or withhold a response and to sustain that attention over time. Thus, awareness allows individuals to continuously monitor incoming stimuli for the cues necessary to determine the desired response, which may need to be inhibitory. The ability to inhibit unwanted or unnecessary responses enables individuals to function appropriately every day, and requires WMC to maintain the necessary information to determine and carry out an appropriate response. As previously noted, WMC and response inhibition are vital for performance of basic daily tasks, while deficits are implicated in multiple psychiatric disorders (e.g., ADHD, BPD, OCD, anxiety, substance use disorders, etc.). As higher levels of mindful awareness were found to be associated with stronger WMC and response inhibition, these findings provide the foundation for further research into whether the practice of mindfulness strengthens these associated cognitive constructs (i.e., WMC and response inhibition), in turn enhancing overall functioning in both healthy and clinical populations. For example, a systematic review by Goldberg and colleagues (2018) across a range of conditions (e.g., psychiatric disorders, pain, addiction) found that mindfulness-based interventions were equivalent to evidence-based treatments (EBTs) for some conditions (e.g., anxiety, depression) and superior to EBTs for other conditions (e.g., smoking).

In summary, as previous research has shown, mindfulness, WMC, and response inhibition are all linked in different ways to healthy functioning and overall wellbeing. Our work demonstrating how these constructs interact not only increases scientific understanding, but provides a direction for interventions. As mindful acceptance was not related to WMC or response inhibition in this study, additional research should explore the underlying constructs related to or influenced by mindful acceptance. Mixed associations between WMC and response inhibition also require further study to clarify how these constructs interact, particularly considering the null relationship between WMC and cognitive inhibition by any measure in the present study. However, this study did provide strong support for a relation between awareness and WMC and also response inhibition (behavioral inhibition, interference control, and cognitive inhibition). WMC and the ability to inhibit responses may be necessary to maintain awareness, while strengthening awareness may be a means to bolster WMC or response inhibition. Future research should continue exploring these interactions, as well as investigating how targeted interventions may be used to promote healthy functioning in daily life

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