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Delineating the contributions of sustained attention and working memory to individual differences in mindfulness

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ABSTRACT

Mindfulness can be deconstructed into two constituent components: present-moment awareness and acceptance. Attention and working memory are theorized to contribute to individual differences in trait mindfulness, although the precise relationship among these constructs remains unclear. The purpose of the present study was to evaluate the association of neurocognitive indices of attention and working memory with a bidimensional trait measure of mindfulness. Fifty-five psychiatrically and neurologically healthy adults completed the Conners Continuous Performance Test, Penn Letter *N*-back Test, and Philadelphia Mindfulness Scale. Results indicated that present-moment awareness was associated with a response speed variability measure of sustained attention, whereas acceptance was more strongly linked to working memory efficiency, even after accounting for general intellectual ability. These findings suggest that sustained attention and working memory capacities may differentially subserve individual differences in present-moment awareness and acceptance, thereby illuminating our understanding of the cognitive mechanisms which may underlie trait mindfulness.

1. Introduction

Mindfulness represents a complex construct which is thought to be composed of two primary trait dimensions: present-moment awareness and acceptance (Cardaciotto, Herbert, Forman, Moitra, & Farrow, 2008). The role of cognition in supporting these two constituents of trait mindfulness has been elaborated upon in theoretical models of this construct. *Awareness* is theorized to be carried out through the self-regulation of attention – "observing and attending to the changing field of thoughts, feelings, and sensations from moment to moment" (Bishop et al., 2004, p. 232). The awareness of present-moment experiences is thus thought to require sustained attention so as to maintain focus toward ongoing events over extended periods of time. *Acceptance* reflects an orientation to experience characterized by a non-judgmental attitude toward internal and external events such that an individual is experientially open to the present moment (Bishop et al., 2004). This dimension of mindfulness is thought to be a relational process whereby individuals are open and receptive to experience, a process which when fostered can lead to a higher level of cognitive complexity. Indeed, continued practice with acceptance can lead to improved differentiation, for example, among thoughts, emotions and physical sensations (Brown & Ryan, 2003). Aside from theoretical models of mindfulness, it remains unclear how specific cognitive functions might serve to support individual differences in mindfulness-based awareness and acceptance.

A small number of studies have examined the contributions of sustained attentional abilities to trait aspects of mindfulness. Schmertz, Anderson, and Robins (2009) evaluated the relationship between several self-report measures of mindfulness and performance indices on a well-validated test of sustained visual attention, the Conners Continuous Performance Test-II (CPT-II; Conners, 2000). This task requires individuals to press a button to target stimuli (i.e., any letter except for *X*) and withhold their responses to a non-target stimulus (i.e., the letter *X*). The results of correlational analyses indicated that lower levels of trait awareness were associated with more frequent omission errors (i.e., failures to respond to target stimuli), suggesting that less awareness of present-moment experiences may predispose one to brief lapses in sustained visual attention. In contrast, variability of response times to target stimuli over the course of task performance was unrelated to trait mindfulness measures. Using a similar visual attention task, Josefsson and Broberg (2011) found that the total score on a multidimensional trait measure of mindfulness was associated with an aggregate index of errors on this task (including omissions, commissions and repeated responses to target stimuli). A study by Mrazek, Smallwood, and Schooler (in press) also showed that higher levels accuracy on a test of sustained visual attention could be linked to greater mindfulness-based awareness. Additionally, this

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investigation found that lower levels of awareness were associated with more erratic reaction times to target stimuli, which stands in contrast to the findings of the study by Schmertz et al. (2009) which found no such relationship. To further understand the relationship between sustained attention and trait mindfulness, Rosenberg, Noonan, DeGutis, and Esterman (2011) developed a novel continuous performance measure that was designed to induce greater response time variability to target stimuli by visually alternating background scenes while participants completed a primary visual attention task. Consistent with the findings of Mrazek et al. (in press), lower of mindfulness-based awareness was associated with greater reaction time variability, although this relationship was limited to conditions under which background visual distractions were introduced. With regard to error-related indices, there were too few errors on this task to meaningfully evaluate their associations with self-reported mindfulness.

Taken together, the results of a small number of studies indicate that higher levels of trait mindfulness may be associated with more accurate detection of visual stimuli on sustained attention tasks. This research, therefore, suggests that there may be a relationship between behavioral measures of attention and self-reports of mindfulness. Additionally, there are emerging data which indicate that a separate index of sustained attention, reaction time variability, may also be associated with trait measures of mindfulness, particularly with respect to the awareness component of this construct. These preliminary findings, however, are based on studies that are limited in a number of ways. First, the mindfulness measures employed in these studies typically did not differentiate between the primary dimensions of present-moment awareness and acceptance. The results reviewed above suggest that the relationship observed between sustained attention and mindfulness is likely most pertinent to the awareness component of this trait, although the research to date is ambiguous in this respect. Second, previous studies did not consistently discriminate between accuracy-based measures of sustained visual attention (i.e., omission errors) versus those based on reaction time variability to target stimuli, both of which have shown some association with mindfulness measures. Third, although theoretical formulations of present-moment awareness emphasize the self-regulation of attention as a critical component of mindfulness, research in this area has tended to disregard the potential contributions of working memory to trait mindfulness. *Working memory* represents a system for temporary storage and updating of information as it becomes available (Baddeley, 1992). Although there is little research to guide our hypotheses in this respect, one might suppose that greater working memory capacity may be associated with higher trait mindfulness, as working memory is presumably associated with "remembering" to be mindful.

The purpose of the present study, therefore, was to examine the relationship of trait mindfulness and its two constituent dimensions (i.e., awareness and acceptance) with indices of sustained attention (i.e., omission errors and reaction time variability) and working memory. Based on previous research (Rosenberg et al., 2011; Schmertz et al., 2009), we hypothesized that the awareness component of a bidimensional trait measure of mindfulness would be related to sustained attentional abilities, although it remains unclear the extent to which accuracy – versus reaction time variability – based indices might be implicated in this relationship. Furthermore, preliminary evidence from a mindfulness training program indicates that the awareness component of mindfulness may be associated with individual differences in working memory capacity (Chambers, Lo, & Allen, 2008). Therefore, we expected that working memory would be associated with trait mindfulness. An aspect of trait mindfulness which has not been studied from a cognitive perspective is that of acceptance; therefore, analyses related to this component of mindfulness are exploratory and may shed light on the cognitive abilities which support this trait dimension. Clarifying the contributions of sustained attention and working memory to trait mindfulness will increase and broaden our understanding of the cognitive mechanisms which may underlie individual differences in this construct, and inform research to isolate the effects of mindfulness-based interventions on cognitive functioning in both clinical and non-clinical populations.

2. Materials and methods

2.1. Participant characteristics

All individuals included in this study were between 18 and 55 years of age, English-speaking, and able and willing to provide written informed consent to participate. Exclusion criteria included a history of serious physical illness or neurologic disorder (e.g., moderate or severe brain injury, seizure disorder), major psychiatric illness (e.g., schizophrenia, bipolar disorder), any serious visual or hearing impairments, or significant manual limitations that would affect performance on the laboratory tasks.

Fifty-five adults met the inclusion and exclusion criteria for this study. Their mean age was 19.9 years (SD = 3.8) and 66% were female. At the time of assessments, participants had completed approximately 13.0 (SD = 1.4) years of education. Overall intellectual level was estimated within the average range (M = 106.0, SD = 7.3) based on the Wechsler Test of Adult Reading (Wechsler, 2001). According to Canadian census categories, the ethnic composition of the sample was as follows: White (11%), Black (9%), Latin American (4%), Chinese (24%), West Asian (4%), Filipino (4%), Korean (4%), Arab (2%), South Asian (29%), and Other (11%). Nearly all participants (96%) were right-handed.

2.2. Procedure

This study received approval from the Social Sciences, Humanities and Education Research Ethics Board at the University of Toronto. Participants were students enrolled in introductory psychology courses at the University of Toronto Scarborough. All individuals gave written informed consent to participate in this research. Participants were compensated up to a maximum of three full course credits (or one full credit per hour) for introductory psychology or $30 at a rate of $10 per hour of participation.

Prior to beginning any of the laboratory procedures, participants completed a urine drug screen to test for the presence of illicit substances (amphetamines, cocaine, methamphetamines, opiates, and marijuana/THC) as these drugs may impact performance on the cognitive tests. All participants were free of illicit substances at the time of assessments. Testing took place within a quiet laboratory and all assessments were administered under the supervision of a licensed clinical psychologist (ACR).

2.3. Measures

2.3.1. Philadelphia Mindfulness Scale (PHLMS; Cardaciotto et al., 2008)

The PHLMS is a bidimensional trait measure of mindfulness that was intentionally constructed to independently measure the two primary dimensions of mindfulness: present-moment awareness and acceptance. Participants are asked to rate 20 statements using a 5-point Likert-type scale (1 = *never*, 2 = *rarely*, 3 = *sometimes*, 4 = *often*, and 5 = *very often*) based on how frequently these experiences occurred over the previous week. Awareness items on the PHLMS capture the extent to which the respondent monitors ongoing internal and external experiences. For example, an item from this scale reads "I notice changes inside my body, like my heart beating faster or my muscles getting tense". Acceptance items

evaluate the extent to which the respondent experiences internal and external events with a non-judgemental attitude. A sample item from this scale reads "I tell myself that I shouldn't feel sad". The internal consistency of the awareness and acceptance scales of the PHLMS has been supported by research involving both clinical and non-clinical samples (Cardaciotto et al., 2008).

2.3.2. Conners' Continuous Performance Test-II (CPT-II; Conners, 2000)

The CPT-II is a widely used and extensively studied measure of sustained attention. This task presents letters of the alphabet one at a time in the centre of a computer monitor. Participants are instructed to press the spacebar for each letter that appears on the screen but to withhold their response to the letter *X*. The CPT-II contains six main blocks, each composed of three 20-trial sub-blocks (totaling 18 sub-blocks) that vary according to inter-stimulus intervals. Several measures of sustained attention are provided by the CPT-II; however, based on previous research using the CPT-II and mindfulness measures, two indices of sustained attention were examined in the current study: Omissions and Variability of Standard Error.

Omissions are determined by the number of targets (i.e., all letters except for *X*) for which the participant failed to respond. High omission error rates are indicative of sluggish response styles and difficulties orienting and responding to stimuli. Variability of Standard Error is a measure of response speed consistency. It differs from the conventional method of calculating the standard error of reaction times to target stimuli because it is considered a within-respondent index of variability (i.e., the amount of variability the participant demonstrates relative to his or her own overall standard error) (Conners, 2000). This Variability of Standard Error is derived from the standard deviation of the 18 standard error values calculated for each block. Poorer scores on this index reflect a diminished ability to sustain optimal performance level throughout the continuous performance task.

2.3.3. Penn Letter N-Back Test (LNB; Ragland et al., 2002)

The LNB is a measure of working memory which presents participants with letters on a computer screen, one at a time, and they are asked to press the spacebar according to rules in three different task conditions: 0-back, 1-back and 2-back. During the 0-back, the participant must press the spacebar when the letter *X* appears on the screen. During the 1-back, the participant must press the spacebar when the letter on the screen is the same as the previous letter. During the 2-back, the participant must press the spacebar whenever the letter on the screen is the same as the letter before the previous letter. The total number of *True Positive* responses (i.e., correct "hits") on 2-back trials was used as the primary index of working memory in this study. An overall LNB *Efficiency Score* can also be calculated based on combined accuracy and reaction time performances for both 1-back and 2-back trials according to the following formula: True Positive Responses for 1-Back and 2-Back Trials/log (Mean of Median RT for True Positive Responses for 1-Back and for 2-Back Trials).

2.3.4. Wechsler Test of Adult Reading (WTAR; Wechsler, 2001)

The WTAR is an oral vocabulary test composed of 50 irregular words. This test is based on a reading-recognition paradigm which eliminates the possibility that participants could have used standard pronunciation rules to sounds out the words. The WTAR has been co-normed with the Wechsler Adult Intelligence Scale-Third Edition (Wechsler, 1997) in individuals ages 16–89, making it possible to estimate each participant's Full-Scale IQ from their WTAR scores.

2.3.5. Structured Clinical Interview for DSM-IV Axis I Disorders – Patient edition (SCID; First, Spitzer, Gibbon, & Williams, 1996)

This semi-structured interview was used to evaluate Axis I clinical syndromes in order to exclude individuals with severe psychopathology (schizophrenia or any other psychotic disorder, bipolar disorder, or severe eating disorder), as these illnesses are known to significantly affect brain functioning. All clinical raters were trained to reliability on the SCID and they completed the assessments under the supervision of a licensed clinical psychologist (ACR).

3. Results

3.1. Descriptive statistics

The mean total score on the PHLMS was 66.28 (SD = 9.40) and ranged from 47 to 88 for this sample of young adults. With respect to the subscales of the PHLMS, the mean score for the Awareness subscale was 36.41 (SD = 5.93, range = 24–48) and Acceptance was 29.86 (SD = 6.89, range = 15–41). These mean scores were very similar to those reported for the normative sample of the PHLMS (Cardaciotto et al., 2008). Internal consistency of the subscales was also comparable with the normative sample: Cronbach's α = .77 for Awareness and .82 for Acceptance. Consistent with the manner in which the PHLMS was constructed, the Awareness and Acceptance subscales were not significantly correlated (r = .09, p = .54).

Performances on the cognitive measures were standardized based on normative data provided in Conners (2000) for the CPT-II and Ragland et al. (2002) for the LNB. All scores were converted to *T*-scores with a mean of 50 and standard deviation of 10. Higher *T*-scores reflected better performances on the respective cognitive measures. Mean *T*-scores for the CPT-II indices consistently fell within the average range: Omissions (M = 43.48, SD = 17.16) and Variability (M = 47.63, SD = 10.98). Similarly, mean *T*-scores for the LNB were in the average range: True Positives for 2-back trials (M = 50.23, SD = 7.91) and Efficiency Index (M = 50.29, SD = 8.76). There were no significant correlations between any of the sustained attention and working memory indices (all p's > .05). As expected, LNB Efficiency was significantly related to True Positives for 2-back trials (r = .66, p < .001). Additionally, WTAR Full-Scale IQ was significantly associated with LNB True Positives for 2-back trials (r = .36, p < .01).

3.2. Correlational and regression analyses

Correlations between the PHLMS and cognitive test scores are presented in Table 1. As expected, a significant inverse relationship was observed between sustained attention on the CPT-II as indexed by reaction time variability and the total score on the PHLMS. Examination of the individual subscales that make up the PHLMS indicated that reaction time variability was specifically associated with the Awareness subscale of this measure. Omission errors were not associated with Awareness scores; however, this index did share a significant inverse correlation with the Acceptance subscale, which was unexpected.

A significant positive association was found between working memory efficiency on the LNB and the total score of the PHLMS. Although both the Awareness and Acceptance subscales showed moderate inverse correlations with the LNB efficiency score (r's > −0.24), only the Acceptance subscale correlation was statistically significant. The False Discovery Rate approach (Benjamini & Hochberg, 1995) was used to control for Type I error associated with multiple comparisons. After employing this procedure, statistically significant correlations were maintained for the relation-

Table 1
Summary of correlations among the Philadelphia Mindfulness Scale, Continuous Performance Test-II and Letter *N*-back Test.

PHLMS Scale	CPT-II Omissions	CPT-II Variability	LNB TP2	LNB Efficiency
Awareness	.06	.37**	.21	.24
Acceptance	.27*	.07	.04	.31*
Total score	.24	.29*	.16	.37**

Note. PHLMS = Philadelphia Mindfulness Scale; CPT-II = Conners Continuous Performance Test-II; LNB = Letter *N*-back Test; TP2 = True Positives 2-Back Condition.
* $p < .05$.
** $p < .01$.

ships between Awareness and CPT-II Variability ($p = .03$), and PHLMS Total Score and LNB Efficiency ($p = .03$).

Given that both the Total Score and Acceptance scales of the PHLMS were associated with sustained attention and working memory indices, multiple linear regression analyses were carried out to determine which cognitive indices were most strongly associated with the mindfulness measures, while also accounting for individual differences in general intellectual ability (see Table 2). The results of these analyses confirmed a robust association between Awareness and Variability, and Acceptance and LNB Efficiency, suggesting that specific aspects of sustained attention and working memory may underlie the two primary dimensions of trait mindfulness.

4. Discussion

The nature of the relationship between trait mindfulness and cognitive ability is an important unresolved issue which has been addressed by only a small number of studies using a variety of sustained attention measures. In the current study, we evaluated the association of a bidimensional measure of trait mindfulness with well-validated tests of sustained attention and working memory to determine how the two primary constituents of mindfulness – present-moment awareness and acceptance – may be subserved by these critical cognitive functions. Based on previous research, we hypothesized that the awareness component of mindfulness would be specifically linked to sustained attentional abilities. This hypothesis was partially supported: awareness was associated with a reaction time variability index of sustained attention, whereas omission errors were unrelated to the mindfulness measures. These findings indicate that the ability to optimally sustain performance over the course of a prolonged visual attention task may be related to individual differences in awareness. This suggests that attentional consistency (an aspect of attentional self-regulation) rather than attentional failure (as reflected in error rates) may be relatively more important in supporting present-moment awareness of experiences. This interpretation is consistent with the theory that mindfulness requires a state of vigilance so as to sustain attention over prolonged periods of time (i.e., minutes or even hours) (Bishop et al., 2004), a construct which may be better reflected by measures of attentional consistency rather than failure.

Table 2
Multiple regression analyses examining the relationship of sustained attention and working memory with trait mindfulness.

Regression variables	*b*	SE_b	*B*	*t*	*p*
PHLMS Awareness[a]					
WTAR IQ	0.09	0.12	0.11	0.78	0.44
CPT-II Omissions	0.01	0.05	0.04	0.26	0.80
CPT-II Variability	0.19	0.08	0.35	2.57	0.01
LNB TP2	1.10	1.37	0.14	0.80	0.43
LNB Efficiency	0.78	1.21	0.11	0.65	0.52
PHLMS acceptance[b]					
WTAR IQ	0.06	0.13	0.06	0.46	0.65
CPT-II Omissions	0.10	0.05	0.26	1.94	0.06
CPT-II Variability	0.03	0.08	0.06	0.41	0.69
LNB TP2	2.25	1.50	0.27	1.50	0.14
LNB Efficiency	3.54	1.32	0.46	2.67	0.01
PHLMS total score[c]					
WTAR IQ	0.32	0.17	0.03	0.18	0.86
CPT-II Omissions	0.09	0.07	0.16	1.24	0.22
CPT-II Variability	0.16	0.11	0.19	1.40	0.17
LNB TP2	1.16	2.07	0.10	0.56	0.58
LNB Efficiency	4.32	1.83	0.40	2.36	0.02

Note. PHLMS = Philadelphia Mindfulness Scale; WTAR = Wechsler Test of Adult Reading; CPT-II = Conners Continuous Performance Test-II; LNB = Letter *N*-Back Test; TP2 = True Positives 2-Back Condition.
[a] $R^2 = .186$, $F(5,54) = 2.24$, $p = .065$.
[b] $R^2 = .200$, $F(5,54) = 2.45$, $p = .046$.
[c] $R^2 = .225$, $F(5,54) = 2.85$, $p = .02$.

Similar results have been observed in previous studies using other variants of the continuous performance measure employed in the current study, although the findings are not consistent across studies and may be moderated by the difficulty level of the particular task (Mrazek et al., in press; Rosenberg et al., 2011). Our findings are in contrast to other studies which found no association between mindfulness measures and reaction time variability but did observe a significant link with omission errors (Robertson, Manly, Andrade, Baddeley, & Yiend, 1997; Schmertz et al., 2009). These discrepant findings across studies could be due to the use of different trait mindfulness measures which may vary in the extent to which they differentiate among the various components of mindfulness (i.e., present-moment awareness versus acceptance). There are, of course, other factors which could contribute to these discrepancies, such as variations in task difficulty and design for the cognitive measures and sample-specific characteristics (e.g., psychopathology) which were more rigorously controlled in this study.

Contrary to expectations, omission errors and working memory efficiency were each associated with individual differences in acceptance. Multiple regression analyses incorporating both indices revealed that working memory efficiency emerged as the sole predictor of acceptance. The precise mechanism underlying this relationship is unclear given that working memory has not been described in theoretical models of mindfulness-based acceptance. One plausible speculation is that working memory efficiency may support a stance of openness to experiences, which has been described as an "active process of 'allowing' current thoughts, feelings, and sensations" (Bishop et al., 2004, p. 233). This active process of acceptance may rely upon working memory capacities to help maintain an accepting attitude toward one's experiences (as opposed to resorting to the perhaps more automatic strategy of experiential avoidance) and to actively utilize acceptance-based strategies from moment-to-moment. On the other hand, Fletcher and Hayes (2005) define acceptance as "a moment by moment process of actively embracing the private events evoked in the moment without unnecessary attempts to change their frequency or form" (p. 319). Given this conceptualization of acceptance, it is possible that by not attempting to modify internal events, individuals with higher levels of this trait may free up working memory to a greater extent. How working memory efficiency might serve to support individual differences in acceptance remains an important unanswered question that should be explored in future research.

Counter to preliminary findings from a mindfulness-based training program (Chambers et al., 2008), we did not observe a remarkable relationship between true positive responses on the 2-back condition of the LNB and trait mindfulness. It is possible that this performance index of the LNB may not be as sensitive as the Efficiency index to the subtle working memory processes

that may be relevant to trait mindfulness. LNB Efficiency was robustly associated with awareness and acceptance and represents a function of performance accuracy and reaction time for both the 1- and 2-back conditions of this task. These findings suggest that while accuracy of working memory performances may not bear direct relevance to trait mindfulness, it is possible that slowing of response times to maintain accuracy may be associated with lower levels of acceptance. More research is needed to determine how possible speed-accuracy trade-offs in working memory may be related to mindfulness-based awareness and acceptance.

Taken together, the results of the present study suggest that sustained attention and working memory may operate through relatively distinct mechanisms to support individual differences in mindfulness-based present-moment awareness and acceptance. There are, however, other aspects of cognition that are likely to contribute to individual differences in mindfulness that were not examined in the present study. For example, specific executive aspects of attention related to inhibition of elaborative processing have also been theorized to underlie mindfulness-based awareness (Bishop et al., 2004) and this assertion has received some empirical support (Heeren, Van Broeck, & Philippot, 2009). To facilitate comparison of findings across studies, future research should differentiate among the primary dimensions of trait mindfulness as the results of the current study indicate that different cognitive functions may support the primary (and theoretically orthogonal) dimensions of this trait. Additionally, it will be important for future research to utilize standardized cognitive measures (such as the CPT-II) so as to allow for comparisons across studies of tasks with equivalent levels of difficulty. Understanding the joint contributions of sustained attention and working memory to trait mindfulness may improve our understanding of the cognitive mechanisms which serve to support awareness and acceptance, and may direct future research to identify key aspects of cognition which may be enhanced by mindfulness-based training programs.

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