Published in final edited form as:

Mindfulness (N Y). 2017 June ; 8(3): 765–774. doi:10.1007/s12671-016-0655-0.

Self-Reported Mindful Attention and Awareness, Go/No-Go Response-Time Variability, and Attention-Deficit Hyperactivity Disorder

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Abstract

The abilities to stabilize the focus of attention, notice attention lapses, and return attention to an intended object following lapses are precursors for mindfulness. Individuals diagnosed with attention-deficit hyperactivity disorder (ADHD) are deficient in the attentional and self-control skills that characterize mindfulness. The present study assessed the relationship between mindfulness and ADHD in young adults using the Mindful Attention and Awareness Scale (MAAS), a computerized Go/No-Go task (the Test of Variables of Attention (TOVA)), the World Health Organization Adult Self-Report Scale (ASRS), a tool used as an adult ADHD screen, the Beck Anxiety Inventory (BAI), and the Beck Depression Inventory-II (BDI-II). We recruited 151 adult volunteers (ages 18 to 40); 100 with confirmed ADHD diagnoses and 51 control participants. Overall, participants with prior diagnoses of ADHD scored lower on the MAAS than controls and ASRS scores were strongly negatively correlated MAAS scores. Attention performance index, response time, and response-time variability subscales of the TOVA were positively correlated with MAAS scores and negatively correlated with ASRS scores. Intrasubject response-time variability on the TOVA, a parameter associated with attention lapses, was also strongly negatively correlated with MAAS scores. Overall, participants' self-reported mindfulness, as measured by the MAAS, was strongly related to self-reports on a clinical measure of attention disorders, anxiety, depression, and multiple indices of concentration and mind wandering on a standardized Go/No-Go task, the TOVA.

Keywords

Mindfulness; Go/no-go; Attention; ADHD; TOVA

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Ethical Approval All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards. This article does not contain any studies with animals performed by any of the authors.

Informed Consent Informed consent was obtained from all individual participants included in the study.

Conflict of Interest Julian Keith declares that he has no conflict of interest. Mallory Blackwell declares that she has no conflict of interest. Rano Mathew declares that he has no conflict of interest. Len Lecci declares that he has no conflict of interest.

Introduction

The concepts of mindfulness and attention are closely related. In Western scholarship, for example, mindfulness has been conceptualized by Marlatt and Kristeller (1999, p. 68) as “bringing one’s complete attention to the present experience on a moment-to-moment basis” and by Kabat-Zinn (1994, p. 4) as “paying attention in a particular way, on purpose, in the present moment, and nonjudgmentally.” The definitions cited above assert that the ability to stabilize attention is a key prerequisite of mindfulness, though mindfulness also encompasses a broader range of psychological processes, including executive cognitive and meta-cognitive processes as well as a non-judgmental attitude toward percepts and emotions. The central role of attention in mindfulness reflects a traditional Buddhist understanding as well. For example, Nyanaponika (1962, p. 25) said of mindfulness: “In its elementary manifestation, known under the term ‘attention’, it is one of the cardinal functions of consciousness without which there cannot be perception of any object at all.”

As a first-person experience, much of the data psychologists gather on mindfulness is based on questionnaires. Mindfulness questionnaires, as one would expect, include items about attentiveness to present moment experiences. Mindfulness researchers recognize that studies that relate responses on mindfulness questionnaires to overt behaviors linked to attention are needed to strengthen both the construct and external validities of questionnaires (Davidson 2010). To this end, studies on mindfulness that have also included computerized Go/No-Go attention tasks such as the Connors’ Continuous Performance Test (CPT) and CPT-II (Brown and Ryan 2003; Galla et al. 2012; Schmertz et al. 2009), the Sustained Attention to Response Task (SART; Mrazek et al. 2014), and the d2-Concentration and Endurance Test (Moore and Malinowski 2009) have reported correlations between objective measures of attention and self-report-based assessments of mindfulness. For Go/No-Go tasks, subjects are instructed to respond (with a button- or key-press) as quickly as possible when target stimuli are presented on a computer screen and to withhold responses when non-target stimuli are presented. Go/No-Go tasks can provide objective evidence of attention lapses in the form of target omission errors and response-time variability. For example, scores on two mindfulness scales, the Cognitive and Affective Mindfulness Scale-Revised (CAMS-R; Feldman et al. 2007) and the Mindful Awareness and Attention Scale (MAAS; Brown and Ryan 2003) were negatively correlated with target omissions on the CPT-II (Schmertz et al. 2009). Target omission errors were positively correlated with CAMS-R and MAAS scores (Brown and Ryan 2003), and higher MAAS scores were negatively related to the number of errors on the SART (Mrazek et al. 2014). Similarly, global scores on the Kentucky Inventory of Mindfulness Scale (KIMS) scores were positively correlated with sustained attention performance on the d2-Concentration and Endurance Test (Moore and Malinowski 2009), and Galla et al. (2012) found that higher scores on one subscale of the KIMS, KIMS-Observe, were associated with lower response-time variability on the CPT.

In terms of descriptors of individual differences in attentional control, attention-deficit hyperactivity disorder (ADHD) and mindfulness are at different ends of the attention control continuum (Kabat-Zinn 2016). Inattention and distractibility, impulsivity, as well as hyperactivity, are hallmark symptoms of ADHD. Although ADHD is most frequently diagnosed in children, it may affect up to 5% of adults (Willcutt 2012). Hyperactive/

impulsive symptoms often decrease with age in individuals with ADHD, but attention lapses remain problematic into adulthood (Feifel 2007; Hechtman 2011).

Whereas mindfulness is associated with psychological, physical, and social well-being, numerous difficulties experienced in everyday life are attributed to attention deficits in people with ADHD, including problems in academic, employment, and home settings (e.g., Doshi et al. 2012). Individuals with ADHD cause almost four times as many car accidents and receive three times as many speeding citations as their non-ADHD peers; car accidents also tend to be more serious, with greater likelihood of bodily injury (Bernfort et al. 2008). Those diagnosed with ADHD are at higher risk for learning, behavioral, and emotional problems as well. For example, adults with ADHD receive fewer years of formal schooling, achieve lower occupational status, and are more likely to have psychiatric problems such as anti-social personality disorder and substance abuse (Kessler et al. 2005a, b).

Predictably, mindfulness traits in adults with ADHD diagnoses differ from those without an ADHD diagnosis (Smalley et al. 2009). In a sample of 105 adults (half with ADHD), Smalley et al. (2009) found that individuals diagnosed with ADHD scored significantly lower on the *Acting in Awareness* subscale of the KIMS, the subscale comprised items most clearly linked to attention (e.g., “When I do things, my mind wanders off and I’m easily distracted.”). Other subscales, *Accepting without Judgment*, *Describing*, and *Observing*, were not affected by ADHD diagnosis.

As with mindfulness, ADHD symptom monitoring in adults relies heavily on self-reports gathered through questionnaires such as the World Health Organization Adult Self-Report Scale (ASRS), an 18-question instrument that asks adult patients to report across a variety of situations how often they have difficulty concentrating, controlling impulses, completing challenging tasks, and remaining still for long periods (Gualtieri and Johnson 2005). The agreement of scores on the ASRS and clinicians’ impressions confirms that ADHD patients are aware of their attention deficits, at least when reflecting on behavior in retrospect.

Procedures that use Go/No-Go tasks to study clinical attention disorders have confirmed that ADHD is associated with attention lapses measured in a laboratory setting. On Go/No-Go tasks that require prolonged sustained attention, response times vary from trial to trial and individual differences in response-time variability are referred to as intrasubject variability in response time (ISV-RT). In general, RT distributions for data acquired on Go/No-Go tasks are positively skewed, with a long tail of slow responses. ISV-RT data from ADHD patients include a greater number of randomly occurring abnormally slow responses. Researchers have conjectured that clusters of abnormally slow RTs are related to attention lapses in ADHD that manifest during Go/No-Go test sessions as slow, periodic fluctuations in concentration rather than as continuous poor attention (Feige et al. 2013).

Overall, RT data can be modeled as convolutions of two distributions collectively termed “ExGaussian” because one distribution is Gaussian and the other is exponential; ExGaussian RT distributions have been characterized as “an exponentially modified Gaussian distribution, or ExGaussian” (Heathcote 1996; Ratcliff 1979). The ExGaussian distribution parameters μ and σ are the mean and standard deviation, respectively, of the Gaussian

component, while τ is exponential decay parameter (Feige et al. 2013). In ADHD patients, both mean RT and RT standard deviation (RTSD) are greater than in non-ADHD controls and analyses of the ExGaussian distributions indicate that such differences reflect increased τ , with normal μ and σ , suggesting that increased ISV-RT seen in ADHD patients could reflect an increased density of slow responses (Feige et al. 2013; Leth-Steensen et al. 2000). Increased τ has been replicated consistently for children, adolescents, and adults with ADHD (Buzy et al. 2009; Feige et al. 2013; Hervey et al. 2006; Kollins et al. 2009; Vaurio et al. 2009).

Previous studies have reported that mindfulness is related to errors on Go/No-Go tasks with high self-reported mindfulness scores being related to more accurate responding (Brown and Ryan 2003; Feldman et al. 2007; Mrazek et al. 2014; Moore and Malinowski 2009; Schmertz et al. 2006). If scores on self-report-based measures of mindfulness accurately reflect the ability to control and stabilize attention, one would predict that ISV-RT and mindfulness would be negatively correlated. Galla et al. (2012) found that one subscale of the KIMS, KIMS-Observe, was significantly correlated with lower response-time variability on the CPT. The KIMS-Observe subscale is composed of items about paying careful attention to subtle perceptual experiences, a finding consistent with the hypothesis that participants' self-report regarding their attention to perceptual experiences corresponds to momentary attention lapses that can be detected in response-time patterns on a Go/No-Go task.

Prior research has demonstrated that trait mindfulness as measured by the MAAS is negatively correlated with depression and anxiety symptomatology (Deng et al. 2014; Way et al. 2010). The literature on relationships between ADHD, anxiety, and depression is equivocal, with some studies finding that adults with ADHD report significantly more anxiety symptoms than do students without ADHD (Knouse et al. 2013; Prevatt et al. 2015) and others finding no relationships between ADHD, anxiety, or depression in college student samples (Nelson and Gregg 2012). If the variables involved in mindfulness overlap with those that are deficient in people with ADHD, one would expect complementary relationships between trait mindfulness and ADHD and anxiety and depression.

Establishing the validity of questionnaires used to quantify individual differences in trait mindfulness is crucial for mindfulness research in general (Davidson 2010). Davidson (2010, p. 9) highlighted a key challenge regarding the utility of self-report mindfulness instruments, such as the MAAS, in simple terms, "... are questionnaire-based self-reports of mindfulness valid? The posing of this question immediately raises the further question of how one would go about validating such a self-report instrument." The MAAS, the mindfulness questionnaire most widely used in published articles to date, relies on first-person report of attention and awareness to quantify individual differences in mindful attention and awareness (Medvedev et al. 2015). Given the wide use of the MAAS in mindfulness research, additional data delineating its relationship with other laboratory and clinical measures of attention informs issues related to the construct and external validity of the MAAS. The aims of the present study, therefore, were to determine if self-reports about attention and awareness as assessed on the MAAS corresponded to self-reports of attention deficits as assessed on the ASRS and Go/No-Go performance in individuals with and

without prior diagnoses of ADHD, a condition characterized by attention traits that are, conceptually speaking, the opposite of mindfulness. Beyond advancing our understanding of the roles of various elements of attention and self-control in ADHD and mindfulness, understanding relationships between these constructs will inform attempts to employ mindfulness training as a complementary method for managing ADHD symptoms, depression, and anxiety (Cassone 2015; Haydicky et al. 2012).

Method

Participants

Participants were students at the University of North Carolina, Wilmington, a public university located in the southeastern USA ($N = 151$, 91 females and 60 males). Enrollment in the study occurred from May of 2013 through February 2016. Participation partially satisfied a research participation course requirement for students enrolled in an introductory psychology course and was a preliminary component of a study on electroencephalography (EEG) neurofeedback effects on attention-deficit hyperactivity disorder (ADHD) symptoms. One hundred participants reported a prior diagnosis of ADHD made by a physician or psychologist. The ADHD sample was large because the neurofeedback study, from which the ADHD sample was drawn, specifically focused on recruiting this population. All ADHD diagnoses were confirmed by a board-certified psychiatrist (RTM) and involved a clinical interview, presentation of evidence of a prior diagnosis (e.g., a prescription for ADHD medication), and the Adult Self-Report Scale (ASRS v1.1) (Kessler et al. 2005a). The ages of the ADHD group ranged from 18 to 37 years old ($M = 22.83$; $SD = 4.37$). The control group ranged in age from 18 to 34 years old ($M = 19.46$; $SD = 3.28$). Approximately 91.4% of the participants identified themselves as Caucasian, 3.9% as Black or African American, and 4.6% as more than one race.

Procedure

All procedures were approved by the University of North Carolina, Wilmington Institutional Review Board, and written informed consent was obtained from all study participants. Participants first completed a packet of questionnaires that included the ASRS v1.1, MAAS, BDI-II, and BAI. For TOVA testing, individuals were taken to a private, sound-attenuated testing room with white noise and seated in a comfortable chair facing a monitor. Automated visual and auditory instructions for the TOVA task were delivered. Participants practiced the TOVA before data acquisition commenced and could repeat the training until they indicated they were confident they understood the procedure (i.e., every participant engaged in at least 74 practice trials). All data collection occurred between 7:00 a.m. and noon. Individuals taking medications for ADHD were instructed not to take their ADHD medications on the morning prior to testing, and participants verbally confirmed their compliance with this instruction.

Measures

TOVA testing was conducted in a quiet, private room, with white noise quietly delivered through a speaker mounted in the ceiling. A laptop computer connected to a 23 in. color monitor administered the TOVA, and participants sat approximately 24 in. from the monitor.

The target stimulus was a small white square positioned in the top half of a larger white square. Version 7 of the TOVA was used in the present study. The TOVA assessment takes 21.6 min to complete during which time monochrome visual targets and non-targets appear for 100 ms with 2000 ms interstimulus intervals (648 stimulus presentations per session, 324 “Go” targets and 324 “No-Go” non-targets). The non-target stimulus was a small white square positioned in the bottom half of a larger white square. Participants used a hand-held single button response device, and were instructed to press the button each time the target appeared (“Go”) and not to press the button when the non-target image appeared (“No-Go”). Response times were measured with one millisecond accuracy. Session results automatically reported by the TOVA for each participant included response times, response-time variability (referred to elsewhere as ISV-RT), omission errors, commission errors, d' (a signal detection measure of sensitivity, $d' = Z_{\text{False Alarm Rate}} - Z_{\text{Hit Rate}}$), and an overall attention performance index (API) score. The API is a comparison of subjects' TOVA performances to identified ADHD sample's performance matched for age and gender. The score tells how similar the performance is to the ADHD profile in the normative sample. The formula used to calculate the API is as follows: API score = response-time Z score (half 1) + d' Z score (half 2) + variability Z score (total). With the exception of the API, TOVA subscale scores are reported as standard scores ($M = 100$; $SD = 15$) that reference a database of age- and sex-normative scores.

The MAAS is composed of items emphasizing open or receptive awareness of, and attention to, what is taking place in the present (Brown and Ryan 2003). The scale shows robust psychometric properties and has been validated with college participants (Carlson and Brown 2005). The 15 items used in the MAAS are related to self-regulation and well-being and use a 6-point Likert scale.

The Adult Self-Report Scale (ASRS) is an 18-question instrument that asks adults to report across a variety of situations how often they have difficulty concentrating, controlling impulses, completing challenging tasks, and remaining still for long periods. ASRS items were based on the DSM-IV Criterion A symptoms of ADHD and when used as an ADHD screening instrument the ASRS agrees with clinician classifications over 98% of the time (Kessler et al. 2005a, b). Each of the 18 items on the ASRS questionnaire is scored on a 5-point Likert scale. The maximum possible score on the ASRS is 76. In a clinical context, individuals who score below 16 are considered unlikely to have ADHD. Scores between 17 and 23 indicate that ADHD is likely and scores of 24 or greater indicate that ADHD is highly likely (Kessler et al. 2005a, b).

The Beck Depression Inventory II (BDI-II) is a standardized 21-item measure of depression (Beck et al. 1996). Each item on the survey contains four statements regarding a particular symptom of depression with severity ranking from 0 to 4. The item scores are summed to compute the total depression score.

The Beck Anxiety Inventory (BAI) is a measure commonly used to assess anxiety disorders. It contains 21 items describing common symptoms of anxiety such as dizziness and fear to which patients respond with either not at all (0), mildly (1), moderately (2), or severely (3). The scores on each question are summed to quantify anxiety (Beck and Steer 1993).

Data Analyses

Statistical analyses were conducted using SPSS v 21 (Released 2012. IBM SPSS Statistics for Windows, Version 21.0. Armonk, NY: IBM Corp.) and GraphPad Prism version 7.00 for Macintosh (GraphPad Software, La Jolla California USA, www.graphpad.com). Simple linear regression models were used to analyze linear relationships between ASRS and MAAS scores and to test whether slopes differed significantly from zero. Correlations between key variables were determined using bivariate Pearson r and group differences between ADHD and non-ADHD participants were analyzed using unpaired t tests. To address the multiplicity problem that occurs when multiple hypotheses are evaluated simultaneously, the linear stepup method (p-stacking) was applied (for a discussion of how this method controls false-discovery rate, see Benjamini et al. 2006). TOVA subscale scores were expressed as standard scores ($M = 100$; $SD = 15$) relative to the TOVA age and gender normative database, with the exception of API, as explained in the section above on study measures.

Results

Five individuals in the ADHD group and one in the control group had TOVA scores outside of normal limits for a valid assessment, indicating unusually low effort. Closer inspection of their data indicated that those subjects stopped responding to stimuli during the last half of the TOVA procedure. Data from these six subjects were omitted from all analyses presented below. Additionally, one participant did not complete items on the second page of the MAAS. The samples analyzed included 95 and 49 participants in the ADHD and control groups, respectively.

Figure 1 shows a scatterplot of participants' scores on the ASRS and MAAS. It is clear from the figure that there is a strong negative linear relationship between ASRS and the MAAS. A linear regression supported this observation ($r = -0.74$, $p < 0.0001$), and the slope differed significantly from 0 ($F(1,142) = 170.4$, $p < 0.0001$). The correlation (Pearson r) between the ASRS and MAAS was present when controls ($r = -0.65$, $p < 0.0001$) and ADHD ($r = -0.74$, $p < 0.0001$) were analyzed as independent groups as well.

Correlations (bivariate Pearson r) between the MAAS and ASRS and other variables examined in this study are presented in Table 1. Significant correlations were found between the MAAS and most of the study variables. Negative correlations were noted between the MAAS and both the endorsement of depression (BDI-II, $r = -0.39$, $p < 0.001$) and anxiety (BAI, $r = -0.37$, $p < 0.001$) symptoms.

The TOVA subscale scores API, ISV-RT, RT, Com Err, Om Err, and d' are computed such that higher values indicate better performance. The ExGaussian parameters μ , σ , and τ , however, are computed such that higher scores indicate poorer performance. To avoid confusion, for all correlations reported below, the scale used for the ExGaussian parameters was inverted so that better performance was indicated by larger scores. All analyses associated with Figs. 2, 3, and 4, as well as Table 1, included both the ADHD and non-ADHD participants. MAAS scores were positively correlated (Pearson r) with better overall attention performance scores on the TOVA API ($r = 0.29$, $p < 0.001$), ISV-RT ($r = 0.27$, $p =$

0.001), RT ($r = 0.21, p = 0.01$), the signal detection measure of Go/No-Go discrimination sensitivity, d' ($r = 0.21, p = 0.012$), and the ExGaussian parameters σ ($r = -0.21, p = 0.011$) and τ ($r = -0.27, p = 0.001$). Commission errors, omission errors, and the ExGaussian parameter μ were not significantly correlated significantly with MAAS scores ($p > 0.05$).

ASRS scores were positively correlated (Pearson r) with depression (BDI-II, $r = 0.23, p = 0.005$) and anxiety (BAI, $r = 0.23, p = 0.005$). ASRS scores were negatively correlated with overall attention performance (API, $r = -0.27, p = 0.001$), ISV-RT ($r = -0.25, p = 0.003$), RT ($r = -0.23, p = 0.007$), omission errors ($r = -0.17, p = 0.04$), d' ($r = -0.19, p = 0.001$), as well as with the TOVA ExGaussian parameters σ ($r = -0.27, p = 0.001$) and τ ($r = -0.23, p = 0.006$). Neither ExGaussian μ nor commission errors correlated significantly with MAAS scores ($p > 0.05$).

MAAS scores were transformed to standard scores based on 14 independent samples of college students ($N = 2277$; $M = 3.83$; $SD = .70$) and participants were classified into high mindfulness ($z > 0, n = 49$) or low mindfulness ($z < 0, n = 94$) groups. Figure 2 shows BDI-II (top) and BAI (bottom) as a function of group (bars are 95% confidence intervals). Unpaired t tests were used to evaluate group differences. High mindfulness participants endorsed significantly fewer depression ($t(140.89) = 5.33, p < 0.001, \eta^2 = 0.13$) and anxiety symptoms ($t(133.42) = 5.71, p < 0.001, \eta^2 = 0.13$).

Figure 3 shows API scores as a function of mindfulness group, and it is clear that high mindfulness participants had higher overall attention performance scores relative to low mindfulness participants ($t(141) = 3.03, p = 0.003, \eta^2 = 0.04$).

Figure 4 shows data from key TOVA measures as a function of mindfulness classification. Unpaired t tests revealed significant differences favoring the high mindfulness group were found for response times ($t(141) = 2.02, p = 0.046, \eta^2 = 0.028$), ISV-RT ($t(141) = 2.92, p = 0.004, \eta^2 = 0.057$), ExGaussian τ ($t(141) = 2.90, p = 0.004, \eta^2 = 0.056$), and omission errors ($t(141) = 2.09, p = 0.038, \eta^2 = 0.03$). Group differences for d' and commission errors were not significant ($p > 0.05$).

Participants with a prior diagnosis of ADHD were compared with controls (Table 2) on the key study variables and significant differences were revealed by unpaired t tests on the ASRS ($t(142) = 7.18, p < 0.001, \eta^2 = 0.340$), the MAAS ($t(142) = 4.64, p < 0.001, \eta^2 = 0.132$), the API ($t(142) = 3.21, p = 0.002, \eta^2 = 0.067$), ExGaussian τ ($t(142) = 2.47, p < 0.016, \eta^2 = 0.041$), ISV-RT ($t(142) = 2.63, p < 0.009, \eta^2 = 0.046$), and response time ($t(142) = 2.53, p < 0.012, \eta^2 = 0.043$). Scores on the BDI-II, BAI, commission errors, omission errors, and d' did not differ significantly between the ADHD and control groups ($p > 0.05$). All effects reported as statistically significant were confirmed using the linear step-up method to control for the multiplicity problem as described by Benjamini et al. (2006).

Discussion

Scores on the MAAS and the ASRS, a well-validated instrument used to screen for attention disorders, were strongly negatively correlated ($r = -0.74$), indicating that self-reported mindfulness and ADHD symptomatology were inversely related. The strong negative

correlation between the MAAS and ASRS provides clear evidence that although they were designed and used for different purposes, the instruments overlap considerably in terms of their agreement on self-reported attentiveness and self-control in situations of everyday life. Participants diagnosed with ADHD scored significantly higher on the ASRS and significantly lower on the MAAS than controls. Our results, therefore, are consistent with those of Smalley et al. (2009) who found that individuals with ADHD diagnoses scored lower on the *Acting in Awareness* subscale of the KIMS. Smalley et al. (2009) used the SADS-LAR to classify participants as positive or negative for ADHD. Like Smalley et al. (2009), our participants with prior diagnoses of ADHD scored significantly lower than those without a prior diagnosis on mindfulness, as measured in the present study by the MAAS. Additionally, quantifying ADHD symptomatology using the ASRS permitted us to quantify the strength of the relationships between ADHD symptoms and mindfulness. The results of the present study, therefore, extend previous findings on the relationship between ADHD and mindfulness by demonstrating that the relationship between these variables is very strong and robustly present even when substantially different instruments are used to measure both ADHD and mindfulness.

Joining with prior research showing that trait mindfulness is negatively correlated with depression and anxiety, we found significant negative correlations between MAAS scores and scores on the BDI-II and BAI (Deng et al. 2014; Way et al. 2010). Moreover, when participants were classified as low or high in mindfulness relative to published norms for the MAAS, participants in our sample with MAAS scores above the normative mean reported significantly fewer depression and anxiety symptoms than those with MAAS scores below the normative mean. Deng et al. (2014) also reported a negative correlation between mindfulness and depression as measured by the MAAS and BDI in a sample of Chinese university students, though their correlation was much stronger than ours ($r = -.808$ versus $-.389$, respectively). Complementing our findings with the MAAS, the positive correlations between the ASRS and measures of anxiety and depression are consistent with those reported by Prevatt et al.'s (2015) based on a much larger sample of college students (473 with ADHD and 200 controls).

A key aim of the present study was to determine if self-reports about attention and awareness as assessed on the MAAS corresponded to objective attention performance as measured on a computerized Go/No-Go task, the TOVA. The answer to this question is clearly affirmative. Our results show that individual differences on trait mindfulness were related to several TOVA parameters. The TOVA attention performance index correlated strongly with the MAAS. Although the MAAS was not significantly correlated with TOVA omission or commission errors, it significantly correlated with several response-time parameters. Overall, lower MAAS scores were associated with slower mean response times, an effect that was likely due to increased trial-to-trial response-time variability associated with higher MAAS scores. Support for this interpretation comes from three parameters of the response-time distribution. First, the TOVA parameter that represents the Gaussian distribution response-time mean, μ , was not significantly correlated with MAAS scores. TOVA measures of variability, ISV-RT (overall variability), and ExGaussian σ (variability within the Gaussian component of the response-time distribution), however, were significantly correlated with MAAS scores such that lower scores were associated with more

trial-to-trial variability. Finally, the TOVA parameter that represents the decay rate of the tail of the exponential response-time distribution, τ , also was significantly correlated with MAAS scores such that a slower decay rate was associated with lower MAAS scores. Increased response-time variability and larger τ values are consistent with periodic fluctuations in concentration rather than continuous poor attention (Feige et al. 2013). Therefore, taken together, the results of the present study indicate that self-reported mindful attention and awareness assessed by the MAAS is related to the ability to maintain stable concentration on events occurring in the present moment. Such findings help establish the validity of questionnaires used to quantify individual differences in trait mindfulness and are crucial for mindfulness research in general (Davidson 2010).

When considering normative interpretations of the MAAS scores, participants who ranked in the upper half of the normative mindfulness distribution consistently outperformed those who scored in the lower half on the TOVA API, RT mean, ISV-RT, ExGaussian τ , and omission errors, reinforcing the conclusion that attention variables underlying the construct of mindful attention and awareness as represented on the MAAS is robustly related to subtle fluctuations in attention performance measured by the TOVA.

The TOVA was created to aid clinicians diagnosing ADHD (Lark et al. 2007). As expected, participants with prior diagnoses of ADHD scored significantly higher than controls on the API, ExGaussian τ , ISV-RT, and RT mean, as well as the self-report measures of attention, the ASRS and MAAS, closely resembling the relationship between the TOVA and mindfulness and adding support to the possibility that ADHD and mindfulness are on the same continuum. This raises the possibility that MAAS normative scores could be used to assist in making diagnostic decisions regarding ADHD. Moreover, to the degree that mindfulness can be improved through interventions, ADHD symptoms may be ameliorated. Although research on mindfulness-based interventions for ADHD is in the early stages, there is some evidence that meditation techniques that cultivate mindfulness reduce ADHD symptoms in children and adults (Bueno et al. 2015; Edel et al. 2014; Mitchell et al. 2013; Zylowska et al. 2008).

Concentration meditation, *Samadhi* (in the Theravada Buddhist tradition) and *samatha* (Tibetan Buddhist tradition), involves single-pointed concentration on a chosen meditative object such as the breath and is considered necessary prior to introducing other meditation (Lutz et al. 2006; Rapgay and Bystrisky 2009). During focused attention meditation, external distractions, and mind wandering compete with the intended object of focus for attention. The meditator is instructed to gently return attention to the meditative object of focus and begin again after each lapse. Not surprisingly, experienced meditators outperform non-meditators on attention tasks that involve disregarding information irrelevant to accurate responding, such as the Attention Network Test, a computerized response-time-based measure that requires a form of executive cognitive control termed “conflict monitoring” (Jha et al. 2007). Evidence that attention can improve with meditation training comes from studies showing that conflict monitoring, as measured by the Stroop task, improves with short-term (ranging from 5 days to 8 weeks) meditation interventions (Chan and Woollacott 2007; Moore and Malinowski 2009; Tang and Posner 2009). Intensive meditation retreat experiences (3 months, 10–12 h/day) resulted in significant reductions in ISV-RT, but not

errors, on an auditory attention task similar to the TOVA (Lutz et al. 2009). The degree to which mindfulness interventions can improve attention and self-control for people on the ADHD end of the attention continuum and how such training affects their quality of life remains to be seen. In establishing that people with ADHD are deficient in the sort of attention cultivated by mindfulness practice, the present results reinforce the conceptual feasibility of employing mindfulness interventions for ADHD.

Limitations

A limitation of the present study is that in focusing primarily on attention, we did not address the full range of symptoms associated with ADHD, including hyperactivity, impulsivity, and disorganization. Future studies that examine relationships between ADHD and mindfulness more comprehensively, including aspects of ADHD other than attention deficits and aspects of mindfulness other than awareness and mindful attention, may reveal broader connections between these constructs than the present study can address.

Another limitation is that our sample consisted of university students in good standing at an institution with high admission and academic standards. Therefore, it should be acknowledged that the participants with ADHD were a subgroup and their high academic achievement in the presence of significant ADHD symptoms may be indicative of either unusually high intellectual aptitude or the development of compensatory behavioral strategies that enable successful academic achievement. On the whole, our ADHD participants demonstrated (meta-cognitive) self-awareness about their deficits in mindful awareness and attention to the present moment, as reflected by the relatively low MAAS scores consistent with evidence of subtle attention lapses during TOVA testing sessions.

The present study results show that individual differences on self-reported ratings of mindful attention as assessed by the MAAS are consistent with individual differences in attention performance on the TOVA, especially parameters sensitive to attention lapses, and are inversely related to ADHD self-reported symptoms and the diagnosis of ADHD by mental health professionals.

Acknowledgments

Funding This study was funded by NCCIH (R15AT007226).

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Fig. 1. Mindfulness (*MAAS*) as a function of ASRS scores. *Dashed lines* are 95% confidence intervals. Higher MAAS scores indicate greater mindful attention and awareness, and higher ASRS scores indicate greater endorsement of attention deficits

Fig. 2. Depression (*BDI-II*, top) and anxiety (*BAI*, bottom) symptoms as a function of high ($z > 0$) and low ($z < 0$) normative mindfulness (*MAAS*) scores. Error bars show 95% CI

Fig. 3. TOVA Attention Performance Index (*API*) scores as a function of high ($z > 0$) and low ($z < 0$) normative mindfulness (*MAAS*) scores. *Error bars* show 95% CI

Fig. 4.

TOVA subscale scores as a function of high ($z > 0$) and low ($z < 0$) normative mindfulness (MAAS) scores. Error bars show 95% CI. Note: High scores indicate better performance on each variable except ExGaussian Tau (τ) for which higher scores indicate a higher occurrence of long latency response

Table 1

Bivariate correlations, $r(p)$, between the MAAS, ASRS, and key study variables ($N = 144$)

Variable	MAAS	ASRS
MAAS		-0.74^a (0.001)
BDI-II	-0.39^a (<0.001)	0.23^a (0.005)
BAI	-0.36^a (<0.001)	0.23^a (0.005)
API	0.29^a (<0.001)	-0.27^a (0.001)
ExG μ	0.13 (0.120)	-0.14 (0.097)
ExG σ	0.21^a (0.011)	-0.27^a (0.001)
ExG τ	0.27^a (0.001)	-0.23^a (0.006)
ISV-RT	0.27^a (0.001)	-0.25^a (0.003)
RT mean	0.21^a (0.011)	-0.23^a (0.007)
Com Err	0.03 (0.741)	0.01 (0.950)
Om Err	0.16 (0.053)	-0.17^a (0.044)
d'	0.20^a (0.019)	-0.19^a (0.001)

ASRS Adult Self-Report Scale, *MAAS* Mindful Awareness and Attention Scale, *BDI-II* Beck Depression Inventory, *BAI* Beck Anxiety Inventory, *API* Attention Performance Index, *ExG* ExGaussian, *ISV-RT* intrasubject variability in response time, *RT Mean* response-time mean, *Com Err* commission errors, *Om Err* omission errors, d' discrimination sensitivity based on signal detection analysis. Note: TOVA variables API, ISV-RT, RT Mean, Com Err, Om Err, and d' are computed automatically by TOVA 7 and expressed as standard scores (using an age and gender normative database) such that higher scores indicate better performance. The ExGaussian parameters were computed by TOVA 7 such that lower scores indicated better performance. To avoid confusion and for consistency with the other TOVA parameters, the signs of the correlations for all ExGaussian parameters were reversed in the table

^aDetermined to be a true discovery based on the two-stage linear step-up procedure of Benjamini et al. 2006 ($Q, 5\%$) to control for multiple independent hypothesis tests

Table 2

Group (ADHD versus control) differences on key variables

Variable	Control	ADHD	$t(df)$	p value	95% CI	η^2
ASRS	32.36	46.36	7.18 (142)	<0.001 ^a	-17.86 to 10.13	0.340
MAAS	3.89	3.15	4.53 (142)	<0.001 ^a	0.37 to 1.08	0.140
BDI-II	10.60	10.59	0.01 (142)	0.990	-2.90 to 2.99	0.001
BAI	9.18	9.42	0.15 (142)	0.870	-3.33 to 2.85	<0.001
API	1.63	-0.41	3.21 (142)	0.002 ^a	0.78 to 3.30	0.067
ExG τ	88.03	106.2	2.47 (142)	0.016 ^a	-32.67 to -3.59	0.041
ISV-RT	91.58	79.59	2.62 (142)	0.009 ^a	2.94 to 21.04	0.046
RT mean	113.60	105.60	2.53 (142)	0.012 ^a	1.74 to 14.26	0.043
Com Err	98.66	95.89	0.91 (142)	0.365	-3.26 to 8.79	0.006
Om Err	87.01	75.40	1.29 (142)	0.206	-6.48 to 29.70	0.011
d'	93.70	87.53	1.85 (142)	0.066	-0.43 to 12.77	0.023

MAAS Mindful Awareness and Attention Scale, BDI-II Beck Depression Inventory-II, BAI/Beck Anxiety Inventory-II, API Attention Performance Index, ExG ExGaussian, ISV-RT response-time variability, RT Mean response-time mean, Com Err commission errors, Om Err omission errors, d' discrimination sensitivity based on signal detection analysis

^aDetermined to be a true discovery based on the two-stage linear step-up procedure of Benjamini et al. 2006 (Q, 5%) to control for multiple independent hypothesis tests