Clinical Psychology and Psychotherapy
Clin. Psychol. Psychother. **14**, 449–463 (2007)
Published online in Wiley InterScience (www.interscience.wiley.com). **DOI**: 10.1002/cpp.544

Mindfulness-Based Stress Reduction and Attentional Control

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This study was designed to test the hypothesis that mindfulness involves sustained attention, attention switching, inhibition of elaborative processing and non-directed attention. Healthy adults were tested before and after random assignment to an 8-week Mindfulness-Based Stress Reduction (MBSR) course (n = 39) or a wait-list control (n = 33). Testing included measures of sustained attention, attention switching, Stroop interference (as a measure of inhibition of elaborative processing), detection of objects in consistent or inconsistent scenes (as a measure of non-directed attention), as well as self-report measures of emotional well-being and mindfulness. Participation in the MBSR course was associated with significantly greater improvements in emotional well-being and mindfulness, but no improvements in attentional control relative to the control group. However, improvements in mindfulness after MBSR were correlated with improvements in object detection. We discuss the implications of these results as they relate to the role of attention in mindfulness. **Copyright © 2007 John Wiley & Sons, Ltd.**

INTRODUCTION

Mindfulness is a form of meditation with roots in Buddhist spiritual practices that has been employed in various clinical psychological practices, including mindfulness-based stress reduction (MBSR; Kabat-Zinn, 1990) and dialectical behaviour therapy (Linehan, 1993). Mindfulness meditation is distinguished from concentration-based forms of meditation that train participants to focus attention on a single stimulus (e.g., an object or a word). By contrast, mindfulness meditation involves a broader observation of one's present moment experience, that is, physical sensations, thoughts and feelings (Baer, 2003). Kabat-Zinn (2003) defines mindfulness as 'the awareness that emerges through paying attention on purpose, in the present moment, and non-judgmentally to the unfolding experience moment by moment' (p. 145).

A growing body of research over the past 30 years has demonstrated that mindfulness-based interventions are clinically effective for a wide range of problematic conditions (for a review, see Baer, 2003; Grossman, Niemann, Schmidt, & Walach, 2004), such as treating the affective symptoms associated with various medical illnesses (e.g., Carlson, Speca, Patel, & Goodey, 2003; Speca, Carlson, Goodey, & Angen, 2000), stress and anxiety in healthy individuals (e.g., Astin, 1997; Shapiro, Schwartz, & Bonner, 1998; Williams, Kolar, Reger, & Pearson, 2001), pain (Kabat-Zinn, 1982; Kabat-Zinn, Lipworth, & Burney, 1985; Kabat-Zinn, Lipworth, Burney, & Sellers, 1987) and reducing the risk of depressive relapse (Ma & Teasdale, 2004; Teasdale et al., 2000). More recently, however, mindfulness-based research has shifted to focus on the operational definition of mindfulness and its underlying mechanisms.

In particular, several investigators have proposed theoretical accounts of how cognitive

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changes may underlie the beneficial effects of mindfulness training. For example, Breslin, Zack, and McMain (2002) suggested that mindfulness may help reduce substance abuse relapse by increasing conscious awareness and controlled processing of relapse triggers. Williams, Teasdale, Segal, and Soulsby (2000) proposed that because mindfulness training involves noticing specific aspects of the environment without judging them or avoiding them, it should improve autobiographical memory, as autobiographical memory benefits from rich encoding of episodic details. They tested autobiographical memory before and after mindfulness-based cognitive therapy (MBCT) or a treatment-as-usual in formerly depressed patients and found improvements at post-test only in the MBCT group. Teasdale et al. (2002) hypothesized that MBCT prevents depressive relapse by improving metacognitive awareness, defined in this study as the ability to see thoughts and feelings as passing mental events rather than an aspect of self. They reported increased metacognitive awareness following MBCT, relative to treatment as usual.

While the above theorists applied aspects of cognitive theory and cognitive tasks to the study of mindfulness, Bishop et al. (2004) have proposed the first formal definition of its cognitive mechanisms as part of a two-component operational definition of mindfulness involving: (1) the *self-regulation of attention* so that it is maintained on immediate experience and (2) the adoption of an open, curious, accepting *awareness* of experiences in the present moment. Specifically, Bishop et al. (2004) proposed that mindfulness involves *sustained attention* to maintain awareness of current experience, *attention switching* to bring attention back to the present moment when it wanders, *inhibition of elaborative processing* to avoid dwelling or ruminating on thoughts or feelings that are outside of the present moment and *non-directed attention* to enhance awareness of present experience, unfiltered by assumptions or expectations. Further, Bishop et al. (2004) view mindfulness as an attentional state that can be evoked when attention is purposefully brought to the present moment while fostering an open orientation to experience. We reasoned that because mindfulness training entails extended practice of these attentional control abilities, and practice generally improves attentional control (e.g., Cepeda, Kramer, & Gonzalez de Sather, 2001; Halperin, Sharma, Greenblatt, & Schwartz, 1991; MacLeod, 1991), mindfulness training should be associated with increased mindfulness and, correspondingly, improved performance on tasks that measure these abilities.

Although we are aware that several laboratories are investigating the specific effects of mindfulness training on attention, to date there have been very few published reports in this area. Most recently, Jha, Krompinger, and Baime (2007) examined alerting, orienting and conflict monitoring using the Attention Network Test (Fan, McCandliss, Fossella, Flombaum, & Posner, 2005) before and after an 8-week MBSR course administered to meditation-naïve participants, a 1-month intensive mindfulness retreat administered to participants with an average of 60 months of prior concentrative meditation experience, or an 8-week no treatment control in meditation-naïve participants. Previous work indicates that alerting, orienting and conflict monitoring are behaviourally and neuroanatomically distinguishable attention subsystems, with alerting being a 'bottom-up' or stimulus-driven system, and orienting and conflict monitoring being more 'top-down' or voluntary systems (e.g., Fan et al., 2005; Posner & Peterson, 1990). Jha et al. (2007) found (1) better conflict monitoring at baseline in the experienced meditators than in the meditation-naïve participants; (2) that participation in the MBSR course improved orienting; and (3) that participation in the intensive retreat improved alerting among the previously experienced meditators. They concluded that meditation training (previously obtained or newly gained) improves voluntary top-down attentional control, leading to improved orienting and/or conflict monitoring, and that prior experience with concentrative meditation allows for the development of improved bottom-up, receptive attention involved in alerting.

Wenk-Sormaz (2005) explored Stroop interference and word production. These attention tasks were administered after brief exposure (three 20-minute sessions in Study 1 and one 20-minute session in Study 2) to mindful sitting meditation, rest or cognitive control conditions in young, healthy meditation-naïve participants. Relative to the control conditions, mindfulness meditation was associated with less Stroop interference and more flexible word production, suggesting that even brief exposure to mindfulness techniques improves attentional control.

Valentine and Sweet (1999) examined performance on a sustained attention task for members of a Buddhist centre versus controls, and found that mindfulness meditators were less vulnerable to unexpected events, suggesting that mindfulness

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DOI: 10.1002/cpp

helps distribute attention, facilitating better awareness of the present moment. Finally, McMillan, Robertson, Brock, and Chorlton (2002) found no positive benefits of MBSR among individuals who had suffered a traumatic brain injury. However, the MBSR course used in their study was of shorter duration than usual (five weeks versus eight weeks) and self-administered (versus administered in a group setting), both of which may have minimized the effects of MBSR training on attention. The participants had suffered significant brain injuries, and their attentional networks may have been too compromised to make remediation via MBSR viable. Overall, the data provided by Jha et al. (2007), Wenk-Sormaz (2005) and Valentine and Sweet (1999) provide exciting evidence for the role of attention in mindfulness.

The goal of the present study was to test the construct validity of the first component of mindfulness described by Bishop et al. (2004). We attempted to manipulate the level of mindfulness in healthy adults with no prior meditation experience. Healthy adults responding to an advertisement for a free 8-week MBSR course were randomly assigned to either begin the course immediately, or after a delay. All participants were administered a 10-item version of the Toronto Mindfulness Scale (TMS) (Bishop et al., 2003),[1] a number of standardized, reliable questionnaires focusing on emotional well-being, and valid and reliable tests of sustained attention, attention switching, inhibition of elaborative processing and non-directed attention before and after the MBSR course or delay. All four attention tests used in the current study require top-down attentional control systems, namely orienting (sustained attention) or conflict monitoring (attention switching, inhibition of elaborative processing and non-directed attention).

Our primary hypothesis was that participation in MBSR would lead to improved attentional control. Specifically, we expected that the MBSR participants' extended practice in attending to the present moment, bringing attention back to the present moment when the mind wanders, inhibiting elaborative processing to avoid rumination, and greater awareness of the present moment unfiltered by expectations would be associated with smaller vigilance decrements, smaller attention switching costs, less Stroop interference and smaller consistency effects in the object detection task. We also hypothesized that increases in the ability to invoke mindfulness as assessed by the 10-item TMS would be associated with these same improvements in attentional control. It should be noted that this is the first study relating mindfulness to attention: previous studies have only examined the effects of meditation experience on attention and have not included an independent measure of mindfulness (Jha et al., 2007; McMillan et al., 2002; Valentine & Sweet, 1999; Wenk-Sormaz, 2005).

METHODS

Participants

Eighty-six adults with no prior experience of any form of meditation, yoga, tai-chi or qigong were recruited through newspaper advertisements. The project was carried out in accordance with the protocol approved by the Research Ethics Boards at the University Health Network and at Baycrest in Toronto. All participants provided informed consent. Participants were randomly assigned to either an 8-week MBSR course led by a certified MBSR therapist or an 8-week waitlist control. The MBSR course involved weekly 2-hour classes in which participants engaged in formal meditation practices (e.g., body scan, mindful stretching, mindfulness of breath/body/sounds/thoughts) as well as informal practices, which encouraged the application of mindfulness skills in everyday life (e.g., eating a meal mindfully) in order to cope more effectively with stress and anxiety. Participants engaged in no other forms of meditation during the duration of the study.

Data are reported here from the 39 participants assigned to the MBSR course who attended at least five of the weekly sessions and completed all four attention tasks at pre- and post-test and from the 33 participants assigned to the waitlist control who completed all four attention tasks at pre- and post-test. Fourteen participants (seven in each group) were excluded from data analysis for not meeting these criteria. The reasons for the seven in the MBSR group were (1) unable to fulfil class and

[1] The 10-item version of the Toronto Mindfulness Scale used in this study was based on an initial factor analysis of the original 42 items (see Bishop et al., 2003). We have since carried out further analyses and now endorse a 13-item scale (Lau et al., 2006) Using the independent samples from the Lau et al. studies, responses on the 10 items used in the current study correlate with the two factors in the 13-item scale ($r = 0.63$ for 'decentering' and $r = 0.56$ for 'curiousity', $n = 174$), show good internal consistency (Cronbach's alpha = 0.79 ($n = 390$) and 0.81 ($n = 99$)) and also increased from pre- to post-MBSR in a sample of 99 clinical patients, paired $t(98) = 6.17$.

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DOI: 10.1002/cpp

nightly practice time commitment ($n = 3$); (2) work schedule interfering with class time ($n = 2$); (3) missing class due to morning sickness ($n = 1$); and (4) failing to show up for more than three classes ($n = 1$). In the control group, the reasons were (1) work schedule interfering with post-testing at required times ($n = 2$); (2) could not be contacted for post-testing ($n = 2$); (3) declined post-testing ($n = 2$); and (4) computer tasks were too hard on eyes ($n = 1$). Intent-to-treat analyses were not conducted because there were equal numbers of dropouts in the two groups, and hence the most conservative estimation of post-test scores (i.e., imputing pre-test scores into post-test under the assumption of no change) would have not affected group mean differences at post-test.

Procedure

At pre-testing and at post-testing, participants sat on a foam mat in a dim room for 10 minutes prior to testing. At pre-test, both groups were asked to relax during this time. At post-test, the control participants were again asked to relax, whereas the MBSR participants were asked to do sitting meditation during this time and to invoke mindfulness while performing the tasks. Participants next completed the four attention tasks in one of four different orders balanced across participants, with the same order used at pre-test and post-test. The four orders were (1) Sustained Attention, Switching, Stroop, Object Detection; (2) Switching, Sustained Attention, Object Detection, Stroop; (3) Stroop, Object Detection, Sustained Attention, Switching; and (4) Object Detection, Stroop, Switching, Sustained Attention. After the attention tasks participants completed the following self-report measures: the 10-item version of the TMS (Bishop et al., 2003), Positive and Negative Affect Scale (Watson, Clark, & Tellegen, 1988), Beck Depression Inventory (Beck, 1993), Beck Anxiety Inventory (Beck, 1993), Anxiety Sensitivity Index (Reiss, Peterson, Gursky, & McNally, 1986), short form of the Novaco Anger Inventory (Kidman, 1986; Novaco, 1975), Anger Rumination Scale (Sukhodolsky, Golub, & Cromwell, 2001), Rumination Scale of the Response Styles Questionnaire (RSQ, Nolen-Hoeksema, Morrow, & Fredrickson, 1993) and Penn State Worry Questionnaire (Meyer, Miller, Metzger, & Borkovec, 1990).

All post-testing took place within four weeks after completion of the MBSR course or waitlist period. The average duration between pre- and post-testing was 71 days for both groups.

Attention Tasks

The Vigil Continuous Performance Test computer programme (The Psychological Corporation) was used to measure sustained attention. Single white Arial 18-point letters appeared in the centre of the screen for 85 ms, followed by an 850 ms interstimulus interval. Different visual noise patterns masked the background and the character box surrounding the letter (set at 99% in the Vigil programme). The purpose of the visual noise patterns was to increase the perceptual difficulty of the task. The task consisted of 800 stimuli. Participants were instructed to press the spacebar as quickly as possible when they saw the letter 'K'. A total of 80 targets were presented, 20 in each set of 200 trials. The entire task lasted about 12 minutes. The reliability (Cronbach's alphas >0.80) and construct validity (reliable correlations with other tests of sustained attention) are reported in the Vigil manual.

Stimulus presentation and response collection in the other three tasks were controlled by E-Prime (Psychological Software Tools, Inc.). The switching task involved a 2 × 2-grid (7.5 cm × 7.5 cm) where on each trial a filled circle (7-mm diameter) appeared in the centre of one of the four grids. A question appeared below the grid, asking either 'Left or Right?' or 'Upper or Lower?' and participants pressed the first (leftmost) button on a five-button response box to indicate Left or Lower responses and the second button to indicate Right or Upper responses. Participants were instructed to respond as quickly as possible. There were six blocks of trials presented in the following order: Left-Right, Upper-Lower, Switch, Switch, Upper-Lower and Left-Right. In the Left-Right and Upper-Lower blocks, participants made a single decision throughout each block of 32 trials. In the Switch blocks, the instructions switched randomly between 'Left or Right?' and 'Upper or Lower?' over 64 trials. As soon as a response was recorded, the filled circle and question disappeared leaving only the blank grid, for 1000 ms. Participants received eight trials of practice prior to the first Left-Right, Upper-Lower and Switch blocks of trials. The examiner provided feedback after each practice trial. Switch costs are defined as the lower accuracy or increased response time in blocks of trials in which the task shifts between two stimulus–response modes from trial to trial, relative to blocks of trials in which the same task is performed on every trial (Rogers & Monsell, 1995). Attention switching tasks of this sort have

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primarily been used in experimental settings, and as such, measures of reliability and validity are under-reported. Nevertheless, switch costs are robust, having been reported in hundreds of studies, and every participant in the current study showed switch costs at both pre-test and post-test. Moreover, a latent variable analysis of various experimental attention tasks revealed attention switching to be an independent, reliable construct, and that switching correlated best with perseverative errors on the Wisconsin Card Sorting Task, the canonical clinical measure of the ability to shift attentional sets (Miyake, Friedman, Emerson, Witzki, & Howerter, 2000).

A Stroop paradigm (Stroop, 1935) was used to measure inhibition of elaborative processing. Prior to relaxing or meditating, participants rated 60 positive (e.g., loyal) and 60 negative (e.g., shallow) adjectives using a seven-point scale ranging from 'Very characteristic of me, extremely descriptive' to 'Very uncharacteristic of me, extremely non-descriptive' (Segal, Gemar, Truchon, Guirguis, & Horowitz, 1995). While the participant was relaxing or meditating, the examiner selected five positive and five negative traits that the participant rated as being most characteristic. Five conditions were administered in one of five different orders, with the same order presented at pre-test and post-test. In each condition, participants saw 40 words appear individually in 32-point Arial font in the centre of the screen in yellow, white, red, blue or green against a black background. Participants were instructed to name the colour in which the words appeared. Each word remained on the screen until a response was detected by the voice key, at which point the word disappeared, and a fixation cross (+) appeared in its place for 750 ms. Participants completed 15 practice trials prior to the experimental block. The conditions administered were Positive (the five positive adjectives rated as being most self-characteristic), Negative (the five negative adjectives rated as being most self-characteristic), Standard (the words 'yellow', 'white', 'red', 'blue' and 'green'), Semantic (the words 'sun', 'snow', 'blood', 'sky' and 'grass') and Neutral (the words 'clear', 'distinct', 'general', 'public' and 'uniform'). Across trials, each word appeared in four of the possible five colours (twice in each colour); words in the Standard and Semantic conditions never appeared in their congruent colours (e.g., 'white' in white or 'sun' in yellow). Neutral words were selected from the MRC Psycholinguistic Database (http://www.psy.uwa.edu.au/Scripts/MRCDatabase/uwa_mrc.htm). Stroop interference is defined as the increased reaction time and lower accuracy associated with naming the ink colours in these conditions relative to a condition containing neutral words. The reliability of Stroop interference measures is well established (c.f., Lezak, 1995; Spreen & Strauss, 1998). There remains debate as to the source of interference, but a recent focus on parallel distributed (connectionist) models (Cohen, Dunbar, & McClelland, 1990) highlights the differential strength of connections along word reading pathways relative to colour-naming pathways and the role of attention (driven by task demands to name the colour) in altering the responsiveness of task-appropriate pathways. Williams, Mathews, and MacLeod (1996) argue that emotional words have higher resting activation levels, and attention biases towards these word pathways lead to significant interference effects for emotionally salient words.

An object detection task (Hollingworth & Henderson, 1998) was used to measure non-directed attention. Each trial began with a fixation cross for 1000 ms, followed by the name of an object (e.g., chicken) for 1500 ms, both in 32-point black Arial font centred on a white screen. Then, a complex line drawing of a common scene (e.g., a farmyard) appeared, filling the entire screen excepting an approximately 3-cm border. This scene remained on the screen until the participant indicated by pressing one of two buttons whether or not the object was in the scene. Thirteen scenes were each presented twice, paired once with an object that was consistent with the scene, and once with an object that was inconsistent with the scene (e.g., the chicken in a classroom). Twenty-six trials were thus presented, and the object was present on 20 of those trials. Participants received four practice trials using different objects and scenes prior to the experimental block. A different set of visual scenes and objects was presented at pre- and post-testing and the order of the sets was counterbalanced across participants. Consistency effects are evident as increased errors or longer durations needed to detect common objects when they are placed in inconsistent than consistent scenes (e.g., a chicken in a classroom versus a chicken in a farmyard). This object detection task is an experimental task, and as such, reliability and validity measures have not been reported in the literature. Consistency effects using this paradigm have been reported by many (Biederman, Mezzanotte, & Rabinowitz, 1982; De Graef, Christiaens, & d'Ydewalle, 1990; Henderson, Weeks, & Hollingworth, 1999; Hollingworth & Henderson, 1998), and we chose this task

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for its face validity in targeting attention to the present moment (stimulus) uninfluenced by expectations.

Both reaction times associated with correct responses and error rates were analysed. It should be noted that error rates are low in sustained attention tasks (the normative rate for this age group on the Vigil task is <1%), Stroop tasks (e.g., 3% for this age group in the clinical Victoria version of the Stroop test; Spreen & Strauss, 1998) and attention switching task (e.g., <3% in non-switch blocks and <8% in switch blocks in Rogers & Monsell, 1995). The object detection task used in this study afforded participants as much time as they needed to respond and hence error rates were expected to be low.

RESULTS

Participants and Validation of the MBSR Course

The two groups were comparable in age (control $M = 41.7$ and MBSR $M = 37.0$ years, $t[70] = 1.68$, $p = 0.10$), and had comparable levels of education (BA/BSc on average, $t[70] = 0.58$, $p = 0.56$) and marital status compositions (single/married/separated or divorced = 14/26/3 for controls and 19/16/4 for MBSR). Mean responses on the self-report measures at pre- and post-test are shown in Table 1. A multivariate analysis of variance (ANOVA) with group (MBSR versus control) as a fixed independent effect revealed equivalency of the two groups on these nine measures at pre-test, $F(9, 62) = 1.30$, $p = 0.25$. Nevertheless, the means suggest some group differences: greater negative affect, depression and anger rumination were identified in the MBSR than in the control group when univariate analyses were conducted (all p's < 0.02). Accordingly, a multivariate ANOVA on these measures at post-test was conducted using the pre-test measures as covariates. The group difference on the nine post-test measures was significant, $F(9, 53) = 2.87$, $p < 0.01$. Univariate analyses revealed larger changes in the direction of better well-being in the MBSR group than in the control group in depression, anxiety, anger, positive affect, general rumination, anger rumination and anger sensitivity (p's < 0.02), and marginally greater changes in general worrying ($p = 0.06$).

Examination of the 10-item TMS scores at pre- and post-test provided further validation of the efficacy of the MBSR course (see Figure 1). Importantly, the two groups reported comparable levels of mindfulness at pre-test, with a trend towards higher baseline mindfulness in the control than in the MBSR group ($p = 0.08$). At post-test, the control group's TMS scores had not changed, $t(32) = 0.70$, $p = 0.49$, but the MBSR group's scores had increased by an effect size of 1.59 (a 'large' effect; Cohen, 1992), $t(38) = 8.70$, $p < 0.001$.

Attention Tasks

Accuracy and reaction times of correct responses were analysed for each of the four tasks. Significant effects were explored further using Sidak-corrected *post hoc* comparisons. Mean reaction times are reported in milliseconds. Analyses of median reaction times provided identical patterns of results except for the Object Detection task as noted below.

Sustained Attention Task

The effects of participation in an MBSR course on sustained attention target discrimination (hit rate

Table 1. Mean (SD) on self-report measures

	Control		MBSR	
	Pre-test	Post-test	Pre-test	Post-test
PANAS positive affect	31.9 (8.8)	32.1 (9.3)	29.6 (8.4)	35.3 (7.3)
PANAS negative affect	18.4 (7.3)	16.8 (6.5)	23.6 (8.4)	18.9 (8.1)
Beck Depression Inventory	8.1 (7.3)	7.6 (7.7)	13.1 (10.1)	6.0 (8.9)
Beck Anxiety Inventory	8.4 (6.5)	7.6 (7.6)	10.4 (9.3)	6.8 (7.2)
Anxiety Sensitivity Index	20.9 (10.1)	19.6 (8.9)	23.2 (11.2)	19.9 (10.9)
Novaco Anger Inventory	47.8 (16.1)	39.8 (16.7)	52.2 (18.4)	39.0 (17.7)
Anger Rumination Scale	35.3 (9.7)	34.7 (10.0)	42.6 (13.8)	36.3 (11.8)
Rumination Scale of RSQ	45.2 (11.6)	43.8 (12.5)	50.2 (12.2)	43.2 (12.3)
Penn State Worry	48.9 (15.5)	45.1 (14.5)	55.3 (15.5)	47.2 (13.5)

MBSR = mindfulness-based stress reduction. PANAS = Positive and Negative Affect Scale. RSQ = Response Styles Questionnaire.

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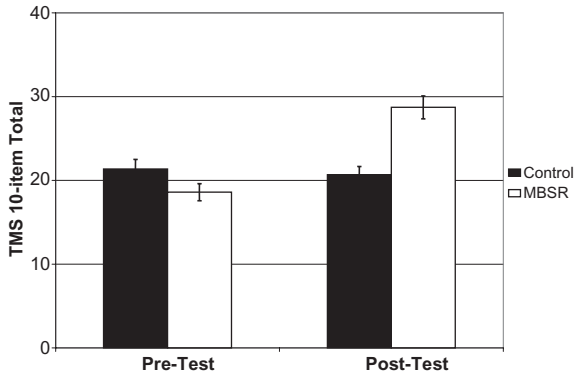


Figure 1. Mean Toronto Mindfulness Scale scores (±1 SEM)

minus false alarm rate) and reaction time (RT) were analysed using separate 2 × 2 × 4 ANOVAs with Group between subjects and Session and Block within subjects. Participants in both groups performed the task very accurately. Discrimination was higher during pre- than post-testing (M's = 0.990 and 0.983, respectively), $F(1, 70) = 4.58$, $p = 0.04$, and decreased from Blocks 1 and 2 to Block 4 (M's = 0.991, 0.989, 0.986 and 0.979 for Blocks 1–4), $F(3, 210) = 5.28$, $p = 0.002$. No other effects were significant. In the analysis of mean RTs, the only significant effect was the Block main effect, $F(3, 210) = 84.10$, $p < 0.001$, with RTs slowing from Block 1 to Block 2 and from Block 2 to Block 3 (M's = 460, 484, 490, 496 ms for Blocks 1–4).

Switching Task

Accuracy on the switching task was high ($M > 0.95$) and was not significantly affected by group, condition or session (all $F[1, 70] < 3.30$, $p > 0.05$). Mean RTs of correct responses were analysed in a 2 × 2 × 2 ANOVA with Group between subjects, and Session and Condition (switch versus non-switch) within subjects (see Figure 2A). RTs were faster at post-test than pre-test, $F(1, 70) = 60.57$, $p < 0.001$, and faster in non-switch than switch blocks, $F(1, 70) = 569.66$, $p < .001$. The Session and Condition effects also interacted, $F(1, 70) = 48.18$, $p < 0.001$, such that switch costs were larger at pre-test than post-test. No other effects were significant.

Switch costs were also analysed within the switch blocks. Trials within the switch blocks were defined as 'stay' trials if the task ('left or right?' versus 'up or down?') was the same as on the previous trial, or 'switch' trials if the task had changed from the previous trial. These data are shown in Figure 2B. A 2 × 2 × 2 ANOVA, with Group between subjects, and Session and Trial Type (switch or stay) on these data revealed that RTs were faster at post-test than pre-test, $F(1, 70) = 64.29$, $p < 0.001$, and faster on stay than switch trials, $F(1, 70) = 11.97$, $p = 0.001$. No other effects were significant.

Stroop Task

True errors (reading the word or naming an incorrect colour), false errors (any non-word utterance, e.g., 'uh' or a laugh) and mean RT were analysed in separate 2 × 2 × 5 ANOVAs, with Group between subjects, and Session and Condition within subjects. In both analyses of errors, the only significant effect was the main effect of Condition, $F(4, 280) = 12.50$, $p < 0.001$ for true errors and $F(4, 280) = 11.75$, $p < 0.001$ for false errors. True errors were most common in the Standard condition ($M = 0.7$) and least common in the Neutral condition ($M = 0.2$), with the frequency in the Positive, Negative and Semantic (all M's = 0.3) conditions falling in between. False errors were higher in the Standard condition ($M = 1.1$) than in all other conditions (M's = 0.3 to 0.5).

The analysis of mean RTs revealed only a Condition main effect, $F(4, 280) = 139.97$, $p < 0.001$. RTs were reliably longer in the Standard condition ($M = 849$ ms) than in the Semantic condition ($M = 737$ ms), which in turn produced longer RTs than the remaining three conditions in which RTs were not reliably different (Neutral $M = 713$ ms; Negative $M = 709$ ms; Positive $M = 701$ ms).

Object Detection Task

One control subject had extremely low accuracy on the object detection task at pre-test (hit rate = 0.10), suggesting that she did not understand the task instructions, and thus her data were dropped from the analyses. Given the differential reliability of the data for Present (20 trials) versus Absent (six trials) objects, the data for Present and Absent conditions were analysed in separate 2 × 2 × 2 ANOVAs, with Group between subjects, and Session and Consistency (i.e., whether the object was consistent or inconsistent with the visual scene) within subjects. In the analysis of accuracy on object Present trials, only the main effect of Consistency was significant, $F(1, 69) = 13.21$, $p = 0.001$, with higher accuracy on consistent ($M = 0.99$) than inconsistent ($M = 0.97$) trials. No effects were significant in the analysis of accuracy on object Absent trials ($M = 0.97$). Hence, even though the scenes were kept on the screen until participants

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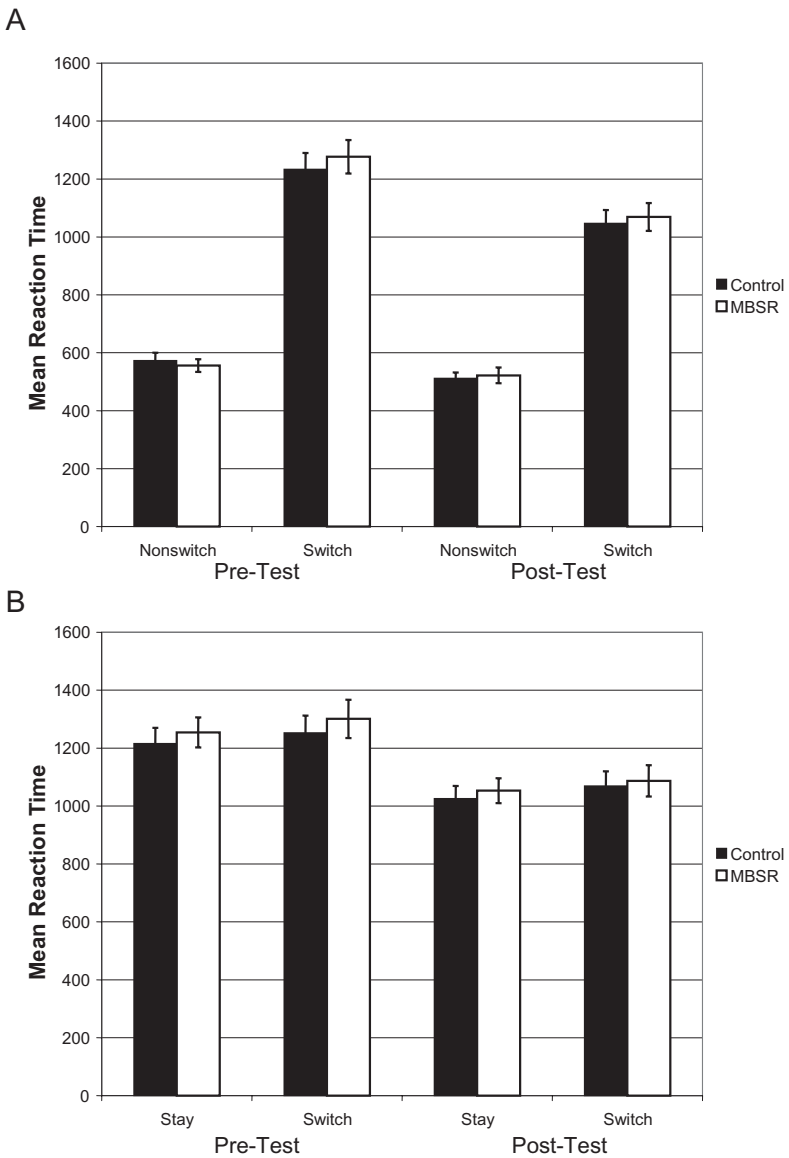


Figure 2. Mean reaction time (in ms, ±1 SEM) on the switching task. A. Comparison of switch and non-switch blocks. B. Comparison of stay versus switch trials within the switch blocks.

responded, detection accuracy was higher when objects were displayed in consistent than inconsistent scenes.

The mean RT data are shown in Figure 3A and B for Present and Absent trials, respectively. For Present objects, RTs were faster at post-test than pre-test, $F(1, 69) = 38.99$, $p < .001$, and faster for consistent than inconsistent objects, $F(1, 69) = 14.28$, $p < 0.001$. No other effects were significant. For Absent trials, RTs were also faster at post-test than pre-test, $F(1, 69) = 10.30$, $p = 0.002$. The Session × Consistency interaction was also significant, $F(1, 69) = 5.32$, $p = 0.02$, such that a Consistency effect was found at pre-test but not at post-test. Note that for object absent trials, participants were faster to rule out the presence of an object in an inconsistent than consistent scene. No other effects were significant. Corresponding analyses of median RTs

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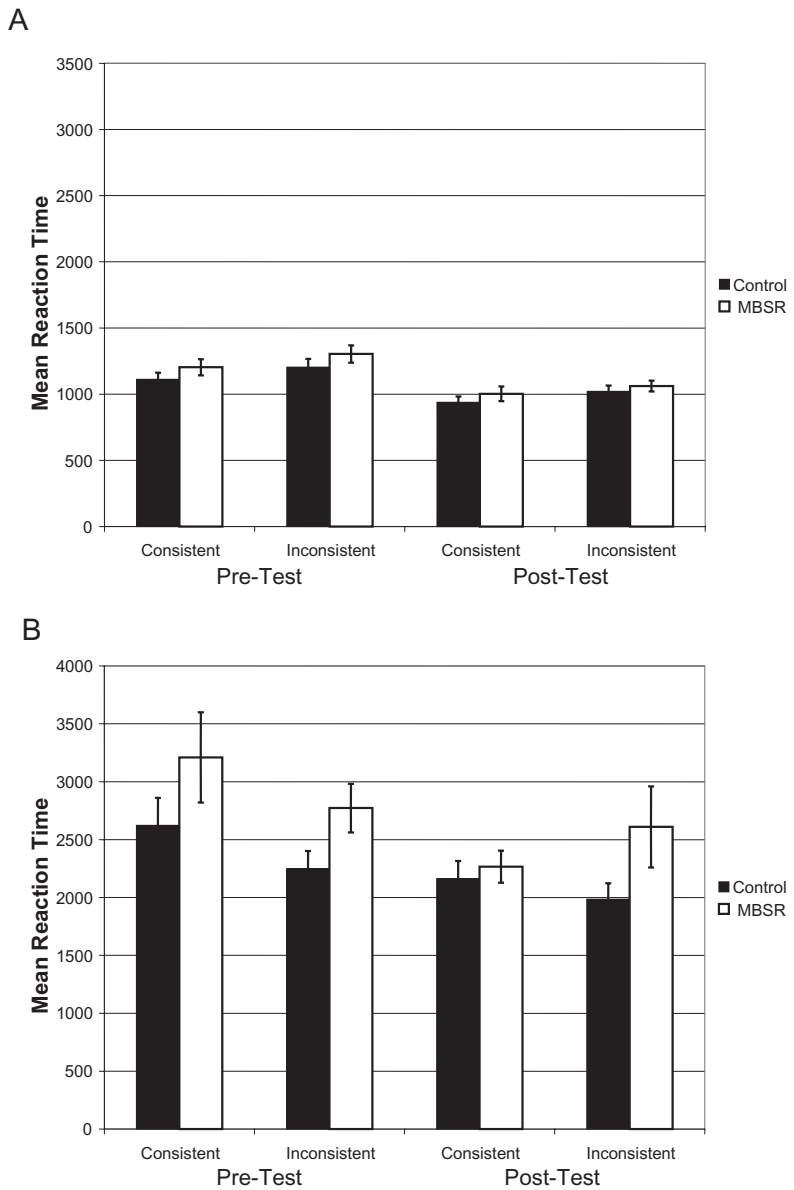


Figure 3. Mean reaction time (in ms, ±1 SEM) on the object detection task for object present trials (A) and object absent trials (B).

showed main effects of Session and Consistency, but no interaction.

Analysis of Potential Confounding Effects

Age

Participants in the control group were marginally older (6 years on average) than participants in the MBSR group. If age-related effects were involved, one would expect larger task manipulation effects (i.e., a larger vigilance decrement and larger Stroop effects) in the control than in the MBSR group at pre-test, yet in no case were there group differences in these effects. Moreover, the same results were obtained on all four tasks when the analyses were repeated with age as a covariate, except the consistency effect in the object present condition of the object detection task was no longer significant.

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Task Order

The mean RTs for each task were re-analysed with task order as an additional between-subject variable. Task order had no influence on mean RTs for the sustained attention task, the Stroop task or the switching task. Participants who performed the object detection task last (i.e., Order 1) had the largest object consistency effects, $F(3, 63) = 2.94$, suggesting that fatigue may exaggerate the consistency effect, but this was equally true for MBSR and control participants.

Variability in Practice

The total minutes spent practicing mindful activities (total minutes spent in sitting meditation, body scan, yoga, mindful movement and informal practice) ranged from 594 to 5005 ($M = 1804$, SD = 909) in the MBSR group and demonstrated a positively skewed distribution. However, the natural log of total practice (to normalize the distribution) bore no association with change in attention on any measure (all p's > 0.10) and hence does not explain the failure to find changes in attentional control associated with MBSR.

Baseline Emotional Well-Being

Although the multivariate analysis comparing the MBSR and control groups on the self-report measures of emotional well-being at baseline was not significant, the MBSR group did report more negative affect, depression and anger rumination than their control counterparts (univariate p's < 0.02) which may have dampened group differences in attentional changes as a function of MBSR. However, when RTs were re-analysed using baseline negative affect, depression and anger rumination as a covariate, in no case were there group differences in pre-post changes on the attention tasks.

Effect of Mindfulness on Emotional Well-Being and Attention

Our final analyses explored whether changes in mindfulness as assessed by the 10-item TMS were related to changes in emotional well-being or attentional control. To help reduce the number of variables, we first conducted a principal components factor analysis on pre-test to post-test changes within the MBSR group on the eight self-report measures of emotional functioning described in the section, *Participants and Validation of the MBSR Course*. This yielded a single factor that explained 55% of the variance. The change scores for each test were then weighted by the respective factor scores and summed to create a composite Emotion Change score. We then used regression analyses to explore the effects of changes in mindfulness on Emotion Change (among the MBSR participants only) and on changes in the primary outcome measures on the attention tasks (separately for both groups). Changes in mindfulness predicted changes in emotional well-being, $F(1, 70) = 18.34$, $p < 0.001$, such that greater increases in the ability to invoke mindfulness were associated with greater emotional well-being for MBSR participants. Changes in mindfulness did not predict changes in sustained attention or changes in inhibition of elaborative processing in either group. There was a relationship between changes in mindfulness and changes in attention switching, but this was driven by three outliers. With their data removed from the analysis, the relationship was not significant. However, changes in mindfulness did predict changes in object detection for participants enrolled in MBSR, $F(1, 37) = 6.33$, $p = 0.02$, but not for the controls, $F(1, 30) < 1$. Figure 4 shows changes in consistency costs (i.e., the extent to which inconsistent objects slowed RT, such that higher numbers represented smaller object consistency effects at post-test than pre-test) plotted against changes in mindfulness (TMS score at post-test minus TMS score at pre-test) separately for the MBSR and control groups. As is evident, greater increases in mindfulness were associated with better object detection, but only for the MBSR participants.

Finally, we conducted a mediation analysis (see MacKinnon, 2006, for a review of statistical mediation analyses) to explore whether the changes in emotional well-being associated with improvements in mindfulness were mediated by improvements in object detection, but this was not the case (p's > 0.05).

DISCUSSION

Our goal was to explore the attentional control mechanisms of mindfulness. Participants completed tasks of sustained attention, inhibition, switching and object detection before and after either an 8-week MBSR course or a wait-list control. Based on Bishop et al. (2004), we hypothesized that the MBSR would lead to smaller vigilance decrements, less Stroop interference, lower attention switching costs and smaller consistency effects in object detection. The results showed that in all of these measures, the MBSR and control

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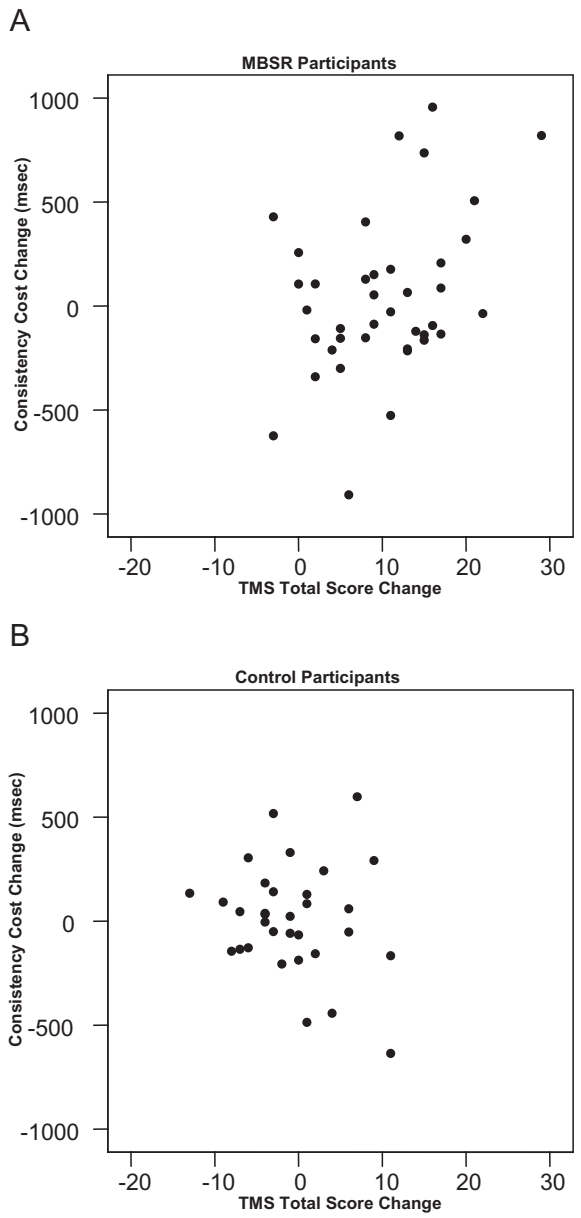


Figure 4. Changes in object present consistency costs in the object detection task (positive scores represent smaller consistency costs at post-test than pre-test) plotted against changes in mindfulness as assessed by the 10-item Toronto Mindfulness Scale for MBSR participants (A) and control participants (B).

groups performed similarly in both testing sessions. In short, we found no evidence that participation in an extensive 8-week MBSR course affected attentional control. We did, however, find that an improved ability to evoke mindfulness was associated with smaller consistency effects in object detection, suggesting that mindfulness is associated with non-directed attention, enhancing awareness of present experience, unfiltered by assumptions or expectations. Thus, while the current study fails to replicate recent reports of positive effects of *MBSR* on attentional control (Jha et al., 2007; Valentine & Sweet, 1999; Wenk-Sormaz, 2005), we do find positive effects of *mindfulness* on awareness of the present moment.

Why did participation in the MBSR fail to improve attentional control in this study? We do not believe that the way the MBSR was delivered or the design of the attention tasks is to blame for these null findings. The MBSR participants, but not the controls, reported significant increases in mindfulness and significant improvements in depression and anxiety symptoms, positive affect, anger, general and anger-related rumination from pre-test to post-test. These positive effects of MBSR on emotional well-being replicate many previous studies (for reviews, see Baer, 2003; Bishop, 2002). Our study furthermore revealed that the improvements in mindfulness that occurred in the context of the MBSR course predicted improvements in emotional well-being.

Moreover, the attention tasks were well-designed and showed the standard effects they were designed to measure, namely a vigilance decrement, difficulty inhibiting incongruent information, task switching costs and longer durations to detect objects presented in inconsistent scenes (De Graef, Christiaens, & Ydewalle, 1990; Hollingworth & Henderson, 1998; Rogers & Monsell, 1995; Rosvold, Mirsky, Sarason, Bransome, & Beck, 1956; Stroop, 1935), and these effects held in mean and median RTs. Additional analyses found no influence of task order effects or group differences in the participants' ages or baseline emotional well-being on these tasks. Finally, lack of power cannot explain the failure to find effects of MBSR participation on attentional control, as attentional performance at pre-test and post-test was essentially equivalent in the MBSR and control groups. Thus, neither the delivery of MBSR nor the task designs can be held responsible for the null effects of MBSR on attention.

Other aspects of the current study may have contributed to the failure to find positive effects of MBSR on attentional control, but most are difficult to resolve with the positive effects reported by Jha et al. (2007) and Wenk-Sormaz (2005). First, the changes in mindfulness and emotional well-being

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as a function of MBSR were based on self-report data, and hence these changes may simply reflect a reporting bias. This seems unlikely, however, given that very similar changes in emotional well-being reported by others have also been linked to objective changes in outcomes such as relapse of major depression (Ma & Teasdale, 2004; Teasdale et al., 2000). Second, a longer MBSR course may be more effective in producing improvements in attentional control, although Jha et al. (2007) and Wenk-Sormaz (2005) reported positive results with interventions of comparable or shorter duration. Third, the 10-minute meditation period prior to the attention tasks may have been insufficient for a group of newly trained meditators to fully evoke a state of mindfulness. However, Jha et al. (2007) found benefits of mindfulness training *without* a meditation prime, and Wenk-Sormaz found benefits to attentional control after a 20-minute meditation prime in meditation-naïve individuals. Fourth, clinical populations with information processing biases (such as observed in depression) may demonstrate improvements in attentional control that were not evident in the current sample of healthy volunteers. Performance on the sustained attention and Stroop tasks did not change from pre-test to post-test, suggesting that performance speed on these tasks may have been near a physiological limit and not malleable to change within subjects, particularly within a healthy population. Similarly, the self-relevant positive and negative adjectives did not produce reliable Stroop effects in this healthy population, perhaps because these words are not maintained at a higher resting state of activation and are not subjected to attentional biases as is argued to be the case in clinical populations (Williams et al., 1996). Nevertheless, Jha et al. (2007), Wenk-Sormaz (2005) and Valentine and Sweet (1999) studied non-clinical samples, yet found positive benefits of mindfulness on attentional control. Finally, Lazar et al. (2005) found increased cortical thickness in regions implicated in attention networks. Thus, it is possible that even if MBSR does not produce behavioural changes on attention tasks, neurophysiological changes may be evident if techniques such as event-related potentials or functional magnetic resonance imaging are employed.

We are intrigued by the fact that increases in *mindfulness* owing to MBSR were associated with an improved ability to detect objects in inconsistent scenes. This suggests that it is not the mere participation in MBSR, or even the total amount of mindfulness practice engaged within an MBSR course, that is related to improved performance, but rather the benefits that such participation and practice confer to the ability to invoke mindfulness. Moreover, the fact that this relationship was found for the object detection task alone, and not for the other tasks, is illuminating. The object detection task required awareness of the present moment, unfiltered by expectations, abilities that seem more closely linked with the second construct of the proposed operational definition of mindfulness suggested by Bishop et al. (2004) than with more basic attentional control. The recent analysis of the TMS by Lau et al. (2006) found two independent mindfulness factors: 'curiosity', a willingness to learning more about one's immediate experience, and 'decentering', a shift from personally identifying with negative thoughts and feelings to relating to one's experience from a broader perspective. Importantly, the analysis did not support the first component of mindfulness proposed by Bishop et al. (2004) related to attentional control. Other self-report measures of mindfulness also load onto a single construct of awareness and acceptance of the present moment, e.g., the Cognitive and Affective Mindfulness Scale-Revised (Feldman, Hayes, Kumar, Greeson, & Laurenceau, in press) and the Freiburg Mindfulness Inventory (Buchheld, Grossman, & Walach, 2001). The Kentucky Inventory of Mindfulness Skills (Baer, Smith, & Allan, 2004) has one factor (Observing) related to basic attentional skills, but approximately half of the scale items load on to either an Awareness or an Acceptance factor. Hence, the role of awareness in mindfulness is better supported by these scales than is the role of attention. One single-factor scale, the Mindful Attention Awareness Scale (MAAS; Brown & Ryan, 2004), stands apart from these other scales, with 15 items describing attention and other cognitive failures. Given its focus on basic attentional abilities, mindfulness-related changes in responses on the MAAS may be associated with changes in performance on the current attention tasks.

In conclusion, we suggest that mindfulness may be more closely associated with changes in the quality of awareness of present moment experience than with basic attentional abilities. The current study found no effects of MBSR on attentional control, but changes in mindfulness were associated with changes in non-directed awareness of the present moment. These results conflict with recent reports of MBSR-related benefits on attention (Jha et al., 2007; Wenk-Sormaz, 2005). Future research may determine the extent to which factors such as the study population (meditation-naïve,

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DOI: 10.1002/cpp

experienced, clinical), the duration of MBSR, the duration of meditation prior to attention testing, the mindfulness self-report measure and the type of attention tests used account for these differences. However, our interpretation of the present results suggests that a different focus may also help illuminate the cognitive mechanisms of mindfulness. Kabat-Zinn (2003, p. 145) defined mindfulness as 'the *awareness* that emerges through paying attention on purpose . . .' [italics added]. The current study focused more on the effects of MBSR and mindfulness on attention than awareness. We recommend that future studies focus on evaluating the effects of mindfulness training on awareness of present moment experience.

ACKNOWLEDGEMENTS

We are grateful to Miriam Aziz and Trixie Reichardt for data collection and analysis and to Tom Buis for his help in analysing the TMS data. This work was supported by an operating grant from the Canadian Institutes of Health Research awarded to the last author when he was a scientist at Princess Margaret Hospital, University Health Network, Toronto, Ontario. Scott Bishop now has a private clinical practice. Mark Lau is now at BC Mental Health and Addiction Services in Vancouver, BC. Nicole Anderson is now at Baycrest in Toronto.

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