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Meditation, mindfulness and cognitive flexibility

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ABSTRACT

This study investigated the link between meditation, self-reported mindfulness and cognitive flexibility as well as other attentional functions. It compared a group of meditators experienced in mindfulness meditation with a meditation-naïve control group on measures of Stroop interference and the "d2-concentration and endurance test". Overall the results suggest that attentional performance and cognitive flexibility are positively related to meditation practice and levels of mindfulness. Meditators performed significantly better than non-meditators on all measures of attention. Furthermore, self-reported mindfulness was higher in meditators than non-meditators and correlations with all attention measures were of moderate to high strength. This pattern of results suggests that mindfulness is intimately linked to improvements of attentional functions and cognitive flexibility. The relevance of these findings for mental balance and well-being are discussed.

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1. Introduction

In recent years the interest in the effects of buddhist meditation practice has been growing rapidly (Barinaga, 2003; Ekman, Davidson, Ricard, & Wallace, 2005; Knight, 2004). In particular, the benefits of utilising meditation as therapeutic measure in the health care setting have been discussed and meditation-based interventions are increasingly being implemented adjunct or complementary to classical medical or psychological approaches. The most popular approach within this emerging field is probably the mindfulness-based stress reduction programme (MBSR) developed by Jon Kabat-Zinn in the early 1980s (e.g. Kabat-Zinn, 1984, 1990; Kabat-Zinn, Lipworth, & Burney, 1985). While the programme is rapidly gaining in popularity and has been subjected to numerous evaluation studies covering a variety of physical and psychological disorders, its effectiveness is not yet established beyond any doubt (Baer, 2003; Bishop, 2002; Grossman, Niemann, Schmidt, & Walach, 2004). Similarly, the mechanisms how meditation practice and improvement in mindfulness contribute to physical as well as psychological well-being are not well understood (Brown, Ryan, & Creswell, 2007; Malinowski, 2009).

An alternative perspective on buddhist meditation practice is concerned with cognitive, emotional and neurophysiological changes resulting from extensive meditation practice, where meditation is often conceptualised in terms of mental or cognitive training (e.g. Cahn & Polich, 2006; Carter et al., 2005; Slagter et al., 2007). Results are frequently discussed with respect to neuroplasticity, as several findings suggest that extended meditation training may lead to functional as well as structural changes of the brain (e.g. Davidson et al., 2003; Lazar et al., 2005; Lutz, Greischar, Rawlings, Ricard, & Davidson, 2004; Pagnoni & Cekic, 2007).

These two approaches provide different perspectives which contribute to a broader understanding of the processes and effects of meditation practice. In an attempt to align western psychological and buddhist thinking about this topic, Wallace and Shapiro (2006) provide a framework that facilitates the integration of such different perspectives. Drawing from

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buddhist sources as well as psychological theory and evidence they propose a four-component model, outlining areas for development that contribute to overall psychological well-being. According to their mental balance model the components *conation* (motivation, intention), *attention*, *cognition* and *affect/emotion* need to be developed and balanced to achieve profound well-being. In particular, though not exclusively, the components attention and cognition bear a close relationship to mindfulness (see Malinowski, 2009), which has been conceptualised in terms of *self-regulation of attention* and *orientation towards one's experiences* (Bishop et al., 2004). Also Kabat-Zinn's operational definition of mindfulness as "the awareness that emerges through paying attention on purpose, in the present moment, and non-judgmentally to the unfolding of experience moment by moment" (Kabat-Zinn, 2003, p. 145) acknowledges these two aspects. Thus, mindfulness meditation encompasses various aspects of attention as for instance the ability to focus and sustain ones attention and a reduced proneness to distraction. Cahn & Polich's definition of meditation as "practices that self-regulate the body and mind, thereby affecting mental events by engaging a specific attentional set" (Cahn & Polich, 2006, p. 180), also indicates that training of attentional functions is an essential aspect of any form of meditation practice. In a similar way traditional buddhist texts describe the practice of bare attention, the attending "to the bare facts of perception without reacting to them by deed, speech or mental comment", as a corner stone of mindfulness (Thera, 2005, p. 3). To cultivate mindful awareness, attention needs to be combined with a non-judgmental orientation towards and openness for the flow of one's experiences.

The aim of the current study is to investigate attentional functions and in particular cognitive flexibility within the theoretical framework outlined above. As Roemer and Orsillo (2003) argue, research that examines the effect of mindfulness on cognitive flexibility is currently lacking. Cognitive flexibility is here understood as the human ability to adapt cognitive processing strategies to face new and unexpected conditions and is intrinsically linked to attentional processes (Cañas, Quesada, Antolí, & Fajardo, 2003). As mindfulness meditation is dependant on the (re-)investment of attention on a moment by moment basis, mindfulness training should hypothetically lead to increased cognitive flexibility and an increased ability to respond in a non-habitual fashion.

In this study we are employing two well-established measures, the Stroop task (Stroop, 1935) and the d2-test of attention (Brickenkamp & Zilmer, 1998), to test participants' ability to suppress interfering information and to focus and direct their attention. As these skills are characteristic of good cognitive flexibility and are practiced during mindfulness training, individuals who practice mindfulness meditation should perform well on such tasks. Although recent research suggests a positive relation between meditative practice and attentional function (Jha, Krompinger, & Baime, 2007; Pagnoni & Cekic, 2007; Slagter et al., 2007; Valentine & Sweet, 1999), a clear link between mindfulness and cognitive flexibility still needs to be established. Only few studies attempted to do so by employing the Stroop paradigm. Wenk-Sormaz's (2005) showed that engaging in meditative practice resulted in a reduction of Stroop interference. However, a study by Anderson and co-workers failed to find an improvement of attentional functions after participation in an 8-week MBSR-programme as assessed by various measures of attention, attention switching and Stroop interference (Anderson, Lau, Segal, & Bishop, 2007). Thus, evidence for a relation between mindfulness and attentional functions remains ambiguous. An important difference between Anderson et al.'s (2007) study and that by Wenk-Sormaz (2005) is that the latter measured the effects of brief exposure to mindfulness meditation *immediately* after the end of the last of three 20 min meditation sessions, administered over the course of 2 weeks. In comparison, Anderson et al. investigated the effects of a more expansive mindfulness training (8-weeks) which usually also includes other aspects such as psychological education and physical exercises, and the tests took place up to 4 weeks after completion of the programme, preceded by a 10 min meditation session. A further difference between these studies is that Anderson et al. employed a modified version of the Stroop task, which originally was developed to assess the self-representation of clinical patients (Segal, Gemar, Truchon, Guirguis, & Horowitz, 1995) rather than the standard Stroop task employed by Wenk-Sormaz. Thus, not finding a reduction of Stroop interference in Anderson et al.'s study may be attributed to the fact that the employed task does not tap attentional functions per se but rather measures the interference of cognitive and affective content on behavioural responses. As in both studies the tests were carried out immediately following the experimental induction of mindfulness, one may, furthermore, argue that the findings only apply to this specific situation, whereas the ecologically more important question regarding changes that pertain to everyday life, were not addressed.

To sum up, the link between cognitive flexibility and mindfulness and its possible relevance for everyday life remains unclear.

Following these ideas, in our study we are comparing a group of meditators with experience in mindfulness meditation with a group of non-meditators on several tests of attention and assess them in a quiet experimental situation, but without inducing a meditative state or state of mindfulness. Furthermore, for estimating their levels of mindfulness, they are required to complete a mindfulness self-report questionnaire, the Kentucky Inventory of Mindfulness Skills (KIMS, Baer, Smith, & Allen, 2004). This approach allows us to compare between meditators and non-meditators and additionally to investigate the relation between mindfulness and cognitive control more closely.

The concurrent use of the d2-test of attention and the Stroop task enables us to test the ability to focus, sustain and direct ones attention and to suppress interfering information. As cognitive flexibility implies the ability to interrupt or deautomatise automated responses, that is to respond non-habitually, we shall briefly introduce the concepts of automatisation and deautomatisation in relation to meditative practice.

According to Shiffrin and Schneider (1977) cognitive processes can typically be classified as being either controlled or automatic. They suggested that automatic processes operate in parallel and independent of attention, "automatic [processes] do not require attention, though they may attract it if training is inappropriate, and they do not use up short-term memory capacity" (Shiffrin & Schneider, 1977, p. 38). Spelke, Hirst, and Neisser (1976) have also stressed that behaviour should only be termed ‘automatic’ if it did not involve certain high-order attentional skills. Additionally, Spelke et al. have shown that whilst certain processes may be thought of as innately automatic, others may become automatic through practice. It is generally accepted that once automated these processes are thought to be initiated unintentionally and effortlessly. Consequently they cannot be easily interrupted or prevented. Numerous researchers (for example Dyer, 1973; Virzi & Egeth, 1985) have proposed that reading is seen as an automatic process, acquired through extensive practice and long-term learning literate adults experienced. The Stroop effect (Stroop, 1935) evidences the difficulty of interrupting the automatic process of reading of words in proficient readers. During the Stroop task participants are asked to attend to the colour in which words are printed, not to the semantics of the words. Participant’s responses are significantly slower and less accurate when asked to identify the colour of an incongruent colour word compared with responses to neutral and congruent words (MacLeod, 1991). In line with Stroop’s account, theories most often explain the Stroop asymmetry as a consequence of automaticity (see Hasher & Zacks, 1979; LaBerge & Samuels, 1974; Logan, 1980). The automatic semantic activation of the word meaning must be overridden in order for participants to respond correctly when faced with incongruent words. As reading is automatic for proficient readers less attentional resources are required for reading irrelevant (neutral) words than for ink colour naming. Consequently, the reading of the word appears obligatory and results in an increase in reaction times and errors when attempting to process incongruent colour words. Increasing the performance in this task would therefore require the reinvestment of attention (deautomatisation) and a non-habitual response.

There is much debate as to whether processes that have become automatised can be brought back under top down control. In view of Shiffrin and Schneider’s (1977) suggestion that automatised processes act independently of attention, it has been proposed that deautomatisation is achieved through the reinvestment of attention in actions and behaviours (Deikman, 1963, 1966, 2000). Considering the definition of mindfulness as ‘‘bringing one’s complete attention to the present experience on a moment-to-moment basis” (Marlatt & Kristeller, 1999, p. 68), the potential link to processes of deautomatisation becomes obvious. If mindfulness-based meditation training improves the ability to invest one’s attention to the present moment, it should be possible to bring processes that became automatised by extensive practice back under cognitive control.

In the current study we thus expected to find a reduction in Stroop interference as well as improvement in focused attention and processing speed (as measure of sustained attention) in a group of buddhist meditators experienced in mindfulness meditation compared to a meditation-naïve control group.

We furthermore expected to find higher self-reported mindfulness in the meditation group and a positive correlation between mindfulness and the different measures of attentional performance and cognitive control. The KIMS consists of four sub-scales which allows breaking down mindfulness into several components (Baer et al., 2004). *Observing* (1) highlights the importance of observing and noticing the full variety of external and internal stimuli. As many forms of mindfulness training include the practice of naming and labelling of the observed phenomena (e.g. Thera, 2005), *describing* (2) captures the resulting ability to verbalise experiences. *Acting with awareness* (3) implies the ability to pay undivided attention to the activity one is carrying out (e.g. Hanh, 1987), without getting distracted. Finally, *accepting without judgment* (4) covers the aspect of being non-judgemental or non-evaluative about the present moment and thus implies the ability to refrain from automatic responses.

When investigating these sub-components of mindfulness, we expected that the two facets *acting with awareness* and *accepting without judgment* will exhibit the strongest correlations with task performance as these two facets most clearly capture the aspects of inhibition of irrelevant and distracting information as well as the deautomatisation of cognitive function.

2. Methods

2.1. Participants

The study used two groups, a meditation group and a matched meditation-naïve control group. Group one consisted of 25 buddhist meditators, who were recruited from a local buddhist centre, where meditation practices that particularly focus on mindfulness meditation are taught. Most of the buddhist participants were enrolled in intermediate classes and had at least completed a 6-week beginners course on meditation. The control group consisted of 25 non-meditators. The majority were recruited from a locally based, multinational credit management company and comprised of a wide spread of professions including telephone operatives, team leaders, IT technicians, finance workers, account managers, upper management and marketing executives. Some participants were also recruited from the local student population. The groups did not differ with respect to gender (12 males, 13 females in each group), age (range: 20–40 years, mean age buddhists: 28.0 years, controls 27.5 years, $p = .78$) and amount of sleep during the night before testing (buddhists: 8.0, control: 7.9 h, $p = .67$).

2.2. Material

We used the *Kentucky Inventory of Mindfulness Skills* (KIMS) to assess the level of mindfulness participants experienced (Baer et al., 2004). The KIMS consists of 39 Likert-scale items, 18 of which are reversely scored. This questionnaire asks the participants to rate the items with respect to ones *general* experience, rather than relating to a specific time point or period. Possible answers are ‘Never or very rarely true’, ‘Rarely true’, ‘Sometimes true’, ‘Often true’ and ‘Very often or always true’. High scores (1–5 for individual items) indicate high levels of mindfulness. The KIMS items are allocated to the four sub-scales *observing* (12 items), *describing* (8 items), *acting with awareness* (10 items) and *accepting without judgment* (9 items). The internal consistencies (Cronbach's Alpha) for these sub-scales have been reported as .91, .84, .83 and .87, respectively (Baer et al., 2004). The respective internal consistencies in the current study were .65, .49, .87 and .82.

As the meditators were tested in the meditation centre it was necessary to use paper–pencil tests to assess the different aspects of attentional performance.

To measure the degree of automatisation/deautomatisation we used a paper–pencil version of the *Stroop task*, created in accordance with guidelines based on empirical results (MacLeod, 1991). It was similar to the original version administered by Stroop (1935) with the addition of neutral words. The test material consists of six columns with 20 items in each (total items = 120). Each column contains an equal number of congruent and incongruent colour words interspersed with neutral colour words. Within each column the words are randomly distributed to avoid priming effects. Participants were assessed by calculating the number of items processed (TNP) during a 2 min time span and by calculating the number of errors committed (SE). To ensure that timing and administration of the test was appropriate, it was piloted with five participants.

To further assess attentional performance and flexibility we also administered the *d2-concentration and endurance test* (d2-test, Brickenkamp, 1962). The d2-test is a timed test of selective attention, which is used in many areas of psychology such as clinical, applied and educational psychology as well as neuropsychology. It allows for an estimation of individual attention and concentration performance as it measures processing speed, rule compliance, and quality of performance. The test is a timed paper–pencil test and has 14 rows each consisting of 47 items (total items = 658). The task is to discriminate and cancel through targets from visually similar non-targets. There are 16 different types of characters, each consisting of a letter "d" or "p" with one, two, three or four small quotation marks. The target is the letter "d" with two quotation marks (") that can appear either above, below or separated, with one mark (') appearing above and the other mark below. The letter "d" accompanied by one, three, or four quotation marks and the letter "p" regardless of the number of quotation marks (1–4) are the distractors. The participant is instructed by the experimenter to stop working on the current row and continue with the next row every 20 s (for a test description also see Spreen & Strauss, 1997).

There are two types of errors that may occur, errors of omission (E1) and errors of commission (E2). Errors of omission occur when targets are not crossed out. E1 is a common mistake and is sensitive to attentional control, rule compliance, accuracy of visual scanning and quality of performance. E2 is a less common error and is associated with inhibitory control, rule compliance, accuracy of visual scanning, carefulness and cognitive flexibility. Numerous measures of performance can be derived from the d2-test. As this study is concerned with cognitive flexibility and inhibitory control only the scores that reflect these constructs will be presented. The raw score E is the sum of all mistakes. This will be presented to illustrate the total errors made by participants. TN − *E* is the total number of items scanned minus error scores (E1 + E2). It provides a measure of attentional and inhibitory control. Finally CP (concentration performance) is derived from the number of correctly cancelled out targets (NC) minus E2. CP provides an index of the coordination of speed and accuracy of performance. It is also being used to guard against superficial scanning. The internal reliability of the d2-test is >.90 and the scores for TN − *E* and CP are in general very highly correlated (mean $r = .93$) as may be expected (Brickenkamp & Zilmer, 1998). Furthermore previous research has shown that the Stroop-test correlates significantly with the TN − *E* ($r = .34$) and CP ($r = .34$) scores of the d2-test (Brickenkamp & Zilmer, 1998).

For an overview of the main measures used in the study refer to Table 1.

2.3. Design and procedure

To examine the relation between mindfulness and attentional performance a correlational approach was employed. The variables that were analysed were the total score on the KIMS, the individual scores for each of the four facets of mindfulness,

Table 1
Overview and brief description of the main measures used in this study.

Label used	Description
Mindfulness scale	
KIMS-total	Overall mindfulness score
KIMS-observe	Subscale "*observe*", paying careful attention to external and internal phenomena and stimuli
KIMS-describe	Subscale "*describe*", the process of labelling the phenomena appearing to ones awareness
KIMS-aware	Subscale "*act with awareness*", engaging one's full attention into a current activity instead of working on 'auto-pilot'
KIMS-accept	Subscale "*accept without judgment*", being non-evaluative about ones current experiences
Stroop-test	
TNP	Total number of items processed
SE	Number of errors committed
d2-test	
TN	Total number of items scanned
E1	Errors of omission (misses)
E2	Errors of commission (false alarms)
E	Total number of errors (E1 + E2)
TN − *E*	Total number of items processed minus number of errors (TN − *E*)
CP	Concentration performance; the number of correctly cancelled out targets minus the number of commission errors (E2)

two scores for Stroop performance (TNP and SE), six scores for performance on the d2-test (TN, E, E1, E2, TN − *E* and CP) as well as age and hours of sleep.

Differences between meditation and control group were tested by means of independent samples *t*-tests for each of the aforementioned variables.

To explore the predictive power of mindfulness on cognitive performance regression analyses were carried out with TN, E, E1, E2, TN − *E*, CP, SE and TNP entered in turn as outcome variables and the four facets of mindfulness entered as predictor variables.

To control for the possible influence of tiredness participants were requested to note the amount of hours of sleep they had the previous night. As stated above, a *t*-test revealed no significant differences between-groups and no significant correlations were found between hours of sleep and task performance (see Table 2).

The meditators were asked to participate in the study prior to any planned meditation session to ensure they completed testing in a similar cognitive state to the non-meditators. Their testing was carried out in a quiet room at the buddhist centre. The non-meditators who worked at a credit management company were tested in a quiet, noise-free office at the workplace. To control for possible work-related stressors testing took place on days when they were off work. Students were tested under similar conditions in a quiet laboratory in the psychology department. All participants were given plenty of time to get settled and relaxed prior to taking the tests.

Participants were requested to use any necessary visual aids (i.e. glasses, contact lenses). All of them first completed the KIMS, which was given to groups of 2–6 participants at a time. To ensure each item was carefully considered participants were advised they had an unlimited amount of time to complete the questionnaire. Following this, half of each group carried out the d2-test first, followed by the Stroop task. For the remaining participants this order was reversed.

The d2-test was also administered in groups (ranging from 2 to 6). Participants received a recording blank with the front page on top and a pencil without an eraser. Participants were instructed as per the instructions stipulated for adult use in the d2-test of attention manual (Brickenkamp & Zilmer, 1998, pp. 7–8). At the beginning participants were required to complete a practice line to ensure they fully understood the instructions. The recording blanks were then turned over and testing began. Every 20 s participants were requested to move to the next line.

The Stroop task was administered individually. Prior to testing participants were given instructions on how to complete the test. Participants were requested to read down the lines one item at a time and speak aloud the colour of the word. They were then allowed to complete a short 10 item practice column which was used to ensure participants understood the instructions they were given. Testing began once participants had confirmed they understood what was expected of them. Participants were advised to proceed as quickly as they could although they were not advised there was a time limit. This was to avoid superficial scanning that could increase errors. Errors were recorded on a separate sheet by the experimenter. Participants were allowed to complete the page although after 2 min no further errors were noted and the total number of items processed up to that point was recorded.

The study was approved by the School of Psychology Research Ethics Panel at Liverpool John Moores University and adhered to the ethical guidelines of the British Psychological Society.

3. Results

As can be seen in Table 2, KIMS total scores were significantly correlated with each of the examined variables (also see Fig. 1 for the most important correlations). Positive correlations were found with the d2-scores TN ($r = .510$, $p < .001$), TN − *E* ($r = .620$, $p < .01$), CP ($r = .667$, $p < .01$) and the Stroop-score TNP ($r = .331$, $p < .05$). This indicates that high levels of mindfulness are correlated with high processing speed, good attentional and inhibitory control, and a good coordination of speed

Table 2
Correlation matrix including all correlations between all KIMS scores (total and sub-scales) with all measures of attentional performance. As control, also the correlations with age and sleep are included. For abbreviations refer to Table 1.

Variables	KIMS				d2-Test						Stroop-test			
	Observe	Describe	Aware	Accept	TN	E	E1	E2	TN − *E*	CP	TNP	SE	Age	Sleep
KIMS														
Total	.846***	.815***	.943***	.912***	.510***	−.527***	−.493***	−.398**	.620***	.667***	.331*	−.780***	−.200	.030
Observe	–	.609***	.701***	.688***	.393**	−.379**	−.329**	−.378**	.469***	.482***	.249	−.663***	−.192	.016
Describe	–	–	.725***	.642***	.373**	−.413**	−.416***	−.202	.461**	.505***	.180	−.638***	−.170	.087
Aware	–	–	–	.841***	.515***	−.498***	−.479***	−.318*	−.615***	.657***	.331*	−.756***	−.170	.054
Accept	–	–	–	–	.487***	−.550***	−.501***	−.478***	.606***	.674***	.367**	−.683***	−.180	−.038
Age	–	–	–	–	−.186	.025	−.006	.063	−.175	−.112	−.141	.054	–	–
Sleep	–	–	–	–	.107	−.102	−.128	.104	.127	.140	.146	.106	–	–

To account for the multiple comparisons that were carried out and control for family-wise error rates, all effects that do not reach the $p < .01$ significance level should be treated with care as they may be spurious.
* $p < .05$.
** $p < .01$.
*** $p < .001$.

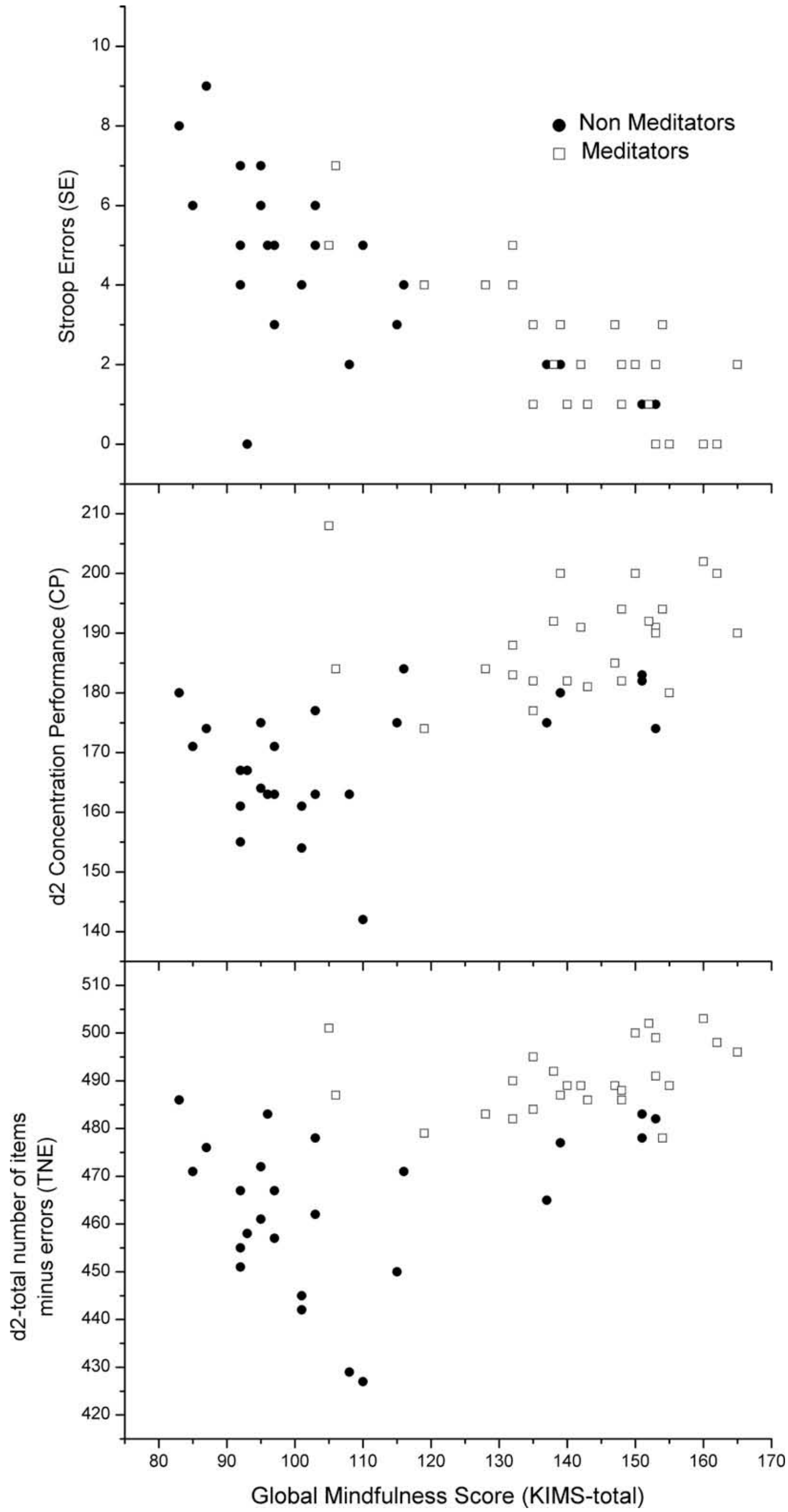

Fig. 1. Scatter graphs illustrating the correlations between the total mindfulness score (KIMS-total) and Stroop errors (top), d2 Concentration Performance (Centre) and d2 total numbers of items processed minus errors (bottom). Control group (non-meditators) values are printed as black circles, meditator values are printed as white squares.

with concurrent accurate performance. Negative correlations were found with the d2-errors E ($r = -.527$, $p < .001$), E1 ($r = -.493$, $p < .001$), E2 ($r = -.398$, $p < .01$) and the Stroop error SE ($r = -.780$, $p < .001$), signifying that higher levels of mindfulness are linked to reduced errors across measures, suggesting greater attentional control, accuracy of visual scanning, inhibitory control, carefulness, cognitive flexibility and quality of performance. These results support the hypothesis that mindfulness would correlate positively with task performance. It is important to note that all of the SE occurred whilst participants were attempting to read the colour of incongruent colour words. Thus, SE may be said to result from a failure to deautomatise.

The same pattern is found when examining each of the four mindfulness facets separately. Each of the four facets retain significant positive correlations with TN, TN − *E*, CP and TNP and negative correlations with E, E1, E2 and SE with a few minor exceptions. It was specifically hypothesised that the acting with awareness and accepting without judgment facets of mindfulness would have the strongest correlations with task performance. As can be seen in Table 2 this hypothesis is also supported as these facets showed the highest correlations with each of the variables.

Several *t*-tests were conducted in order to examine inter-group differences. These results are detailed in Table 3. Significant between-group differences were found for all dependent variables ($p < .01$ or lower), confirming our expectation to find higher levels of self-reported mindfulness as well as better attentional performance and thus cognitive flexibility on all measures. As the scatter graphs in Fig. 1 also distinguish between meditators and non-meditators they provide a further illustration of these differences.

Regression analyses were carried out to assess the combined predictive power of the mindfulness facets. As the high inter-correlations of these mindfulness sub-scales already suggest, in most cases regression models with only one significant factor emerged, highlighting the multicollinearity of the sub-scales. Obviously, the significant factor always was the one correlating highest with the predicted variable (see Table 2). The only exception to this pattern was that Stroop errors (SE) were best predicted by a 2-factor solution including the factors KIMS-aware (standardised beta: −.57 $p < .001$) and KIMS-observe (standardised beta, −.26, $p < .05$) and an adjusted explained variance $R^2 = .59$ ($p < .001$).

Finally, we calculated the inter-correlations between the mindfulness sub-scales separately for the meditation and the control group. As can be seen in Table 4, these inter-correlations tended to be higher for the non-meditators than for the meditators. Comparing them to inter-scale correlations reported previously (Baer, Smith, Hopkins, Krietemeyer, & Toney, 2006; Baer et al. 2004) it turns out that particularly the inter-scale correlations for the control group were higher than previously reported.

4. Discussion

This investigation into the link between meditation, self-reported mindfulness and cognitive flexibility overall suggests that attentional performance and cognitive flexibility are positively related to meditation practice and levels of mindfulness. Meditators performed significantly better than non-meditators on all measures of attention. Furthermore, self-reported mindfulness was higher in meditators than non-meditators and correlations with all attention measures were of moderate to high strength. This pattern of results indicates that mindfulness is intimately linked to improvements of attentional functions and cognitive flexibility.

The finding of decreased Stroop interference in meditators furthermore implies that – as assumed by Deikman (1963, 1966, 2000) – cognitive processes that became automatised can be brought back under cognitive control and previously

Table 3
Outcome of between-group *t*-tests and mean group differences for all dependent measures; standard deviations in brackets.

	t-value	Sig. level	Non-meditators Mean	Meditators Mean
Mindfulness scale				
KIMS-total	6.40	<.001	107.7 (21.5)	141.6 (15.5)
KIMS-observe	3.99	<.001	31.0 (5.9)	37.7 (6.0)
KIMS-describe	2.98	<.01	22.2 (5.3)	26.2 (4.0)
KIMS-aware	6.70	<.001	28.1 (7.4)	40.6 (5.7)
KIMS-accept	7.32	<.001	26.4 (5.9)	37.2 (4.4)
Stroop-test				
TNP[a]	3.92	<.001	91.9 (7.4)	98.5 (4.1)
SE	3.18	<.01	4.2 (2.3)	2.3 (1.8)
d2-Test				
TN[a]	5.68	<.001	480.3 (16.7)	501.1 (7.3)
E	4.47	<.001	16.6 (4.5)	10.6 (5.0)
E1	3.60	<.01	13.6 (4.3)	9.1 (4.5)
E2	5.03	<.001	3.0 (1.3)	1.4 (1.0)
TN − *E*[a]	7.53	<.001	463.7 (16.3)	490.5 (7.1)
CP	7.54	<.001	169.0 (10.2)	189.0 (8.5)

All degrees of freedom are 48, except for ‘a’, where due to unequal variances degrees of freedom were adjusted. To account for the multiple comparisons that were carried out and control for family-wise error rates, all effects that do not reach the $p < .005$ significance level should be treated with care as they may be spurious.

Table 4
Inter-correlations between mindfulness skills split by group and the inter-correlations reported by Baer et al. (2004, 2006).

	KIMS-describe	KIMS-aware	KIMS-accept
Control group			
KIMS-observe	.68***	.66***	.57**
KIMS-describe	–	.81***	.67***
KIMS-aware	–	–	.71***
Meditation group			
KIMS-observe	.32	.46*	.53**
KIMS-describe	–	.46*	.35
KIMS-aware	–	–	.63**
Baer et al. (2004)			
KIMS-observe	.22**	.09	−.14**
KIMS-describe		.26**	.34**
KIMS-aware			.29**
Baer et al. (2006)			
KIMS-observe	.26**	.15**	−.07
KIMS-describe	–	.30**	.21**
KIMS-aware	–	–	.34**

* $p < .05$.
** $p < .01$.
*** $p < .001$.

automatic responses can be interrupted or inhibited. While these results are in line with the outcome of Wenk-Sormaz's (2005) study they are at odds with those from Anderson et al. (2007), who failed to find effects of meditation/mindfulness training on attentional performance. Anderson and colleagues also included the Toronto Mindfulness Scale (TMS, Bishop et al., 2003, cited in Anderson et al., 2007), another self-report measure of mindfulness, in their study. Unfortunately, they do not report correlations between mindfulness and measures of attentional performance (esp. Stroop interference), which could have provided some further, valuable information regarding its link to mindfulness. But as they employed an unusual version of the Stroop task, it is difficult to directly relate the findings to each other. Jha et al. (2007) used the Attention Network Test, which assesses several sub-components of an assumed attentional network (Fan, McCandliss, Sommer, Raz, & Posner, 2002) and found that an experienced meditation group differed from a meditation-naïve control group in their susceptibility to distraction, a task that bears some similarities to the Stroop task as in both tasks potentially interfering information needs to be inhibited. Interestingly, in the experienced meditation group mindfulness training did not increase this ability more than in a control group that did not take part in any training. Alexander and co-workers (Alexander, Langer, Newman, & Chandler, 1989) reported that reduced Stroop interference is also linked to a quite different form of meditation, Transcendental Meditation (TM), which was brought to the West by Maharishi Mahesh Yogi (e.g. Dillbeck & Orme-Johnson, 1987; Maharishi, 1969). In addition to investigating TM they also included a method of inducing a mindful cognitive state, and found a similar reduction in Stroop interference. However, their operationalisation of mindfulness was derived from a discourse within social psychology (Langer, 1992; Langer & Moldoveanu, 2000), where a mindful/mindless distinction is discussed in relation to cognitive functioning and the amount of reliance on cognitive categories drawn up in the past. Using a guided attention technique, the applied mindfulness intervention did not involve meditation exercises. Coming from yet another direction, Raz and collaborators showed a reduction of Stroop interference as a result of a posthypnotic suggestion in highly hypnotisable participants (Raz, Moreno-Iniguez, Martin, & Zhu, 2007). However, as there are fundamental differences between meditation, mindfulness and hypnosis such findings can merely be understood as providing further evidence that Stroop interference can be overcome.

The ability to focus attention and to sustain this focus over time was particularly assessed by the total number of items processed in the Stroop task (TNP) as well as in the d2-test (TN), combined with the total number of correct items processed in the d2-test ($TN - E$). In both tests meditators performed significantly better than the control group (Table 3). As the d2-test is geared towards measuring processing speed while in the Stroop task this is of only subordinate relevance, a more pronounced correlation of mindfulness with TN and $TN - E$ ($r = .51$ and .62, respectively) than with TNP ($r = .33$) is in keeping with what would have been expected. Several studies into the link between meditation and attention are in line with our findings. Valentine and Sweet (1999) reported that mindfulness meditators and concentrative meditators performed better on an auditory sustained attention task than a control group. Pagnoni and Cekic (2007) used a rapid visual presentation task to investigate age-related effects of meditation practice in buddhist meditators (Zen), linking them to cerebral grey matter volume. While in their meditation-naïve control group an age-related decrease of attentional performance was observed, no such decrease was present in meditators. Even more, estimations of grey matter volume confirmed a normal age-related decline in the control group, whereas no significant decline was found in the Zen meditators. For the putamen, a subcortical brain structure implicated in temporal aspects of attentional processing (Coull, Walsh, Frith, & Nobre, 2003), a positive correlation between attentional performance and grey matter volume was detected. These findings corroborate data from a study indicating less age-related decrease in cortical thickness in prefrontal areas of the brain that are involved in attentional processing in a group of buddhist meditators compared to non-meditators (Lazar et al., 2005). Although such cross-sectional studies have to be treated with care and the evidence-base is still limited, these data suggest possible neuroprotective effects of buddhist meditation practice. Realising a longitudinal test–retest design Slagter et al. (2007) used electroencephalography (EEG) to investigate the effects of three months of intensive meditation training on the distribution of attentional resources. The attentional blink paradigm they employed highlights the processing limitations of the human visual system. It denotes the effect that, within a sequence of rapidly changing stimuli, a second target stimulus tends to be missed, if it appears within a time frame of 500 ms after a first target (Shapiro, Arnell, & Raymond, 1997; Ward, Duncan, & Shapiro, 1996). This deficit is assumed to result from competition between the two targets for limited processing resources. After three months of meditation training participants showed a significant reduction in the size of the attentional blink, compared to a matched control group, indicated by increased detection rates when the second target followed the first target within the time window of the attentional blink. The analysis of the EEG-data furthermore suggests that the improvement in performance results from the fact that less resources were allocated to the first target, providing more processing resources for detecting the subsequent target.

Thus, a number of recent studies corroborate our finding that meditation practice and increased mindfulness are related to improved attentional functions and cognitive flexibility. Some of these studies furthermore contribute evidence that these observed changes may be reflected in structural as well as functional changes of the brain.

A further intention of this study was to investigate the influence of the various facets of mindfulness. The regression analyses we carried out revealed that our central measure of cognitive flexibility (SE) was best predicted by the combined influence of the two factors *acting with awareness* and *observing*, explaining about 60% of variance. All other measures of attentional performance were best predicted by only one facet of the KIMS. To investigate this aspect further, we scrutinised the unusually high inter-correlations of the KIMS sub-scales (Table 2) by analysing them separately for the meditation and the control group. As Table 4 illustrates, inter-scale correlations for the control group are higher than those in the meditation group, some of which were not significant. A possible explanation for this pattern could be that without any exposure to mindfulness training participants may lack the awareness to distinguish between the different mindfulness skills. Furthermore, especially the inter-correlations within our control group where much higher than those reported previously by Baer et al. (2004, 2006). One needs to be careful, though, when interpreting correlational data based on such sample sizes (25 per group), where individual data points may exhibit a disproportional influence. In comparison, the sample sizes in Baer et al. (2004, 2006) were much larger (445 and 615, respectively) and did not specifically test meditators (mainly undergraduate students). Furthermore, Baer et al. (2006) did not use the pure KIMS-scale but included items from other mindfulness scales to calculate the different sub-scale scores.

5. Conclusions

The finding that regaining or increasing attentional control and cognitive flexibility seems possible may have further implications beyond the domain of cognitive psychology. Within Wallace and Shapiro's (2006) mental balance model, attentional and cognitive balance play an important role in promoting well-being. They make the case that meditation training and the cultivation of mindfulness improve these aspects of mental balance and in conjunction with conative and affective balance contribute to overall well-being of the individual. While in our study we did not assess levels of well-being, our data corroborate their model in so far as they show a clear positive link between meditation, mindfulness and attentional/cognitive flexibility. Meditators showed higher levels of mindfulness, better attentional performance and higher cognitive flexibility. Attentional performance as well as cognitive flexibility were positively related to levels of mindfulness. As Wallace and Shapiro outline, according to buddhist principles of mental training and well-being, cognitive flexibility can be fostered by building on improved attentional abilities, which are initially trained and cultivated. The gained cognitive flexibility provides the mental space to detect incorrect and unwholesome cognitive evaluations, which would usually go unnoticed and would lead to mistaken attitudes and emotions, which in turn would affect our well-being (see also Malinowski, 2009). While empirical evidence for a direct link between well-being and cognitive performance is currently sparse, a recent representative study of a population above 50 years of age reported that "higher levels of psychological well-being were associated with better global cognitive function and performance in multiple cognitive domains" (Llewellyn, Lang, Langa, & Huppert, 2008, p. 688). More extensive studies will have to scrutinise whether the hypothesised link between mindfulness and well-being can be confirmed empirically. As the assumed mechanism, outlined above, is implied in a variety of mindfulness-based therapeutic interventions, as for instance the mindfulness-based cognitive therapy (Teasdale, Segal, & Williams, 1995), such studies may have far-reaching relevance. The current study indicates how mindfulness, attentional performance and cognitive flexibility may usefully be assessed.

Based on our own data, we may tentatively conclude that meditation practices that improve mindfulness skills will have a positive effect on cognitive flexibility and the ability to focus and sustain attention. This conclusion has to be provisional, though, as a cross-sectional design without experimental manipulation of meditation practice, cannot provide conclusive data as to how causality runs. Cross-sectional results like ours may have been affected by a self-selection bias. We cannot completely rule out that the meditators in our study possess better cognitive and attentional abilities independently of their engagement with meditation. It may be that because of their abilities they experience meditation practice as rewarding and keep involved while people with less developed cognitive and attentional abilities may not do so. Furthermore, motivational differences may have contributed to the group effects we found. It could be that the buddhist meditators were especially motivated to perform well in the tests; their alertness and attentional focus may have been heightened by their wish to prove that the time and energy they invested in meditation was worth the while. While ultimately only longitudinal studies with experimental manipulation of meditation and/or mindfulness will be able to fully resolve these uncertainties, the fact that we found significant linear relations between mindfulness and attentional performance and cognitive flexibility suggests that our findings not merely reflect a selection bias or motivational differences. This is even more relevant as the correlations between cognitive flexibility (SE) and overall mindfulness (KIMS-total) remained significant also within each group (non-meditators: $r = -.71$, $p < .001$; meditators: $r = -.80$, $p < .001$), highlighting a general link between mindfulness and cognitive flexibility independent of meditation practice. It seems unlikely that, while there is a relation between cognitive flexibility and naturally occurring mindfulness, the systematic development of mindfulness would not lead to an enhancement of cognitive flexibility.

Thus, this study indicates that, as hypothesised, meditation and mindfulness training may improve attentional performance, in particular with respect to processing speed, susceptibility to interference and cognitive flexibility. The results make a strong case for further investigating the underlying processes in a longitudinal study with experimental manipulation of meditation practice.

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