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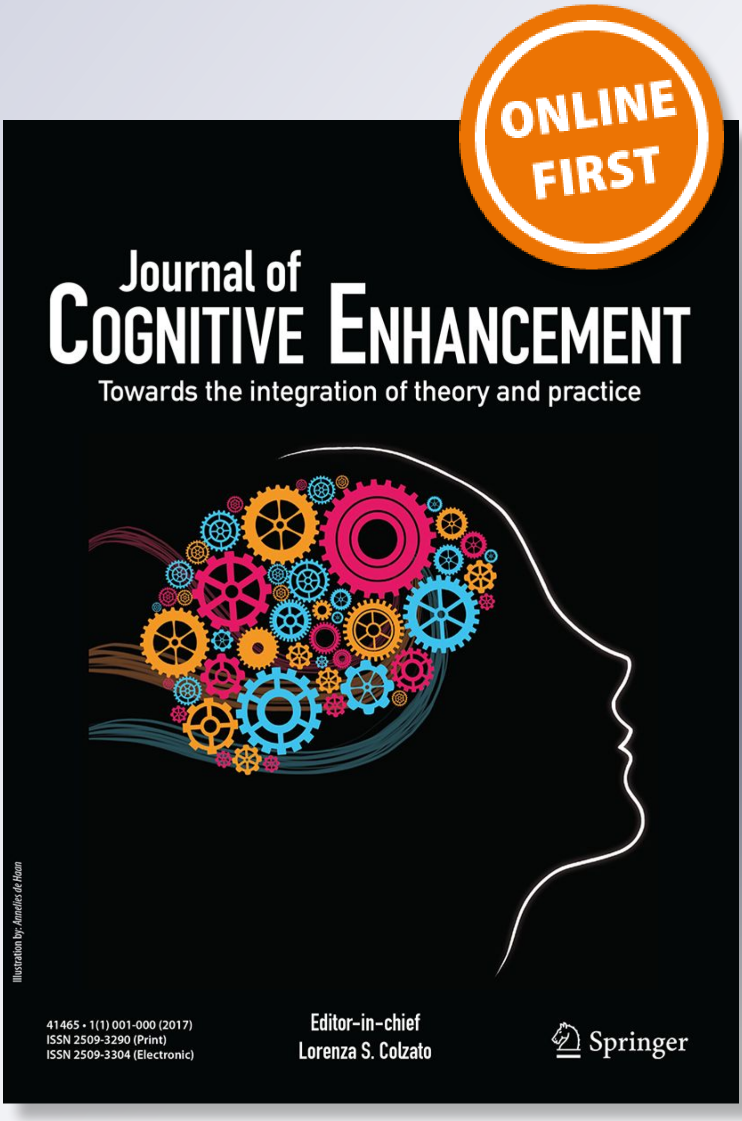

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ORIGINAL ARTICLE

Meditation, Cognitive Flexibility and Well-Being

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Abstract A number of previous studies have suggested that mindfulness meditation can enhance cognitive performance. Although both western empirical findings and Buddhist psychological theory have emphasised a role for cognitive flexibility in the development and maintenance of mental health, few studies have specifically focused on flexibility in relation to mindfulness. The present study used a range of objective, behavioural measures to assess cognitive flexibility in 41 individuals before and after a 6-day intensive Vipassana (mindfulness) retreat. Subjective assessments of mindfulness, positive functioning and well-being were also taken. A comparably sized control group of students and government employees was given the same pre- and post-test measures. In contrast to our expectations and to previous reports, there were no significant changes in cognitive performance, over and above practice-related improvements also shown by the control group. Retreat participants did, however, register positive improvements on the subjective measures. We discuss possible limitations with our experimental design and highlight important issues that may assist future studies aiming to assess effects of mindfulness in the cognitive domain.

Keywords Mindfulness · Meditation · Vipassana · Cognitive flexibility · Cognitive functioning · Stroop · Attention · Well-being

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Introduction

In recent years, scientific interest in mindfulness meditation has grown exponentially. Mindfulness meditation derives from a Buddhist meditation practice and was developed as a stress coping strategy in the 1980s (Kabat-Zinn 1982, 1990). Numerable clinical programmes are currently based in mindfulness meditation practice (see e.g. mindfulness-based cognitive therapy (MBCT); Segal et al. 2002; Dialectical Behavioral Therapy (DBT); Linehan 1993, Acceptance and Commitment Therapy (ACT); Hayes et al. 1999), also called mindfulness-based interventions (MBIs). In traditional Buddhist contexts, mindfulness meditation is intended to increase awareness, tranquillity, insight, compassion and equanimity so that mental suffering is reduced and overcome (see e.g. Buddhagosa 1975; Debordes et al. 2015; Goldstein 2002; Wallace and Shapiro 2006). Accumulating evidence suggests positive effects of mindfulness meditation on attentional processes and emotion regulation (see e.g. Chambers et al. 2008; Chambers et al. 2009; Jha et al. 2007; Kabat-Zinn 2003; Lutz et al. 2014; Valentine and Sweet 1999), cognitive flexibility (Moore and Malinowski 2009; Moore et al. 2012), memory performance (Jha et al. 2010; Mrazek et al. 2013; Tang et al. 2007; Zeidan et al. 2010) and general well-being (e.g. Wallace and Shapiro 2006; Carmody and Baer 2008; Grossman et al. 2008; Chiesa and Serretti 2009; Williams et al. 2014).

The increase in scientific interest in mindfulness practice is mostly fuelled by its promising clinical potentials, thus focusing on its effects relative to other 'treatments', or tapping into (neuro) cognitive behavioural correlates of *dispositional* mindfulness relative to behavioural functioning. As to the underlying processes of mindfulness meditation, theories on meditation are becoming more specific, but further research needs to specify the exact cognitive and neurobiological processes by which its putative beneficial effects are mediated

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(Brown et al. 2007; Moore and Malinowski 2009). Identifying the mediating processes of mindfulness practice has been slowed down by the absence of an unequivocal definition and operationalisation (see e.g. Chiesa 2013; Lutz et al. 2015). This lack of definition has also given rise to a diversity in protocol and practice that makes up the body of literature.

This state of affairs almost certainly reflects the novelty of this field of research, but it also mirrors the complex interplay of the various cognitive, emotional and behavioural processes that cross several disciplines of Western science. Scholars and scientists in the field have called for an integration of Buddhist psychology in Western scientific frameworks, to better understand the processes involved in mindfulness meditation (e.g. Grossman 2011; Kabat-zinn 2003). The coherence and consistency of the body of literature that is lending support to the claim that mindfulness has beneficial effects on cognition, brain and behaviour have been questioned because of methodological limitations related to the foregoing (see e.g. Sedlmeier et al. 2012; Chiesa 2013; Grossman 2008; Goyal et al. 2014 for critical reviews). Meanwhile, mindfulness meditation is increasingly used as a basis for clinical programs. It thus seems relevant to further identify and understand cognitive and neurobiological processes that underpin mindfulness meditation, while applying a broad inclusive theoretical framework.

Mindfulness and Attentional Processing

Mindfulness meditation can be described by two components: (1) *self-regulation of attention*, directed towards the present moment experience of bodily and mental sensations; and (2) engaging *an inner stance* of curiosity, openness and acceptance towards that experience (Bishop et al. 2004). Thus, mindfulness meditation entails *sustained attention*—being able to maintain awareness over longer time frames (Posner and Rothart 1992) of 'the present moment', *inhibition*—being able to lessen the interference of secondary processing of thought, feelings, and sensations that co-arise in response to the stimulus or spontaneously in the present moment, and *flexibility*—being able to shift attention from one engagement to another (Posner and Peterson 1990) and from a mind-wandering, distracted state, back to the present moment (Bishop et al. 2004). Mindfulness meditation training thus implies strategic use of attentional resources and subsequently enhanced cognitive processing in areas that are mediated by attentional constraints.

Accordingly, mindfulness meditation training is increasingly reported to be associated with improved attention-related cognitive processes (Chiesa et al. 2011), including memory (Jha et al. 2007; Brown et al. 2016; Raffone and Pantani 2010), sustained attention (Lutz et al. 2009; MacLean et al. 2010, Jha et al. 2007; Valentine and Sweet 1999) and conflict monitoring (Jha et al. 2007; Tang et al. 2007). Interestingly, such positive changes in attention-related cognitive processes were even observed after relatively short, but intensive retreats of 4 (Zeidan et al. 2010) or 8 days (Chambers et al. 2008). Optimised strategic use of attentional recourses in relation to mindfulness meditation practice was remarkably illustrated by a decreased 'attentional blink' (AB) deficit following a 3 months intensive Vipassana (mindfulness) retreat (Slagter et al. 2007). The AB deficit refers to the phenomenon that a second visual stimulus presented within 500 ms after a first goes unnoticed by the observer. Such an effect is thought to relate to the refractory period needed to recover depleted attentional resources. The reported decreased AB deficit correlated with decreased allocation of brain resources to the first stimulus, suggesting a more efficient organisation of attention allocation in serial presented stimuli. The decrease in the AB effect was attributed to reduced distracter interference (mental noise), i.e. more attentional resources remain available to current moment incoming stimuli (Slagter et al. 2007).

Mindfulness Meditation, Cognitive Flexibility and Mental Health

Because attention is a central component of mindfulness practice, most research thus far has focused on attention-related cognitive processes. However, a recent neuropsychological review points into the direction of flexibility of cognition (Lao et al. 2016). Since emotion regulation requires continuous attention, the improvement of attentional abilities has been suggested to play a role in the reported positive changes in the emotional domain (e.g. Wallace and Shapiro 2006; Carmody and Baer 2008; Jha et al. 2010; Moore et al. 2012). More specifically, attending to diverse and ambiguous incoming sensory data requires flexibility and inhibition of automatised predictive processing of perception (see e.g. Baer et al. 2008; Bishop et al. 2004; Kabat-zinn 1990). In this context, cognitive flexibility is defined as the ability to adapt cognitive strategies in response to new and unexpected conditions, and as intimately related to the (re-)investment of attention (Cañas et al. 2003).

Relying on attentional processes, flexibility has thus recently been proposed to play a mediating role in the psychological effects of mindfulness meditation (Moore and Malinowski 2009; Moore et al. 2012). Independently, cognitive flexibility has been connected to healthy mental functioning and emotional well-being (Wallace and Shapiro 2006; Moore and Malinowski 2009; Moore et al. 2012; Barendregt and Raffone forthcoming), and serves as an indicator of healthy cognitive functioning. Measures of cognitive flexibility, such as task switching (see e.g. Couyoumdjian et al. 2010; Hiesh 2012) and Stroop interference (Stroop 1935), are typically used to assess cognitive decline in older adults and cognitive development in young children (Deák 2003). Moreover, a lack of cognitive flexibility or 'mental rigidity' is identified as a feature of a great variety of mental disorders (DSM V, Kashdan and Rottenberg 2010). Importantly, lack of cognitive flexibility has been reported to be reduced by mindfulness training (Greenberg et al. 2012). Kashdan and Rottenberg (2010) thus proposed cognitive flexibility as the cornerstone for mental health. They argue that flexibility, before any other static concept related to mental health, is crucial to meet and adapt to the changes and challenges of everyday life, making it possible to stay mentally healthy and balanced (Kashdan and Rottenberg 2010).

Interestingly, the notion of cognitive flexibility, translated into mental flexibility, resilience or 'agile-ness' is endorsed as an outcome of mindfulness practice from a Buddhist perspective and recognised as constituent for mental balance (Buddhaghosa 1975; Wallace and Shapiro 2006; Barendregt 2011). Buddhist philosophy, the origins of the secular mindfulness movement, emphasises our struggle in navigating the ever changing world around us and inside of us (impermanence) as the root of suffering. The practice of mindfulness is thus propagated for its cultivation of equanimity and mental flexibility in response to the ever changing influx of experience. As such, it is seen as crucial to the reduction of suffering and sustaining mental health (Buddhaghosa 1975; Barendregt 2011; Debordes et al. 2015; Wallace and Shapiro 2006). Since mindfulness relies on continuously paying attention to moment-to-moment experience of incoming stimuli, an increase of mindfulness should promote less reliance on habitual responses and foster flexibility (Moore and Malinowski 2009).

Aim of the Current Study

The aim of the current study was to help clarify the nature of the cognitive processes that might underpin the putative beneficial effects of mindfulness meditation. To do this, we collected a battery of behavioural tasks, based on standard cognitive measures and applied them in the context of a mindfulness retreat (Vipassana). More specifically, data from behavioural measures, as well as self-report measures of well-being and mindfulness, were collected at the beginning and end of a 6-day mindfulness retreat (Vipassana), using a quasi-experimental design. Our question was whether we could measure objective and subjective changes related to the investment of attention, cognitive flexibility, levels of mindfulness and well-being following rigorous training of mindfulness meditation (Vipassana retreat). In addition, the use of a novel range of tasks and their implementation as mobile applications hopefully makes a useful methodological contribution to the field.

The performance of the meditators was compared to a training-naïve control group that was not specifically matched for age. The purpose of this comparison was to establish an estimate of the performance advantages that might be observed as simple practice effects. Participants in the control group were not required to perform any tasks during the 6 days pre-post-test interval. In spite of the quasi experimental design of the study, we believe that it is informative to explicitly compare performance in the meditation and control groups—as we do in the following sections—but clearly, some caution will be needed in interpreting the results. In the 'Discussion' section, we provide further details of possible limitations in this regard.

Methods

Participants

Data was collected from two samples of participants: the meditation group (N = 40), aged from 25 to 80 years (16 males, M = 48.9 years, SD = 12.9), and the control (N = 30), aged from 18 to 61 years (6 males, M = 28.5 years, SD = 13.5). Participants of the meditation group were recruited directly from the Vipassana retreat. The control group was recruited through the student's network of the Department of Cognitive Science at the University of Malta and through the network of government employees of the city of Amsterdam. All participants had normal or corrected to normal vision and provided written informed consent prior to data collection. As the two groups were not matched in age, we might expect baseline differences in performance on some tasks. These are noted in the 'Results' section and are also evaluated in the 'Discussion' section.

Measures and Equipment

Five standard behavioural measures, implemented as iPad applications, were selected from a range of tasks previously developed at the Department of Cognitive Science, University of Malta (e.g. Jóhannesson et al. 2016; Kristjánsson et al. 2014; Thornton and Horowitz 2015). The use of tablets as research devices is becoming more common as they provide greater flexibility and display standardisation, compared to conventional computerised tasks, without compromising scientific efficacy or reliability (Miller 2012). Descriptions of each of the tasks are provided below. Methodological details and precise display characteristics have been omitted here for the sake of brevity, but appropriate citations are provided where these details can be easily accessed.

All iPads had a screen dimension of 20 × 15 cm and an effective resolution of 1024 × 768 pixels. iPads were placed flat on a table in front of the participant with a viewing distance of approximately 50 cm. In addition to the iPad tasks, two self-report scales were included for the measurements of mindfulness and well-being. Self-report measures were collected through pen and paper questionnaires. Experiments were run in a quiet large room, with normal lightning.

Next, we provide more details on each of the tasks as well as a brief rationale for why the measure was selected.

Simple Reaction Time

The speed with which an observer can react to a stimulus has long been used to assess information processing efficiency (e.g. Donders 1880; see Posner 2005 for review). Here, we used an iPad app (iReact) that presented a simple game where participants had to respond quickly to random visual events by removing their index finger from a home key to touching the relevant flashing object. On each trial, we thus obtained both a lift and touch reaction time, and participants completed 125 trials. Since mindfulness is suggested to lead to clear and efficient use of attentional resources, we were interested in whether this would be reflected in a decrease in response time at the post-test following the mindfulness training.

Visual Foraging

Here, we adopted a task designed to assess visual foraging strategies in humans (Kristjánsson et al. 2014). In the current context, visual foraging refers to a form of visual search (Treisman and Gelade 1980; Treisman and Sato 1990; Wolfe 2010) in which participants are required to select multiple targets from different categories on each trial. The term 'foraging' links this type of task with studies that explores how birds and animals select between different types of food (Dawkins 1971; Dukas and Ellner 1993; Kamil and Bond 2006; Tinbergen 1960). Here, we used an iPad app developed by Kristjánsson et al. (2014) to explore attentional constraints during foraging. When targets can be distinguished by a single feature (e.g. colour), selection is rapid and targets from different categories are selected at random, giving rise to many short 'runs' of the same target type. When targets are defined by a conjunction of features (e.g. colour and shape), selection is slower and most participants use only a few extended runs of one category before switching to the next. There are, however, clear individual differences in how participants adapt their foraging behaviour as target selection becomes more difficult. This is not surprising as foraging is thought to draw on several subsets of cognitive functions including working memory, inhibition, motor-action planning and cognitive flexibility (Kristjánsson et al. 2014; Woods et al. 2013). More specifically, it has been suggested that individuals with better attentional control are likely to continue to switch more often with conjunction targets than those who have poorer attentional control (Jóhannesson et al. 2016, 2017). Our interest was whether search speed or run behaviour would differ following the mindfulness training. On each trial of the 'feature' condition, participants were required to touch and cancel 20 red and 20 green target dots that were randomly displayed among a field of 20 blue and 20 yellow distractors. In the 'conjunction' condition, the targets were red squares and green circles and the distractors were green squares and red circles. Participants completed 10 trials of each condition, and we measured the speed and the pattern of runs.

Task Switching

A key component of higher cognitive control is the ability to switch between more than one task in a manner that is both fast and efficient. The importance of this skill is reflected in the large number of tasks that have been developed over the last three decades to explore task switching (see Hiesh 2012; Monsell 2003; Schneider and Logan 2009; Vandierendonck et al. 2010 for review). For the aim of this study, we developed a task-switching application that implemented the alternating-runs paradigm (Rogers and Monsell 1995). This paradigm uses alternating blocks of a fixed number of trials with predictable switches. Here, participants were presented with digit sequences (numbers 1–9 excluding 5) which had to categorised as either odd/even or smaller/larger than 5 by pressing a designated key with the left/right hand. The digits appeared at the centre of the screen surrounded by a task cue (either a large white diamond or square border) which switched every ten trials (see Hartkamp 2016 for more details). Generally, responses to switch trials take longer to process than responses to repeated trials. This phenomenon is known as the switch cost (Monsell 2003). Based on previous literature, mindfulness meditation was hypothesised to have a decreasing effect on switching costs.

Stroop Interference

The Stroop paradigm (Stroop 1935) has been long used to assess flexibility of attention and inhibition of automatic responses. Participants are typically required to name the colour of the ink in which target words are printed. When target words are colour terms, they can be either congruent (the word 'red' printed with red ink) or incongruent (the word blue printed in green ink). Stroop interference refers to the difference in processing time between the congruent and the incongruent condition. Here, we developed an iPad app that implemented a four-colour word version of the Stroop task. The task used the words blue, red, yellow and green presented in the middle of the screen. In the congruent condition, the words were written in corresponding ink, and in the incongruent condition, the presented colour word was written in one of the other colours, chosen at random on a trial-by-trial basis. Participants were asked to indicate the colour of the ink in which each word was presented by touching one of four corresponding buttons at the bottom of the screen. In total, 160 trials were completed, of which the first 40 were excluded from analyses. Congruent and incongruent trials alternated in blocks of 10. The Stroop effect was then derived as the difference in the response time between the congruent and incongruent blocks. See Hartkamp (2016) for further details.

Although the theoretical framework explaining Stroop interference has recently been questioned (Flaudias and Llorca 2014), it is generally held that the Stroop paradigm taps into inhibition of automatic processing. In line with previous findings from the meditation literature (e.g. Moore et al. 2012; Moore and Malinowski 2009; Wenk-Sormaz 2005), Stroop inference was predicted to reduce following the mindfulness training.

Multiple Object Tracking

Multiple object tracking (MOT; Pylyshyn and Storm 1988) is a well-established paradigm to assess sustained visuospatial attention (see Scholl 2009 for a review). In a typical MOT task, a subset of identical objects are designated as targets during a preview period. The display is then set in motion, and the (now indistinguishable) targets need to be tracked for a certain duration after which they must be identified by the observer. Here, we made use of an iPad implementation of this task which assesses the number of items that can be tracked by means of an adaptive staircase procedure (see Thornton et al. 2014 for details). Initial displays contained two target and two distractor objects that moved randomly for 20 s. Targets were then identified by touch. If all targets were correctly identified, the display increased by one target and distractor, errors resulted in a corresponding reduction, down to the minimum set size of four items.

In contrast to other measures of attention that require brief attentional effort in response to a cue (e.g. Posner cueing paradigm; Posner 1980), the multiple object tracking paradigm requires sustained attention maintained over time. In addition, attention needs to be distributed over a number of targets, rather than directed towards one focal point. MOT is generally considered to be an 'active' rather than a 'reactive' task. Because mindfulness meditation has been associated with improved attentional control and sustained attention, it was expected that the number of correctly tracked objects would increase following the mindfulness training.

FFMQ

The Five Facet Mindfulness Questionnaire was used to assess baseline mindfulness score and the level of mindfulness after the mindfulness retreat. The Five Facet Mindfulness Questionnaire (FFMQ) derived from a comprehensive factor analysis of all pre-existing mindfulness self-report scales. Five aspects of mindfulness, contained in 39 items were identified and validated. These facets are *observing, describing, acting with awareness, non-judging* and *non-reactivity* (Baer et al. 2008). Consistent with previous studies, it was predicted that participants would score higher after retreat than before.

PFI-12

The Positive Functioning Inventory (PFI) 12-item self-report scale was developed to assess functioning within the range of mental distress to well-being and provides an index of general psychological health in which a higher score reflects the presence of positive psychological functioning (Joseph and Maltby 2014). Given the reported relation between mindfulness practice and increased feelings of well-being, it was predicted that participants would rate higher on the PFI after the retreat compared to the baseline.

Intervention: Vipassana/Mindfulness Retreat

Meditation taught in the retreat of the present study followed the operationalisation in which two modes of meditation are distinguished: (1) focussed attention meditation (FA) and (2) open monitoring meditation (OM). Mindfulness meditation involves both of these modes (Lutz et al. 2008). Specifically,

1. Focussed attention (FA) refers to the meditative state of keeping one's focus on a chosen object, such as the movement of the abdomen while breathing. This meditative state includes a constant monitoring of the quality of attention. While building up concentration, the quality of attention is likely to dilute and the mind will wander off. The meditation practice consists of intentionally redirecting one's attention towards the object of meditation. The practice of FA meditation, besides the cultivation of stability of sustained attention, thus also involves regulation of attention in the form of (a) *monitoring*, remaining vigilant to distractions, while trying to sustain the focus, (b) *disengaging*, the distraction that caught attention needs disengaging from, and then (c) *redirecting*, attention needs to be redirected to the initially chosen object of focus, like the breath. This process requires attentional effort. The progress of this practice is partly measured by the amount of attentional effort that is exerted to maintain the focus. When FA is cultivated, the regulative modalities of attention—monitoring, disengaging and redirecting—are more skilfully and efficiently employed and the focus is maintained and sustained with less effort. At an advanced level of FA, the stability of the attention on the chosen object becomes effortless. FA meditation practice typically involves a narrow, pointed scope of attention, so that phenomena occurring outside that scope of attention are hardly noticed, of course depending on the quality of the focus.
2. Open monitoring meditation (OM) fosters a more general divergent attentive awareness, compared to FA

meditation, which cultivates attention with the quality of one pointed of concentration. Still, the practice of open monitoring meditation requires a certain amount of FA in the beginning. This is to reduce mental noise and settle the mind. Once access concentration is established and attention has become stable, the focus of attention shifts and opens up from the meditation object (e.g. breath) into the open field of awareness. Anything that may occur in the field of awareness is paid attention to without engaging explicitly. The open monitoring modality becomes itself the focal point, while a more generalised reflexive awareness sets in. This mode of paying attention to whatever arises usually gives access to a broad field of on-going (mental) phenomena. Among the phenomena that arise in the field of awareness are the emotional triggers and mental proliferations. While the mind is attentive but not engaging in any of the mental phenomena that show up, no selection or deselection of attention takes place. Gradually, the field of awareness becomes more quiet and empty and the non-selective state of awareness is sustained effortlessly.

The practice and process of mindfulness require both the building up of sustained focused attention (FA) and the cultivation of an open monitoring attentive state (OM). The experimental group received intensive mindfulness training that consisted of at least 10 h of meditation a day, and the control group just lived their life as usual between the two measures. Practical instructions included inviting meditators to focus on the movement of the abdomen during sitting meditations, while gaining a more open awareness to whatever arises in the field of consciousness and paying attention to the sensations in the feet during walking meditation. Throughout the day, sitting and walking meditation are alternated and only interrupted for breakfast, lunch, dinner, daily interview, and question and answer sessions. Meditation sessions lasted 45 min. The entire retreat was conducted in silence and took place in an active monastery of Fara Sabina, Italy. The retreat was led by Prof. Dr. H.P. Barendregt and assisted by Prof. A. Raffone and M. Hartkamp. Prof. Dr. H.P. Barendregt was authorised to teach in the Vipassana tradition in the lineage of Mahasi Sayadaw, in which the development of mindfulness is a crucial part.

Procedure and Experimental Design

The experiment followed a simple pre-test/post-test design, with two sessions separated by 6 days. The meditation group ($N = 40$) consisted of participants that had registered for the intensive Vipassana retreat and that agreed to be included in the study. The control group ($N = 30$) was recruited through the student network of the Department of Cognitive Science at the University of Malta and through a network of employees of the City Hall in Amsterdam.

Participants completed the assessment in groups of three to five at individual desks, either at the monastery, the Malta University Campus, or the city hall building of Amsterdam, depending on their experimental/control group assignment. To make administration of the group sessions practical, we opted to run the behavioural tasks in a fixed order, starting with the least demanding and ending with most demanding. Specifically, the order was Simple Reaction Time, Visual Foraging, Stroop, Task Switching and MOT. After the completion of each task, participants were given the opportunity to take a short break. In addition, each task provided the possibility to pause in-between trials or blocks of trials. The questionnaires were filled out after the completion of the behavioural tasks. The battery of behavioural tasks took approximately 60 min to complete. The filling out of the self-report scales took another 20 min.

Results

Data files were extracted from individual iPads, collated and checked for missing values. RT distributions for correct responses were examined for outliers for each individual in each condition. Any values that were plus or minus 2.5 standard deviations from the mean were excluded from analysis. Differences between the pre- and the post-condition of the experimental group (meditators) and of the control group (non-meditators), as well as differences between these groups, were examined through various analyses of variance (repeated measures ANOVA and mixed repeated measures ANOVA). In addition, correlational analyses were performed to examine the relationship between FMMQ and self-reported positive functioning (Pearson's r). Bonferroni correction was applied in the case of post hoc t tests.

Self-report: Five Facet Mindfulness Questionnaire

Table 1 shows the mean scores on the five facets mindfulness questionnaire and the total mean. As is shown in Table 1, the meditation group increased by 27 points on the FFMQ total score on the post-test compared to the pre-test. The control group showed a decrease of two points on the total mindfulness score on the post test, compared to the pre-test (see Table). A 2 (group) by 2 (phase) mixed ANOVA revealed significant main effect of Phase $F(1, 68) = 53.85$, $MSE = 105.13$, $p < .001$, $\eta_p^2 = .442$, and significant group by phase interaction, $F(1, 68) = 69.04$, $p < .001$, $\eta_p^2 = .504$. Post hoc measures showed that the scores of the group did not significantly differ at baseline, $t(69) = .505$, $p = .615$. As there was no significant change over time for the control group, $t(29) = 1.2$, $p = .230$, this suggests that the main effect of

Table 1 Scores FFMQ pre and post, meditation (n = 40) and control (n = 30) group

	Meditation group (6 days Vipassana)			Control group (6 days life as usual)		
	Baseline, mean (SEM)	Post-retreat, mean (SEM)	Mean change	Baseline, mean (SEM)	Post non-intervention, mean (SEM)	Mean change
Total score FFMQ	127 (3.2)	155 (3.02)	27	125 (3.5)	123 (3.4)	−2.00
Observing	24.6 (0.55)	32.9 (0.69)	8300	27.33 (0.82)	25.83 (0.78)	−1.5
Describing	29 (0.83)	31.32 (0.83)	2300	27.07 (1.11)	25.33 (1.01)	−0.73
Acting with awareness	24.6 (0.97)	30.6 (0.89)	6000	25.5 (0.91)	25.2 (0.9)	−0.3
Non-judging	27.4 (1.2)	33.6 (0.92)	6250	24.97 (1.)3	25.93 (1.23)	0.97
Non-reacting	22.13 (0.58)	26.65 (0.68)	4520	21.1 (0.74)	20.97 (0.72)	−0.13

Phase and the Group × Phase interaction can be attributed to the increased rating of the meditation group.

Self-report: Positive Functioning Inventory

The results of 40 participants of the meditation group and 30 of the control group were included in the analysis of the Positive Functioning Inventory (PFI).

Figure 1 shows an increase of 4.9 points on PFI scale on the post-test compared to the pre-test (Mpre = 21.18, SEM = .86, Mpost = 26.1, SEM = .82) in the meditation group versus an increase of 0.43 points on the PFI scale in the control group (Mpre = 23.03, SEM = .97, Mpost = 23.4, SEM = .94).

A 2 (group) by 2 (phase) mixed ANOVA revealed a significant effect of Phase, $F(1, 67) = 22.29$, $p < .001$, $\eta_p^2 = .25$, and a significant Group by Phase interaction, $F(1, 67) = 15.66$, $p < .001$, $\eta_p^2 = .189$. Following up this interaction indicated that there was no significant difference between groups at baseline, $t(68) = -1.6$, $p = .121$, and that the control group did not significantly change over time, $t(29) = -0.67$, $p = .509$), indicating that the difference in scores in the meditation group again accounts for the main effect and interaction.

Relation Positive Functioning Inventory with Self-reported Mindfulness of the Meditation Group

The post-test scores of the Positive Functioning Inventory were examined for correlations with the post-test scores on the Five Facet Mindfulness Questionnaire. Table 2 shows the correlations of FPI with the total score of FFMQ and the 5 subscales. FPI scores were significantly related with FFMQ total score, $r = .59$, $p < .01$, and with the following subscales; *observing:* $r = .52$, $p < .01$; *describing:* $r = .5$, $p < .01$, acting with awareness: $r = .51$, $p < .01$, and *non-reacting:* $r = .41$, $p < .05$. There was no significant correlation with the subscale of the FFMQ *non-judging,* $r = .3$, $p > .05$.

Simple Reaction Time

Figure 2 provides a summary of the time it took participants to lift their fingers from the home key in response to a visual target. We report only liftRT data as the touchRT patterns were qualitatively identical. The control group appeared to respond consistently faster across both phases with a difference of 18 ms (*Mmed* = 439 ms, SEM = 8, *Mcon* = 421 ms, SEM = 7). It is well established that simple reaction time

Table 2 Relations Pearson's r FFMQ scores with PFI score

Variables	Correlations						
Post	**1**	2	3	4	5	6	7
1. FFMQ Observing							
2. FFMQ Describing	.490**	1					
3. FFMQ Act with awareness	.610**	.444**	1				
4. FFMQ Non-judging	0.226	.335*	599**	1			
5. FFMQ Non-reacting	.583**	.340*	.523**	.350*	1		
6. FFMQ Total Score	.745**	.700**	.861**	.712**	.714**	1	
7. PFI Positive Functioning Inventory	.522**	.495**	.508**	0.298	.405*	.590**	1

*Correlation is significant at the 0.05 level (two-tailed)

**Correlation is significant at the 0.01 level (two-tailed)

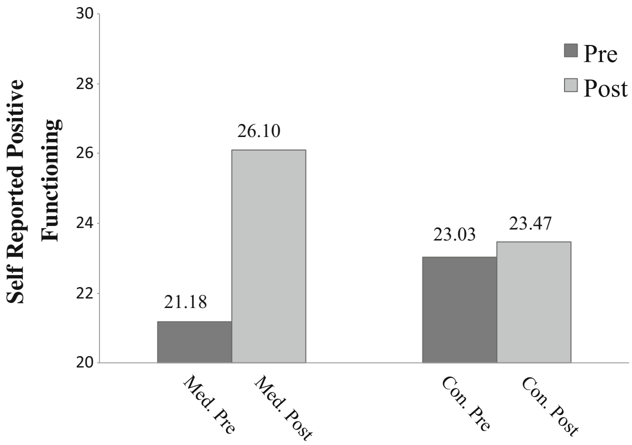

Fig. 1 Scores on Positive Functioning Inventory of the meditation and the control group pre and post

slows with age (e.g. Der and Deary 2006). The most likely explanation for such a pattern would be that, as noted above, our control group were considerably younger than the meditation group. Both groups also showed a decrease in response time over phase (*Mmed* = 19 ms vs *Mcon* = 16 ms). However, a 2 (Phase) by 2 (Group) mixed ANOVA found only a significant main effect of Phase, $F(1, 67) = 31.35$, $MSE = 331.11$, $p < .001$, $\eta_p^2 = .32$. There was and no main effect of Group, $F(1, 67) = 2.72$, $MSE = 4117.75$, $p = .104$ and no Phase * Group interaction, $F(1, 67) = 0.21$, $MSE = 331.11$, $p = .649$.

Visual Foraging

Data on the overall speed and the pattern of foraging 'runs' were analysed separately using the same 2 (Phase: pre/post) × 2 (Condition: feature/conjunction) × 2 (Group) design. For the run data, there were no significant main effects or interactions that involved Group. Thus, the control and meditators had the same patterns of foraging. The only significant effects are illustrated in Fig. 3. As expected, there was a main effect of Condition, $F(1, 63) = 215.68$, $MSE = 27.7$, $p < .001$, $\eta_p^2 = .77$,

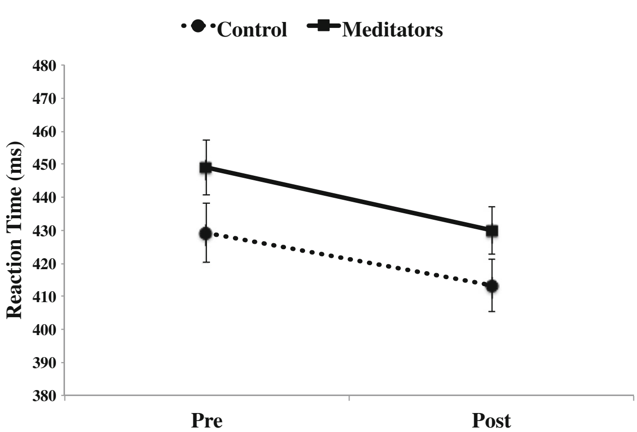

Fig. 2 Summary of simple reaction time task. *Bars* indicate standard error of the mean (SEM)

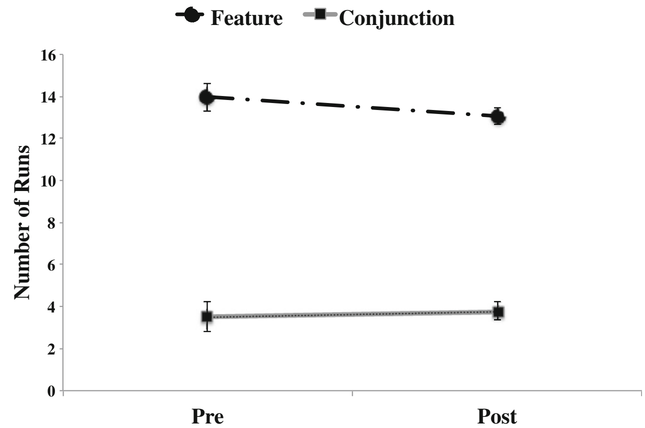

Fig. 3 Foraging performance in terms of number of runs, as a function of Phase and Condition. *Bars* indicate standard error of the mean (SEM)

with the number of runs greatly reducing in the more difficult conjunction condition. This replicates previous findings. There was also a significant Condition × Phase interaction, $F(1, 63) = 4.15$, $MSE = 4.95$, $p < .05$, $\eta_p^2 = .06$, such that difference between the two feature and conjunction foraging appears to narrow at the post-test phase. No other effects were significant.

For the reaction time data, all three main effects were significant. Participants foraged reliably faster in the post-test (Mpost = 16.39 s, SEM = 0.54) than the pre-test (Mpre = 17.63 s, SEM = 0.56), $F(1, 63) = 23.35$, $MSE = 4.03$, $p < .001$, $\eta_p^2 = .27$. As expected, they were also faster in the feature condition (Mfeat = 14.94, SEM = 0.40) than the conjunction condition (Mconj = 19.08, SEM = 0.72, $F(1, 63) = 79.62$, $MSE = 13.22$, $p < .001$, $\eta_p^2 = .56$. Consistent with the simple reaction time data, meditators (Mmed = 19.03, SEM = 0.84) were also reliably slower than the control participants (Mcontrol = 14.99, SEM = 0.67), $F(1, 63) = 14.17$, $MSE = 70.76$, $p < .001$, $\eta_p^2 = .18$. Again, this pattern most likely reflects age differences between the groups. The only other significant effect is illustrated in Fig. 4. This Group × Condition interaction, $F(1, 63) = 4.55$, $MSE = 13.22$, $p < .05$, $\eta_p^2 = .07$, suggests that the cost associated with increased attentional load during conjunction foraging was higher for the meditation group than the control group. As there were no higher-order interactions involving Phase, this pattern does not relate to the experimental manipulation.

Task Switching

Figure 5 provides a summary of the average cost of switching between tasks for each group as a function of phase. Consistent with previous studies, all switch costs were positive, indicating that participants took longer to respond to switch trials versus repeat trials. Overall, the control group (Mctl = 465 ms) was less affected by switching tasks than the meditation group (Mmed = 595 ms), and both groups

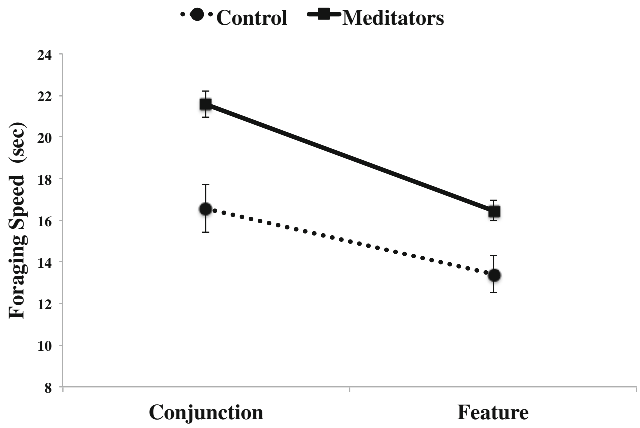

Fig. 4 Foraging speed, as a function of Group and Condition. *Bars* indicate standard error of the mean (SEM)

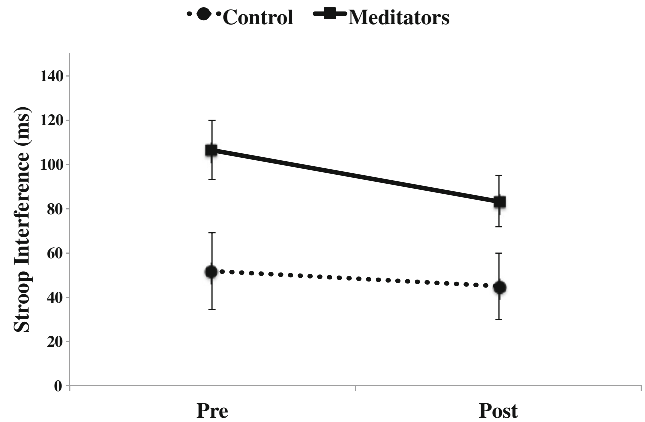

Fig. 6 Stroop interference as a function of Group and Phase. *Bars* indicate standard error of the mean (SEM)

showed a comparable reduction in costs during the post test (Mdiff = 136 ms). A 2 (Phase) by 2 (Group) ANOVA confirmed that there were main effects of both Phase $F(1,68) = 21.49$ $MSE = .03$, $p < .001$, $\eta_p^2 = .24$, and Group, $F(1,68) = 4.6$, $MSE = .13$, $p < .05$, $\eta_p^2 = .06$. The Phase × Group interaction was not significant, $F(1,68) = 0.001$ $MSE = .03$, $p = .971$.

Stroop Interference

Figure 6 summarises the pattern of Stroop interference results. Consistent with previous work, all scores are greater than zero, indicating that participants took longer to identify the colour of the ink when word labels were incongruent than when they were congruent. The control group (Mctl = 48 ms, SEM = 14 ms) showed overall lower levels of interference than the meditation group (Mmed = 95 ms, SEM = 12 ms). However, the meditation group saw a slightly larger reduction in interference across phase (*Mdiff* = 23 ms) than the control group (*Mdiff* = 7 ms). However, a 2 (Phase) by 2 (Group) ANOVA found only a significant main effect of Group $F(1,67) = 6.24$, $MSE = .012$, $p < .05$, $\eta_p^2 = .09$. Both the main effect of Phase, $F(1,67) = 3.03$ $MSE = .002$, $p = .087$, and the Phase * Group interaction, $F(1,67) = 0.97$ $MSE = .002$, $p = .334$, were non-significant.

MOT

Figure 7 provides a summary of the average number of tracked objects. Numerically, both groups tracked a slightly higher number of objects in the post-test than the pre-test, although this difference was only in terms of fractions of objects (*MpreMed* = 3.36, SEM = 0.08; *MpostMed = 3.45*, SEM = 0.06, *MpreCon* = 4.12, SEM = 0.09; *MpostCon* = 4.16, SEM = 0.065). There was a clear difference between the Groups, with the Control participants (Mcon = 4.14, SEM = 0.06) consistently tracking more objects than the meditation participants (Mmed = 3.40, SEM = .05). A 2 (Group) by 2 (Phase) ANOVA showed that only the main effect of Group was significant, $F(1,69) = 79.63$, $MSE = .024$, $p < 0.001$, $\eta_p^2 = .54$. There was no main effect of Phase, $F(1,69) = 0.79$, $MSE = .17$, $p = .378$, and no Group × Phase interaction, $F(1,69) = 0.13$, $MSE = .17$, $p = .717$.

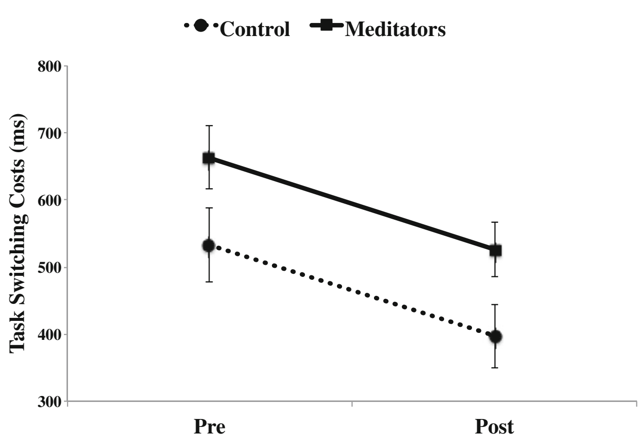

Fig. 5 Task switching costs as a function of Group and Phase. *Bars* indicate standard error of the mean (SEM)

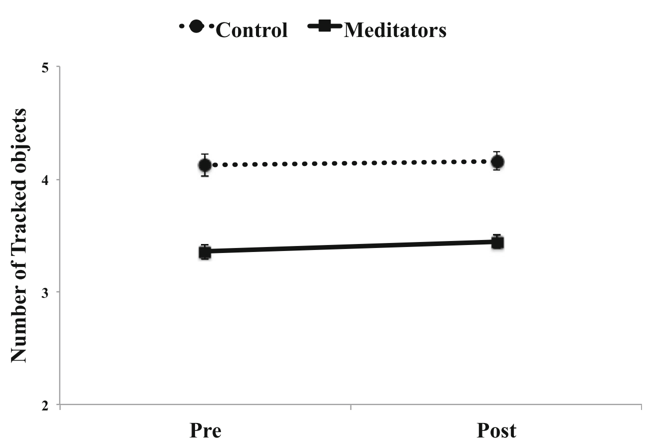

Fig. 7 Number of tracked objects as a function of Group and Phase. *Bars* indicate standard error of the mean (SEM)

Discussion

The aim of the present study was to examine the effects of an intensive mindfulness/Vipassana training on attentional abilities, cognitive flexibility and well-being. More specifically, data was obtained from behavioural measures of simple reaction time, sustained attention (MOT), task switching, inhibition of automatic responses (Stroop) and visual foraging. Self-report measures were also used to assess levels of mindfulness (FFMQ) and feelings of well-being (PFI). Data was collected before and after 6 days of an intensive mindfulness retreat. We also collected data from a training-naïve control group, which allowed us to gauge general levels of pre-post-test task improvements.

Our findings showed significant differences between the meditation and the control group in self-reported mindfulness and self-reported well-being. In contrast, none of the behavioural measures showed any improvement in performance over and above that observed with the control group. Our findings with the subjective rating scales are consistent with previous literature indicating that increased levels of mindfulness are associated with improved feelings of well-being (e.g. Wallace and Shapiro 2006; Carmody and Baer 2008; Grossman 2008; Chiesa and Serretti 2009). However, our findings from the cognitive measures contrast with previous literature suggesting that the cultivation of mindfulness improves attentional abilities and cognitive functioning (see e.g. Lutz et al. 2009; Jha et al. 2007; MacLean et al. 2010). We begin the discussion by exploring this discrepancy before returning to assess the implications of the pattern of subjective ratings.

As discussed in more detail below, many of our cognitive measures did show improvements between the pre- and post-testing phases. However, it appears that in the current study, such improvement is more in terms of a general practice effect, as our control group showed comparable or better performance on most measures. We noted in the 'Introduction' that the design of our study may be limited in certain ways compared to a standard experimental intervention study. In particular, our control group differed in important respects from the meditation group. We discuss these differences shortly. Our sample sizes of between 30 and 40 participants per group may also have been smaller than is typical for intervention studies. Having said that, it is comparable or larger to many previous mindfulness studies in similar settings that have shown effects (see e.g. Chambers et al. 2008; Wimmer et al. 2016; Orzech et al. 2009) and is larger than would usually be found in cognitive studies that have used similar tasks (e.g. Thornton et al. 2014; Kristjánsson et al. 2014). Nevertheless, standard power analysis (assuming typical Type I and Type II error rates of 0.05 and 0.2, respectively) does suggest that with our current sample, only moderate to strong effect sizes (e.g. Cohen's $d > 0.5$) would be detectable. We can thus not rule out the possibility that small group difference might have been missed. More generally, it seems wise to urge some caution when evaluating our results as it remains possible that our failure to find marked improvement in our meditation group on the cognitive tasks arises due to design-related measurement limitations.

We should note that several previous studies have also failed to find clear evidence of improvement in objectively assessed cognitive performance. Lykins (2009), for example, compared meditators with non-meditators using several paradigms, including Stroop, and was unable to replicate previous findings of the effect of mindfulness on attentional control and cognitive flexibility. Chambers et al. (2008) reported increased attentional control and working memory following a 10 days Vipassana retreat but found no effect on cognitive flexibility (Chambers et al. 2008). More recently, Quickel et al. (2014) found that individuals that score higher on mindfulness scales do not show higher performances on attentional tasks than individuals that score lower on mindfulness scales. These findings illustrate the complexity of relating subjective to objective measures, and more fundamentally, they call into question the validity of the current operationalisations and measures of mindfulness per se (Quickel et al. 2014). If we also assume that the mindfulness literature follows the general tendency in science to favour publication of positive results over null results or failures to replicate (e.g. Coronado-Montoya et al. 2016), then the presumed relationship between attention-related cognitive performance and meditation might be less robust than is generally assumed. If such performance improvements are relatively difficult to measure, then it will be important to identify the factors that may mask or remove them in a given study. Next, we consider specific aspects of the current design that may be relevant in this regard.

In four out of five of the behavioural tasks, we did find clear improvements in performance between the pre-test and the post-test. However, the magnitude of these improvements did not differ between the meditation and the control group. In designing the study, the issue of an appropriate control condition was a concern. The meditation group was strongly motivated individuals who underwent intensive training every day. As this was our initial study, we opted to use an unconstrained control group. That is, they were randomly selected from the local academic/work community, had no common interests or motivations, and continued with their normal day-to-day activities between the pre- and post-tests. As our expectation—based on previous research—was that meditators would outperform the control group in terms of performance gains, we were more concerned that we had not engaged the control group in any sort of consistent activity on each day and that they would be at a disadvantage. Nonetheless, both groups showed the same levels of gains. It seems highly likely that these gains reflect some sort of general practice effect. Practice effects refer to enhanced performance due to familiarity and practice with the task demands and task paradigm. Most cognitive behavioural tasks are susceptible to practice effect (Goldberg et al. 2015).

In addition to the issues raised previously, the current design does not control for initial differences connected to self-selection of the meditation group. If the meditators were more responsive to stress as a 'group trait', than the controls, this may have affected the 'performance gains' over time negatively for the meditators relative to the control and mask possible cognitive improvements due to the intervention.

Another limiting factor in the current study is that, as already mentioned, the control group did not match the meditation group in terms of age (meditation group: $M = 48.0$ $SD = 12.9$; control group: $M = 28.5$ $SD = 13.5$). Although the relation of age and magnitude of practice effect has not been unequivocally established, age has been reported to affect the magnitude of practice effects negatively (Salthouse 2010). Thus, the discrepancy between our findings and the existing body of literature could be explained if performance in the meditation group—consisting of older adults—was actually a combination of small practice effects plus positive effects of the intervention. We should note that re-analysing the behavioural data with age as a covariate did not qualitatively change the pattern of results, making this explanation less likely. However, clearly in future studies, more precise age matching of the control group would be preferable and would also likely remove baseline group differences in performance that were observed in several of the current tasks.

Another possible explanation for the discrepancy between our findings and the standing body of literature could be that cultivation of mindfulness through meditation practice does indeed lead to improvements of attentional abilities, but that the paradigms we selected simply failed to tap in to those specific attentional abilities. Although this possible explanation cannot be ruled out, our protocol did include behavioural paradigms that closely align with the abilities examined in previous studies (Stroop Interference, task switching, MOT) (see e.g. Moore and Malinowski 2009; Moore et al. 2012; Wenk-Sormaz 2005).

However, it is the case that many of our tasks focused on reaction time as the main dependent measure. Although response time is commonly used to index cognitive processing, perhaps it is not an entirely appropriate dimension with which to assess mindfulness-related shifts in attentional processes. For example, mindfulness training may lead to a changed interplay between bottom-up and top-down processing. Since mindfulness typically promotes 'paying close attention to the present moment', attention may be trained to become more dependent on bottom-up processing of current incoming stimuli, rather than taking advantage of top-down prediction that could lead to processing speed advantages (Clark 2013; Friston 2010; Hohwy 2013). The question of how mindfulness affects the regulation of top-down and bottom attentional processing seems a promising line of inquiry for future research. In the present context, it might suggest that the future studies should also include more tasks that rely on accuracy or sensitivity rather than response time.

Another possible explanation for having failed to replicate previous cognitive advantages might be that a large number of previous studies were performed within a clinical context. Participants in clinical studies generally qualify for inclusion based on psychological dysfunction and/or emotional distress. The Positive Functioning Inventory included in our protocol showed no signs of emotional distress or psychological dysfunction in any of our participants. Clinical interventions incorporate mindfulness practice because of its reported contribution to healthier emotion regulation (see e.g. Chambers et al. 2009, 2008; Jha et al. 2007; Kabat-Zinn 1990). Healthy emotion regulation prevents emotional interference in cognitive processing. Improvements in cognitive functioning reported in previous studies as a direct outcome of mindfulness practice may then be, in fact, a secondary effect deriving from the psychological benefits of mindfulness (Chambers et al. 2008; Linehan 1993). Consistent with this line of thought, Masicampo and Baumeister (2007) suggested that previous studies examining the effect of mindfulness may have overlooked crucial variables, such as emotional self-regulation. Since previous non-clinical trials generally did not account for psychological functioning, more data is required in order to clarify this possible gap in the present theoretical understanding of emotional and cognitive mechanisms of mindfulness.

Finally, we return to the results of the Five Facet Mindfulness Questionnaire and the Positive Functioning Inventory. As hypothesised, participants that scored higher on the mindfulness scale also scored higher on the well-being scale, indicating a strong relation between mindfulness and well-being. The strongest correlation of the FFMQ subscales with well-being was *observing*. Our findings are consistent with prevailing literature supporting the use of mindfulness-based interventions for clinical purposes. The use of mindfulness as a clinical tool relies on the claim that mindfulness facilitates the ability of adjusting the default inner stance towards inner experience (Ivanovski and Malhi 2007; Kabat-Zinn 1990), thus allowing for a more conducive engagement with emotions. Neutrally observing inner experiences, without engagement, reduces worrying or rumination (Chambers et al. 2009; Bridges et al. 2004) and prevents supressing or overriding negative thoughts and feelings, thus allowing for a mental space to relate to inner experience in an attentive, wholesome manner (Hayes and Feldman 2004). Mindfulness cultivates the acceptance of all mental phenomena as transitory mental events. This accepting stance can be fostered through impartially observing phenomena without acting upon them (Brown and Ryan 2003), thus, articulating the importance of *observing* on the five facet mindfulness scale as an important component of mindfulness for psychological well-being.

As already noted, there is a coherent body of literature documenting the relationship between the cultivation of mindfulness through meditation and psychological health and well-being. However, most of these findings, like ours, rely on self-report measures. The reliability of self-report measures has been largely questioned, not in the least because of the crucial assumption that individuals are able to accurately rate their own level of what is measured by the scale (see e.g. Grossman 2008). A related confounding factor regarding self-report scales is that respondents may be biased in their self-rating, due to their inclination to have improved on the variable that is assessed. As noted above, Quickel et al. (2014) also found that individuals that score higher on mindfulness self-report scales do not necessarily perform better on attentional tasks than those who score lower on mindfulness scales (Quickel et al. 2014). Their findings raise questions about the adequacy of conceptualisations of mindfulness that are currently used by subjective measures of mindfulness. Finally, a more fundamental philosophical and/or phenomenological question is whether inner experiences in consciousness can accurately and comprehensively be represented discursively as such.

In answer to the absence of objective measures of mindfulness, Witmarsh (2013) developed an objective measure of mindfulness, assessing meta-awareness through a neuro-phenomenological procedure. In this procedure, EEG measures of attention are combined with real-time behavioural feedback. While performing a simple computerised task consisting of paying attention to a stimulus, subjects are instructed to press a button at the moment they notice that attention has wandered off. The subject's meta-awareness of his or her attentional pattern is then compared to the patterns of attention revealed by the EEG measures, thus assessing the accuracy of metacognitive awareness. Metacognitive awareness is a crucial component to mindfulness and open monitoring meditation (Whitmarsh 2013). This method has not been extensively used yet; nevertheless, it opens up a promising direction for future research that combines phenomenological and neurobiological methods.

Conclusion

In summary, the current study affirms the previous reported relation between mindfulness and positive psychological functioning. However, and in contrast to the literature, the results of the cognitive behavioural tasks did not provide support for the hypothesis that mindfulness meditation has enhancing effects on attentional abilities. While several possible explanations were given in the previous sections, two potential explanations in particular seem to highlight a promising direction for future research: first, the deemed effect of mindfulness on the interplay of top-down and bottom-up processing in relation to enhanced attentional control and, second, enhancements of cognitive functioning and attentional abilities as a secondary effect of mindfulness resulting from improved emotion-regulatory abilities, rather than a direct effect. Finally, although the field of mindfulness and meditation research has evolved greatly during the past three decades, operationalisations and measures still need further refinement and differentiation.

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Compliance with Ethical Standards

Conflict of Interest The authors declare that they have no competing interests.

Ethical Approval Ethics approval for the experiment was given both by the University of Malta (Media & Knowledge Sciences Faculty Ethics Committee) and the organising body of the retreat, the Dutch Insight Meditation Foundation (SIM). All participants were provided with written information sheets in their own language and were invited to ask questions before reading and signing an informed consent form. Participation in this experiment took place on an utterly voluntary basis, and participants were clearly informed that they had the right to withdraw from the experiment at any time, in any given moment without further explanation.

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