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Does mindfulness training improve cognitive abilities? A systematic review of neuropsychological findings

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ABSTRACT

Mindfulness meditation practices (MMPs) are a subgroup of meditation practices which are receiving growing attention. The present paper reviews current evidence about the effects of MMPs on objective measures of cognitive functions. Five databases were searched. Twenty three studies providing measures of attention, memory, executive functions and further miscellaneous measures of cognition were included. Fifteen were controlled or randomized controlled studies and 8 were case–control studies. Overall, reviewed studies suggested that early phases of mindfulness training, which are more concerned with the development of focused attention, could be associated with significant improvements in selective and executive attention whereas the following phases, which are characterized by an open monitoring of internal and external stimuli, could be mainly associated with improved unfocused sustained attention abilities. Additionally, MMPs could enhance working memory capacity and some executive functions. However, many of the included studies show methodological limitations and negative results have been reported as well, plausibly reflecting differences in study design, study duration and patients' populations. Accordingly, even though findings here reviewed provided preliminary evidence suggesting that MMPs could enhance cognitive functions, available evidence should be considered with caution and further high quality studies investigating more standardized mindfulness meditation programs are needed.

Contents

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1. Introduction

Mindfulness meditation practices (MMPs) are a subgroup of meditation practices which are receiving growing attention (Chiesa & Serretti, 2010; Ivanovski & Malhi, 2007). The word "mindfulness", currently used to describe a particular way of paying attention to the present moment characterized by a receptive and non-judgemental attitude (Kabat-Zinn, 1994), derives from the Pāli word *sati* which can be originally found in the Abhidamma (Kiyota, 1978) and later in the Vishuddimagga (Buddhaghosa, 1976), a summary of the part of the Abhidamma that deals with meditation. Indeed, such term is frequently used to describe a particular type of meditation practices characterized by an open monitoring of present moment experiences which are usually separated and considered as a possible development of concentrative or "focused attention" meditations (Lutz, Slagter, Dunne, & Davidson, 2008).

The concept of mindfulness has its roots in Buddhist philosophy and MMP is a key element of several Buddhist meditations including Vipassana (Gunaratana, 1993) and Zen meditations (Kapleau, 1965). In the last decades mindfulness training has been widely incorporated into several clinically oriented group based meditation programs such as Mindfulness Based Stress Reduction (MBSR) (Kabat-Zinn, 1990) and Mindfulness Based Cognitive Therapy (MBCT) (Segal, Williams, & Teasdale, 2002). In addition, a number of psychological interventions including, among others, Dialectical Behavior Therapy (DBT) (Linehan, 1993) and Acceptance and Commitment Therapy (ACT) (Hayes, Strosahl, & Wilson, 1999), are usually considered as consistent with current conceptualizations of mindfulness and included among modern mindfulness based interventions (Baer, 2003). Note, however, that such interventions only partially incorporate formal meditation training and are characterized by significant differences as compared with other MMPs (Chiesa & Malinowski, in press; Rapgay & Bystrisky, 2009).

Of note, current evidence suggests that mindfulness training could have significant benefit on health, including reduced alcohol and substance consumption (Bowen et al., 2006), reduced blood pressure (Chiesa, 2009), decreased anxiety, depressive symptoms and relapses (Coelho, Canter, & Ernst, 2007; Kim et al., 2009) as well as significant benefits for patients suffering from various types of chronic pain (Chiesa & Serretti, in press), stress problems (Chiesa & Serretti, 2009), cancer (Ledesma & Kumano, 2009) and several further medical disorders (Chiesa & Serretti, 2010). Even though many studies on MMPs have been criticized for the lack of scientific rigor, including the lack of high quality randomized controlled studies designed to differentiate between the specific (i.e. specifically related to repeated sitting meditation practice) and the non specific (i.e. related to benefits' expectations) effects of such practices (Chiesa & Serretti, 2010; Toneatto & Nguyen, 2007) and the frequent use of self report instruments as measures of clinical improvements following mindfulness training (e.g. Chambers, Gullone, & Allen, 2009; Ivanovski & Malhi, 2007), overall available studies provide preliminary evidence for the clinical usefulness of such interventions.

It is noteworthy, however, that the bulk of studies investigating the clinical benefits of MMPs stands in stark contrast with the paucity of studies aimed at investigating more objective correlates of such practices, such as their effects on attention and other cognitive functions, at least up to recent years. On the other hand, as recent conceptualizations of MMPs consistently claim that they improve self regulation of attention (e.g. Bishop, Lau, & Shapiro, 2004; K. W. Brown & Ryan, 2003; Lau et al., 2006), the paucity of scientific studies investigating such issue is somewhat surprising and points out the need of a more thorough investigation and review of the cognitive correlates of mindfulness training. In addition, mindfulness meditation masters and instructors have frequently pointed to the benefits that MMPs could have on cognitive abilities, including attention, memory and other cognitive functions (e.g. Gunaratana, 1993; Kapleau, 1965; Teasdale, Segal, & Williams, 1995), and such measures could provide empirical evidence concerning possible enhanced cognitive abilities associated with mindfulness training. Note also that significant psychological benefits linked to mindfulness training, including, among others, reduced cognitive reactivity (Raes, Dewulf, Van Heeringen, & Williams, 2009) as well as decreased avoidance and rumination (Kumar, Feldman, & C., H. S., 2008), could depend, at least initially, on the development of attentional control and inhibition of unnecessary elaborative processing (Baer, 2003; Bishop et al., 2004).

Accordingly, the aim of this paper is to review current evidence about the effects of MMPs on objective measures of cognitive functions, defined here in their broadest terms so as to include processes such as attention, memory and executive functions, and to provide a preliminary theoretical integration of reviewed findings. Critical issues concerning differences in the definition of mindfulness and current conceptualizations of cognition are explored, followed by a systematic description of the effects of MMPs on different domains of cognitive functions.

1.1. Critical issues related to the construct of mindfulness

The state of mindfulness has frequently been described as a state of "presence of mind" which concerns a clear awareness of one's inner and outer worlds, including thoughts, sensations, emotions, actions or surroundings as they exist at any given moment (Gunaratana, 1993; Kapleau, 1965; Rahula, 1974). Accordingly, it has often been termed as "bare" attention (Gunaratana, 1993; Nyaniponika, 1973; Rahula, 1974), or alternatively as "pure" or "lucid" awareness (Das, 1997; Sogyal, 1992), emphasizing that mindfulness is supposed to reveal what is occurring, before or beyond conceptual and emotional classifications about what is or has taken place.

Unfortunately classical descriptions of mindfulness are usually somewhat poetic and abstract and they do not easily lend themselves to a scientific operationalization that could be used for scientific purposes on this topic. As a consequence, several authors have recently attempted to provide psychologically oriented definitions of mindfulness designed to overcome the difficulties related to early conceptualizations, emphasizing at least two points. The first component of mindfulness is usually referred to as a mental state characterized by full attention to internal and external experiences as they occur in the present moment (Bishop et al., 2004; K. W. Brown & Ryan, 2003; Kabat-Zinn, 1994). The second component is usually described as a particular attitude characterized by non judgment of, and openness to, current experience (Bishop et al., 2004; K. W. Brown & Ryan, 2003; Kabat-Zinn, 1994), which is supposed to lead to higher levels of exposure to negative stimuli and emotions (Kabat-Zinn et al., 1992) as well as to higher acceptance (Brown & Ryan, 2004; Hayes,

1994) and concurrent reduction of experiential avoidance (Hayes et al., 2004). Note, however, that significant discrepancies exist so far across current operational definitions of mindfulness (Baer, Smith, & Allen, 2004; Baer, Smith, Hopkins, Krietemeyer, & Toney, 2006; K. W. Brown & Ryan, 2003; A. M. Hayes & Feldman, 2004; Lau et al., 2006; Roemer & Orsillo, 2003).

In addition, it is noteworthy that several differences exist across different MMPs in terms of daily and total length of practice, types of meditation encompassed under the mindfulness "umbrella term" and specific instructions as to how the mindfulness state should be developed and maintained (for a comprehensive review see Lutz, Dunne, & Davidson, 2008). In sum, MMPs are currently delivered both as clinically oriented group based meditation programs, such as MBSR and MBCT, where mindfulness skills are usually taught over a period of 8 weeks and practitioners are asked to meditate for about 45 min daily (Kabat-Zinn, 1990; Segal et al., 2002), and as intensive retreats, where mindfulness techniques are practiced for 10 h or more daily (Forte et al., 1987–1988). Furthermore, the effects of mindfulness training have sometimes been explored as brief (e.g. 10 min) mindfulness-induction interventions (e.g. Erisman & Roemer, 2010). Although it has been pointed out that such interventions should be better labeled as brief "acceptance-based processing" (or with other labels that take into account the specific subcomponents of mindfulness treatments under investigation in each study) rather than "mindfulness training", such brief laboratory manipulations have been considered as an important aspect of understanding how the cognitive system incorporates new information or procedures and what effects such change has (Williams, 2010).

Note also that in other cases mindfulness is operationalized as a dispositional mental trait (e.g. Brown & Ryan, 2003) which could have arisen through a complex interaction of genetic predisposition, environmental circumstances, and explicit training (Davidson, 2010) and which levels can vary both among different and within single individuals at different time points. It should be pointed out, however, that such different levels of dispositional mindfulness cannot be properly or easily attributed to specific mental training and they are thus systematically excluded from the present review. Nor this review addresses Langer's cognitive model of mindfulness (Langer, 1989; Langer, 1997), which includes alertness to distinctions, context, and multiple perspectives, openness to novelty, and orientation in the present (Sternberg, 2000), and usually involves working with material external to the participants, such as information to be learned or manipulated. Nevertheless, such mindfulness training, as Langer herself have explained (Langer, 1989), should be distinguished from other types of MMPs.

In addition to the issues outlined above, it is noteworthy that mindfulness (often referred to as open monitoring as well) training is usually associated with concentrative (or focused attention) training, such that in early stages of practice the monitoring faculty is needed to detect when mind wanders from the object onto which focused attention is directed, whereas in most advanced stages the practitioner gradually reduces the focus on an explicit object and the monitoring faculty is concurrently emphasized (Lutz, Dunne, et al., 2008; Lutz, Slagter, et al., 2008). Of further concern is the notion that, while in some cases the open monitoring faculty is seen as the final aim as well as the essence of practice, in other cases the open monitoring faculty becomes the basis that subsumes the development of a "reflexive awareness" as a means to understand the moment to moment flow of adaptive and maladaptive thoughts and feelings as well as their triggers and consequences (Lutz, Dunne, et al., 2008; Lutz, Slagter, et al., 2008; Rapgay & Bystrisky, 2009). Accordingly, in order to avoid discrepancies due to systematic differences in the underlying meditation practices, the present review is specifically concerned with cognitive substrates of mindfulness/open monitoring faculty either as a standalone intervention or as a development of prior focused attention meditation training.

1.2. Current classifications of cognition

Similar to the definition of mindfulness, there is no clear consensus as to how cognition and its constituents should be properly classified and categorized. Although an exhaustive overview of cognitive functions is out of the aims and possibilities of the present work, this section is aimed at exploring some of the main cognitive functions in order to provide a simplified theoretical framework that underpins our presentation of available findings about MMPs. In particular, we focused on attention, memory, and executive functions since they are the most represented ones in the studies included in this review.

Numerous theories have attempted to identify subcomponents of attention. One of the most consistent theoretical frameworks of attention suggests that it consists of three functionally distinct neural networks: alerting (also referred to as sustained attention or vigilance), orienting (or selective attention or concentration) and executive attention (or divided attention or conflict monitoring) (McDowd, 2007; Posner & Petersen, 1990; Posner & Rothbart, 2007). According to this model, alerting consists of achieving and maintaining a vigilant or alert state of preparedness, orienting regulates and limits attention to a subset of possible sensorial inputs, and executive attention prioritizes among competing thoughts, feelings, and responses (Posner, 2008; Posner & Petersen, 1990; Posner & Rothbart, 2007). In addition to these subsets of attention, the model suggested by Mirsky, Anthony, Duncan, Ahearn, and Kellam (1991) also includes shift of attention/attention switching referred to as "the ability to change attentive focus in a flexible and adaptive manner" (p. 112).

Memory is not a unitary process as well. Several types of partially independent memories, modulated by different brain regions, have been identified in both humans and animals (Budson, 2009; Henke, 2010). These memory types include, among others, semantic and episodic memory, procedural memory and working memory. This classification of memory systems evolved from the traditional dichotomy in the neuropsychological literature between long- and short-term memory. More in detail, all memory types mentioned above pertain to long-term memory, with the exception of working memory which brings together the fields of short-term memory and attention. The distinction between semantic and episodic memory, described for the first time by Tulving (1972), is essential to understand the existing difference between remembering the conceptual meaning of the word 'pen' (what is it? what is used for?) and remembering that in a specific time and place (for instance, during an experiment) we heard the word 'pen'. In the first case we refer to our acquired general knowledge. In the second case we refer to our capacity to remember specific episodes. A completely different system is represented by procedural memory, which is linked to the acquisition and use of cognitive and behavioral skills, that are automatically retrieved and utilized in step-by-step procedures, such as when one rides a bicycle (Squire & Zola, 1996; Willingham, Nissen, & Bullemer, 1989). Finally, one of the most investigated memory systems is the one of working memory, which is assumed to be necessary for the maintenance of information in mind while performing complex tasks such as reasoning, comprehension and learning (Baddeley, 1986;2010; Baddeley & Hitch, 1974). Working memory has traditionally been divided into three distinct components which are corroborated by imaging studies (Smith & Jonides, 1999): one processing and storing phonologic information, one processing and storing spatial information, and an executive system allocating attentional resources (Baddeley, 1998). Of note, memory can also be categorized in other ways, such as explicit versus implicit memory (Schacter, 1992; Squire & Zola, 1996) and verbal (Wagner et al., 1998) versus visual memory (Brewer, Zhao, Desmond, Glover, & Gabrieli, 1998).

Finally, under the label of executive functions are usually comprised higher-order cognitive abilities that facilitate the flexible modification of thought and behavior in front of novel cognitive or

environmental demands. Executive functions include a number of abilities such as problem solving, planning, concept formation and decision making, attention and working memory that have been recently distinguished from emotional/motivational executive functions (Ardila, 2008). Among them, three core abilities have been reported to be clearly separable, even if moderately correlated with one another as well: information updating and monitoring, response inhibition (inhibitory control), and shifting (cognitive flexibility) (Miyake et al., 2000). In particular, information updating and monitoring capacities correspond to the above described executive component of working memory, whereas the other two executive functions are partially overlapping with attention models.

In conclusion, this brief overview highlights how summarized models of attention, memory and executive functions are not necessarily orthogonal in terms of either theoretical conceptualization or neural underpinnings (Gruber & Goschke, 2004). The reader should consider such interconnections in the evaluation of the following results.

1.3. Research hypotheses

As outlined above, both meditation practices in general and MMPs in particular encompass a large number of different practices. Taking into account the difficulties related to provide a comprehensive description of the specific traits of each MMP included in the present paper, the hypotheses of the present review will rely on one of the most consistent theoretical frameworks of meditation practices as elucidated by Lutz and colleagues (Lutz, Dunne, et al., 2008; Lutz, Slagter, et al., 2008). In sum, according to this model, the practice of mindfulness/open monitoring meditation is usually preceded and can be seen as the result of a sustained concentrative/focused attention meditation practice. This is consistent with historical accounts of meditation suggesting that concentrative attention should be mastered before receptive attention is cultivated (e.g. Kapleau, 1965), so as to avoid mind wandering and train the mind to be anchored to the present moment (Brown, 1977). According to Lutz et al.'s model (Lutz, Dunne, et al., 2008; Lutz, Slagter, et al., 2008), the practice of focused attention meditations involves the development of at least four different faculties, including sustained attention to a target object, monitoring faculty (so as to detect mind wandering), the ability to disengage from a distracting object without further involvement (attention switching), and the ability to redirect focus promptly to the chosen object (selective attention) (Lutz, Slagter, et al., 2008). As focused attention training advances, the well developed monitoring skill becomes the main point of transition into mindfulness/open monitoring practice, which is characterized by a gradual reduction of the focus on an explicit object and a concurrent monitoring of all present moment experiences without any explicit object (Lutz, Slagter, et al., 2008).

On the basis of this model one could hypothesize that early phases of MMPs could be mainly characterized by: (a) the development of conflict monitoring related to the continuous detection of mind wandering, (b) attention switching related to disengagement of distracting stimuli and redirection of attention to target objects, (c) selective attention related to the inhibition of cognitive processes different from the focus of concentration, and, as the practice advances, (d) increasing levels of sustained attention (I). On the other hand, most advanced stages of MMPs could be associated with further improvements of conflict monitoring and attention switching related to early detection and disengagement from distractions, and particularly to the development of unfocused sustained attention characterized by a more distributed attentional focus in comparison with early stages of practice (II). Additionally, even though both historical and modern conceptualizations of mindfulness have more rarely dealt with other cognitive functions, one could speculate that specific relationships could exist between MMP and (III) the development of working memory, which is closely related to several domains of attention (McVay & Kane, 2009; Redick & Engle, 2006), (IV) increases in memory specificity and meta-awareness, possibly related to the suppression of unnecessary elaborative processing (Bishop et al., 2004), and (V) executive functions such as measures of problem solving or verbal fluency, as a result of an improved ability to respond to external stimuli in more flexible rather than habitual reactive ways (e.g. Kabat-Zinn, 1990; Segal et al., 2002).

2. Methods

2.1. Literature research

A literature research was performed using MEDLINE, ISI Web of Science, PsychINFO, Cochrane database, Google Scholar and references of retrieved articles. The search included papers written in English and published up to May 2010. The main search terms were “mindfulness meditation”, “Vipassana meditation”, “Zen meditation”, “mindfulness based stress reduction”, “mindfulness based cognitive therapy”, “mindfulness training” and “meditation training” in combination with “attention”, “memory”, “executive functions” and “cognition”.

2.2. Selection of trials

Included studies had to: 1) provide objective correlates of a MMP on at least one cognitive function, 2) include participants aged 18 or higher, 3) clearly describe the type of the employed meditation training (so as to ascertain whether the term mindfulness was not erroneously used to indicate other types of meditation practices), 4) clearly state that mindfulness/open monitoring training was included either alone or in combination with focused attention meditation training, 5) include an active (such as a relaxation training) or an inactive (such a waiting list) control condition providing a contrast condition for the effects of mindfulness training and 6) provide quantitative measures supported by adequate statistical methodology. Reasons for exclusion were: 1) uncontrolled trials, 2) qualitative reports, 3) speculative reports, 4) studies investigating cognitive correlates of dispositional mindfulness or mindfulness methods not including formal meditation as the main intervention, 5) meditation practices inappropriately described as mindfulness methods (such as pure Samatha practices) and 6) reviews and meta-analyses.

2.3. Outcome measures

Our primary outcome of interest was the evaluation of the effects of any type of MMPs on attention, memory, executive functions and further miscellaneous measures of cognition. In addition, whether such information was described in reviewed papers, we have also explored whether improvements in specific cognitive abilities were related to specific clinical and neurobiological changes (such as changes in self reported levels of mindfulness or brain structures' volume).

2.4. Data extraction and synthesis

All data were independently extracted by two authors from the original reports. Possible disagreements concerning particular classifications of cognitive functions were solved through discussion. In case of persisting disagreements, the third reviewer was consulted. Primary outcome of interests were grouped according to the type of investigated outcomes in four main sections namely attention, memory, executive functions and miscellaneous measures of cognition. Under the heading “miscellaneous measures of cognition” we have collected measures of cognition other than those categorized above, such as meta-awareness and general intelligence. The first two

broad areas of cognitive functions (attention and memory) were further split according to the specific outcome of interest into: sustained attention, selective attention, executive attention, attention switching and "miscellaneous measures of attention" as well as working memory, memory specificity and "miscellaneous measures of memory" respectively. Type of subjects included in each study, including clinical populations and healthy subjects, was also reported. Healthy subjects were defined as subjects with no specific mental or physical disorders as assessed by standard investigations. Finally, each sub-section was structured according to the study design of the included studies. More in detail, in each sub-section prospective controlled and randomized controlled studies were firstly reviewed, followed by case–control studies.

3. Results

3.1. Search results

The original search retrieved 4515 papers. 4480 papers were excluded because they either did not focus on MMPs or did not provide objective measures of cognition following MMPs (Fig. 1). Afterwards, inclusion and exclusion criteria were applied to the remaining 35 studies, 12 studies were excluded and 23 were included in the present review. Excluded studies and reasons for exclusion are shown in Table 1. A summary of included studies is shown in Tables 2, 3 and 4.

3.2. Characteristics of included studies

Included studies comprised 8 controlled, 7 randomized controlled and 8 case–control studies. Aside from a few exceptions, prospective studies focused on novice meditators whereas case–control studies focused on expert meditators. Four studies focused on MBSR, 3 on MBCT, 3 on Vipassana meditation, one on Zen meditation and 10 studies on miscellaneous MMPs, including intensive retreats, MMPs inspired to MBSR or to Zen meditation and other practices consistent with mindfulness training methods. Eleven studies compared MMP with a waiting list/no treatment condition, 3 studies with relaxation, two studies with concentrative meditations, 1 study with physical exercise, one study with treatment as usual and 1 study with simple rest as well as with a cognitive learning strategy. Further, eight studies compared meditators with matched controls. The large majority of included studies focused on healthy subjects aged between 18 and 75 years. Moreover, 4 studies focused on subjects with various types of chronic pain, traumatic brain injuries and individuals suffering from major depression (see Tables 2, 3 and 4 for details). A brief description of the main neuropsychological tests mentioned in the present review is provided in Box 1.

Table 1
Excluded studies and reason for exclusion.

Excluded studies	Reason for exclusion
Alexander, Langer, Newman, Chandler, and Davies (1989)	Inappropriate definition of mindfulness
Brown and Ryan (2003)	Dispositional mindfulness
Creswell, Way, Eisenberger, and Lieberman (2007)	Dispositional mindfulness
Haydicky (2010)	Non adult sample
Herndon (2008)	Dispositional mindfulness
Moore, Brody, and Dierberger (2009)	Dispositional mindfulness
Napoli, Krech, and Holley (2005)	Non adult sample
Schmertz, Anderson, and Robins (2009)	Dispositional mindfulness
Semple, Lee, Rosa, and Miller (2009)	Non adult sample
Slagter, Lutz, Greischar, Nieuwenhuis, and Davidson (2009)	No objective neuropsychological measures of cognitive functions
Waters et al. (2009)	Dispositional mindfulness
Zylowska et al. (2008)	Uncontrolled trial

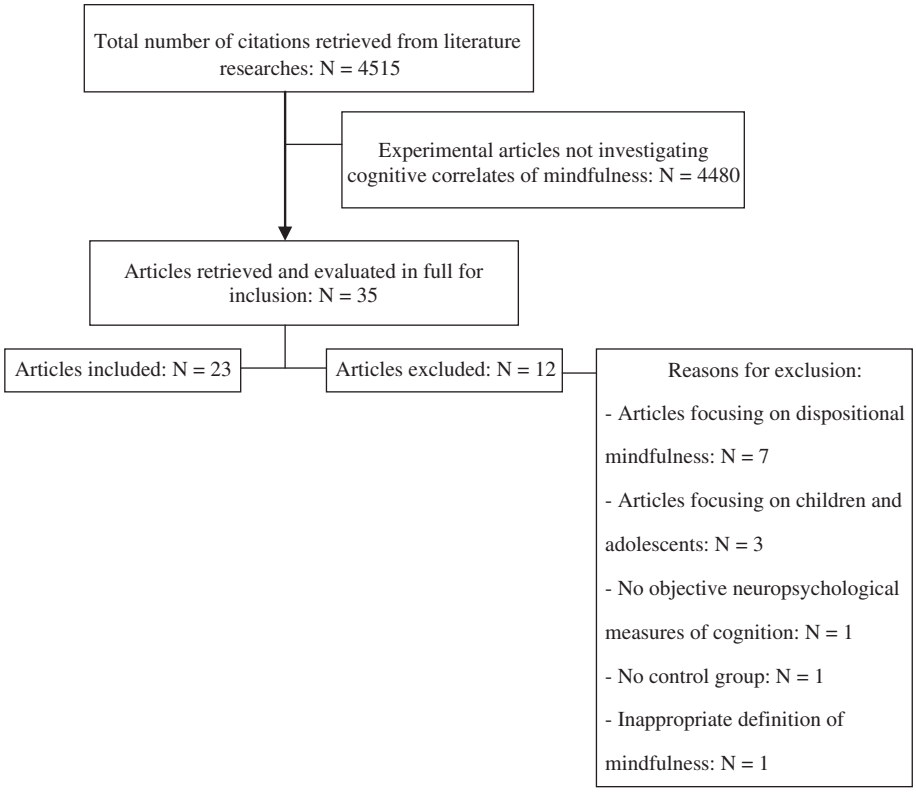

Fig. 1. Flow diagram of the review process.

Table 2
Prospective controlled and randomized controlled studies providing objective measures of cognition following mindfulness training.

Author (date)	Study design	Type of subjects	Number of subjects	MMP/control condition	Measures of cognition	Main findings
Anderson et al. (2007)	RCT	Healthy	39 33	MBSR Waiting list	4GC ODT ST VCPT	No improvements in MBSR group relative to control group on measures of attention. Improvements in mindfulness levels in MBSR group correlated with improvements in object detection
Chambers et al. (2008)	CT	Healthy	20 20	Vip. Retreat No practice	DSB WAIS IST	Significant improvements in sustained attention and working memory in the Vipassana group as compared with controls
Cusens et al. (2010)	CT	Chronic pain	33 20	Breath. Prog. TAU	CPT	No significant difference between groups at any time
Hargus et al. (2010)	RCT	Suicidal major depression	14 13	MBCT Waiting list	RSSI MACAM	Significant improvements in MBCT over control group in meta-awareness. Significant decreases in the control group in memory specificity at time 2
Heeren et al. (2009)	CT	Healthy	18 18	MBCT Waiting list	AMT HT TMT VFT	Increased specific and decreased general autobiographical memories following MBCT. No significant differences on other measures
Jha et al. (2007)	CT	Healthy	17 17 17	MBSR Intens retr. No treatment	ANT	At time 1 expert concentrative meditators prior to intensive retreat demonstrated higher conflict monitoring as compared with naïve meditation subjects. At time 2 MBSR group showed higher orienting abilities and retreat participants improved alerting components
Jha et al. (2010)	CT	Military personnel before stress	29 17	MBMFT No treatment	OST	Improvements in working memory abilities in the high practice MBMFT group and decreases in the low practice MBMFT group and controls
Mcmillan et al. (2002)	CT	Traumatic brain injury	48 38	ACT Phys. Ex. No treatment	AMIPB PASAT TAE TMT	No significant difference on any measure
Ortner et al. (2007)	RCT	Healthy	21 23 24	MM Relaxation Waiting list	EIT	MM group showed a reduction from T1 to T2 in emotional interference from unpleasant pictures as compared with other groups
Polak (2009)	RCT	Healthy	50 50 52	Mindf. Induct. Relax. Induct. No treatment	ANT ST WRAML	At T2 mindfulness practitioners showed improved sustained attention abilities whereas relaxation group showed worsening on the same measure. No further significant differences
Slagter et al. (2007)	CT	Healthy	17 23	Vipas. Retr. No treatment	AB	Significant improvements on attentional blink in meditators in comparison with controls
Tang et al. (2007)	CT	Healthy	40 40	IMBTR Relaxation	ANT RM	Significant improvements in MMP group on conflict monitoring abilities
Wenk-Sormaz (2005)	RCT	Healthy	20 20 20	Mindf. Breath CLS Rest	ST WPT	Reduction in Stroop interference and significant improvements in meditators on unusual responding to the word production task
Williams et al. (2000)	RCT	Major depression	21 20	MBCT Waiting list	AMT	Significant group × time interaction related to a higher number of specific responses in meditators at T2
Zeidan et al. (2010)	CT	Healthy	24 25	Brief Retreat Story listening	COWAT DSBF WIAS SDMT	Mindfulness training improved verbal fluency, visual coding and working memory, although only the first 2 measures were significantly higher in meditators than controls at endpoint

Study design: CT = Controlled trial; RCT = Randomized controlled trial; MMP and control condition: ACT = Attentional control training; MBCT = Mindfulness based cognitive therapy; MBMFT = Mindfulness based mental fitness training; MBSR = Mindfulness based stress reduction; Mindf. Induct. = Mindfulness induction; MM = Mindfulness meditation; MMP = Mindfulness meditation practice; Phys. Ex. = Physical exercise; Relax. Induct. = Relaxation induction; Vip. = Vipassana; Measures of cognition: 4GC = circle appearing in the centre of 1 of 4 grids; AB = Attentional blink; AMIPB = Adult Memory and Information Processing Battery; AMT = Autobiographical memory test; ANT = attention network test; COWAT = Controlled Oral Word Association Test; CPT = Continuous performance task; DSB(F) WAIS = Digit span backward (and forward) of the Wechsler Adult Intelligence Scale; EIT = Emotional interference task; GST = Go/stop test; HT = Hayling task; IST = internal switching task; LM = Logical memory task of the Wechsler Memory Scale; MACAM = Measure of Awareness and Coping in Autobiographical Memory; ODT = object detection task; OST = Operation Span Task; PASAT = Paced auditory serial addition test; RM = Raven's standard progressive matrices; RSSI = Relapse signature specificity inventory; SDMY = Symbol Digit Modalities Test; ST = Stroop test; TEA = Test of everyday attention; TMT = Trail making test; VCPT: Vigil Continuous Performance Test; VFT = Verbal fluency task; VPA WAIS = Verbal Paired Associates subtests of the Wechsler Memory Scale; WPT = Word production task; WRAML = Wide Range Assessment of Memory and Learning.

3.3. Effects of MMPs on attention

3.3.1. Sustained attention

Ten studies (7 controlled or randomized controlled trials and 3 case–control studies) provided measures of sustained attention. Among the former 7 studies, only two observed significant improvements in sustained attention scores in MMP groups as compared with control groups. In the first of such studies (Chambers, Lo, & Allen, 2008), significant interaction effects of condition by group ($p = 0.04$), condition by time ($p = 0.005$) and time by group ($p = 0.04$) were observed, such that the Vipassana retreat group's overall reaction times (RTs) in the affective (but not in the neutral) condition of the

Table 3
Case–control studies providing objective measures of cognition following mindfulness training.

Author (date)	Type of subjects	Number of subjects	MMP/control condition	Measures of cognition	Main findings
Chan and Woollacott (2007)	Healthy	30 20 10	Meditators Meditators Controls	GLLT ST	Meditation experience, as measured by minutes of meditation/day, negatively correlated with Stroop interference and positively with reaction time on GLLT
Hodgins and Adair (2010)	Healthy	100 100	Meditators Controls	AIPST CBFT GV SAT	Mindfulness meditators significantly better than controls on measures of non directed attention, concentration accuracy, selective attention and attention switching.
Josefsson and Broberg (2010)	Healthy	94 92	Meditators Controls	SuAT ST	No significant difference on sustained attention and Stroop task. However longer meditation experience associated with faster SuAT reaction time
Moore and Malinowski (2009)	Healthy	25 25	Meditators Controls	CET ST	Both Stroop task scores and concentration and endurance test scores significantly related to meditation experience
Pagnoni and Cekic (2007)	Healthy	13 13	Meditators Controls	TRVIP	Significant inverse correlation between age and sustained attention in non meditators, no significant worsening related to age in meditators
Valentine and Sweet (1999)	Healthy	8 11 24	Meditators Meditators Controls	WCT	Meditation practice associated with higher sustained attention in comparison with controls, particularly in expert meditators. Mindfulness better than concentrative meditators when the stimulus was unexpected
Van den Hurk et al. (2010)	Healthy	20 20	Meditators Controls	ANT	Vipassana meditators significantly better on measures of sustained attention. A trend towards significance observed for executive attention
van Leeuwen et al. (2009)	Healthy	17 17 17	Meditators Age matched controls Younger controls	AB	Meditators showed levels of attention as high as younger controls and significantly higher levels of attention as compared with age matched controls

MMP and control condition: MM = Mindfulness meditations; MMP = mindfulness meditation practice; Measures of cognition: AB = attentionsl blink; AIPST = Ambiguous image perspective-switching task; ANT = Attention network test; CBFT = Change blindness flickering task; CET = Concentration and endurance test; GLLT = Global local letters task; GV = Gorilla video; SAT = selective attention task; ST = Stroop test; SuAT = Sustained attention test; TRVIP = Task of visual information processing; WCT = Wilkins counting test.

internal switching task (Lo & Allen, submitted for publication) significantly improved from T1 to T2, whereas the controls' did not. In the second study comparing subjects with no prior meditation experience addressed either to a MBSR program or to a waiting list with expert concentrative meditators after a 1-month intensive mindfulness retreat, no significant difference was observed between two novice groups. However a significant reduction in RTs scores, as measured with the attention network test (ANT), was observed in the intensive retreat group as compared with novices ($p<0.001$) (Jha, Krompinger, & Baime, 2007). It should be noted, however, that both studies were limited by a non randomized design which could introduce some biases such as undetected differences across groups.

On the other hand no significant difference was observed between meditators and controls in the remaining studies (Mcmillan, Robertson, Brock, & Chorlton, 2002; Polak, 2009; Tang et al., 2007). Note however that two of such studies tested the effects of mindfulness training in novices after very short periods of MMPs, including a 5 day retreat (Tang et al., 2007) and a 2 session induction (Polak, 2009) respectively, and 1 study focused on a sample of patients with traumatic brain injuries (Mcmillan et al., 2002). The remaining studies compared subjects addressed to a MBSR or a closely related intervention to a waiting list or a treatment as usual (TAU) respectively (Anderson, Lau, Segal, & Bishop, 2007; Cusens, Duggan, Thorne, & Burch, 2010), finding no difference in sustained attention as measured with the Continuous performance test (CPT) (Halperin, Sharma, Greenblatt, & Schwartz, 1991). However, in one of such studies, significant improvements from T1 to T2 were observed in both groups (Anderson et al., 2007).

Three further studies compared long term meditators with matched controls employing a case–control design (Josefsson & Broberg, 2010; Pagnoni & Cekic, 2007; Valentine & Sweet, 1999). All such studies observed significantly higher performances in tasks involving sustained attention in meditators as compared with controls, even though one study found that this was true only for meditators with higher experience (Josefsson & Broberg, 2010). In addition, Pagnoni and Cekic (2007) observed that, while control subjects displayed the expected negative correlation of both gray matter volume and sustained attentional performance with age, meditators did not show a significant correlation of either measure with age. Further, Valentine and Sweet (1999) found that, even though there was no significant difference between concentrative and mindfulness meditators when the stimulus was expected, mindfulness meditators showed superior performance when the stimulus was unexpected, suggesting the development of a more distributed attentional focus in mindfulness as compared with concentrative meditators. Note, however, that on account of the methodological design of the latter studies it is not possible to ascertain a causal relationship between MMP and the development of higher sustained attention or alternatively the presence of predisposing factors in subjects more prone to meditate. Accordingly, such results should be considered with caution.

3.3.2. Selective attention

Eight studies, 4 prospective and 4 case–control studies, investigated the effects of MMP on selective attention. The only non randomized controlled study in this group reporting significant changes following mindfulness training showed significant improvements on selective attention as measured with the ANT in the MBSR group as compared with the 1-month intensive retreat and control groups, reflecting an enhancement in the ability to exclude unwanted stimuli following early stages of practice (MBSR in novice meditators) but not in expert meditators specifically concerned with training their open monitoring faculty (Jha et al., 2007). However no significant difference was observed in other three studies, possibly because of excessively short practice in two studies (Polak, 2009; Tang et al., 2007) or differences in target population (people with traumatic brain injuries) in the remaining one (Mcmillan et al., 2002). It is worth mentioning, however, that in one of such studies a significant positive

Table 4
Description of included interventions.

Author (date)	Interventions/ conditions	Study duration	Number and duration of meetings	Lenght of daily practice*	Type of daily practice*	Prior meditation experience	Mean number of days/weeks between program completion and final neuropsychological assessment	Neuropsychological tests assessed immediately following a meditation session*
Prospective studies								
Anderson et al. (2007)	MBSR Waiting list	8 weeks	8 weekly meetings of 2 h	N.S.	Body scan, mindful stretching, mindfulness of breath/body/ sounds/thoughts (in following boxes referred to as "common MMP exercises")	No	4 weeks	Yes
Chambers et al. (2008)	Vip. retreat No practice	10 days	10 sessions of about 10 h each	About 10 h	N.S.	No	9 days	No
Cusens et al. (2010)	Breath. Prog. TAU	8 weeks	8 weekly meetings of 2.5 h	30–45 min	Common MMP exercises	No	0–4 weeks	N.S.
Hargus et al. (2010)	MBCT Waiting list	3 months	8 weekly meetings of 2 h	45 min	Common MMP exercises	No	N.S.	N.S.
Heeren et al. (2009)	MBCT Waiting list	8 weeks	8 weekly meetings of 2 h	45 min	Common MMP exercises	No	5 days	N.S.
Jha et al. (2007)	MBSR Intens retr. No treatment	8 weeks	MBSR: 8 weekly meetings of 3 h Intens retr: 30 sessions of about 10–12 h each	MBSR: 30 min Intens retr: 10–12 h	MBSR: Common MMP exercises Intens retr. group: mainly sitting and walking MM practice	MBSR and no treatment groups: no experience. Intens retreat group: 4–360 months of prior concentrative meditation experience	≤10 days for MBSR group; immediately following the retreat for intens retr. group	N.S.
Jha et al. (2010)	MBMFT No treatment	8 weeks	8 weekly meetings of 3 h and a full-day retreat	30 min	Common MMP exercises	No	N.S.	N.S.
Mcmillan et al. (2002)	ACT Phys. Ex. No treatment	4 weeks	4 weekly meetings of unspecified duration	N.S.	Common MMP exercises	No	Immediately following the training and at 52 weeks	N.S.
Ortner et al. (2007)	MM Relaxation Waiting list	7 weeks	7 weekly meetings of 1.5 h	N.S.	Common MMP, visualizations and mantras	Various ranging from 1 month to 29 years of prior mindfulness (Tibetan or Vipassana) practice	N.S.	N.S.
Polak (2009)	Mindf. Induct. Relax. Induct. No treatment	2 days	2 sessions of 15 min each	None	Focused attention on the breath	No	Immediately following the second session	Yes
Slagter et al. (2007)	Vipas. Retr. No treatment	3 months	30 sessions of about 10–12 h each	10–12 h	Concentrative meditation followed by a non-reactive form of the whole sensory awareness	Expert meditators with different backgrounds	N.S.	No
Tang et al. (2007)	IMBTR Relaxation	5 days	5 daily sessions	20 min	Effortless meditation characterized by restful alertness	No	N.S.	N.S

Wenk-Sormaz (2005)	Mindf. Breath CLS Rest	1 day	A single session of 20 min	20 min	Mindful attention on the breath	No	Immediately following the session	Yes
Williams et al. (2000)	MBCT Waiting list	6 months	8 weekly meetings of 2 h	45 min	Common MMP exercises	No	4 months	N.S.
Zeidan et al. (2010)	Brief Retreat Story listening	4 days	4 daily sessions	N.S	Focus on the breath and on any sensations that arose in the body1	No	Immediately	Yes
Case–control studies								
Chan and Woollacott (2007)	Meditators Meditators Controls	N.A	N.A	6–150 min	Various meditation practices: meditators divided depending on the their main practices into concentrative and mindfulness meditators	Expert mindfulness and concentrative meditators (total hours of practice 82–19200 h) compared with novices	N.A.	N.S.
Hodgins and Adair (2010)	Meditators Controls	N.A	N.A	N.S.	Various mindfulness meditation practices	N.S.	N.A	N.S.
Josefsson and Broberg (2010)	Meditators Controls	N.A	N.A	N.S.	Various mindfulness meditation practices	Meditators with various degree of experience (1 month–>15 years) compared with novices	N.A	No
Moore and Malinowski (2009)	Meditators Controls	N.A	N.A	N.S.	Unspecified MM	Meditators with various degrees of experience (at least 6 weeks) compared with novices	N.A	N.S.
Pagnoni and Cekic (2007)	Meditators Controls	N.A	N.A	N.S.	Complete openness to one's own mental Processes	Meditators with at least 3 years of daily practice compared with novices	N.A	N.S.
Valentine and Sweet (1999)	Meditators Meditators Controls	N.A	N.A	N.S.	MM: Extended attention/awareness to as many events as possible. Concentrativer meditators: focused attention on a single point	N.S.	N.A	Yes
Van den Hurk et al. (2010)	Meditators Controls	N.A	N.A	8–60 min	Both concentrative and mindfulness meditation used in Vipassana tradition	Meditators with a mean meditation experience of 14.5 years compared with novices	N.A	N.S.
van Leeuwen et al. (2009)	Meditators Age matched controls Younger controls	N.A	N.A	N.S.	Mainly mindful attention on the breath	Meditators with 1–29 years of experience compared with age matched and younger novices	N.A	N.S.

Interventions and conditions: ACT = Attentional control training; MBCT = Mindfulness based cognitive therapy; MBMFT = Mindfulness based mental fitness training; MBSR = Mindfulness based stress reduction; Mindf. Induct. = Mindfulness induction; MM = Mindfulness meditation; MMP = Mindfulness meditation practice; Phys. Ex. = Physical exercise; Relax. Induct. = Relaxation induction; Vip. = Vipassana. Further abbreviations: N.A. = not applicable; N.S. = not specified; * = details reported in these columns are referred to the active conditions only.

Box1
Main neuropsychological tests mentioned in the manuscript.

	Attentional tests
Attention network test	Attention assay that uses the Ericksen flanker task as a target. It requires participants to determine whether a central arrow points left or right. Three subtractions provide scores for alerting, orienting and executive attention.
Attentional blink	Process where if a second target stimulus of two target stimuli is presented within 500 ms of the first one in a rapid sequence of distracters, it is often not detected
Continuous performance task	Attention assay in which participants are required to press a space bar immediately following presentation of any letter except an X and inhibit responding on presentation of an X
D2-concentration and endurance test	Timed test of selective attention with 14 rows each consisting of 47 items. The task is to discriminate and cancel through targets from visually similar non-targets
Global local letters task	Task in which participants must read letters that are made up by a bunch of tiny letters. They then must process either the large letter or the smaller letters that makes up the large letter.
Internal switching task	Psychological test that involves maintaining a count of how many words of a given category are serially presented on a computerized display. During this task, subjects are asked to maintain a silent mental count of how many words they saw from each of the two semantic categories. They also have to press a spacebar, as quickly as possible while maintaining accuracy, when they have updated their mental count.
Stroop test	Test measuring executive attentional functioning by demanding that participants ignore their habitual and automatised process of word reading, in favor of attending to and responding to a less typical task: the colour the word is printed in.
Trail making tests	Trail making test (TMT) part A involves drawing a line connecting consecutive numbers from 1 to 25. TMT part B involves drawing a similar line that connects alternating numbers and letters in sequence. TMT part A performance is usually assumed to provide a baseline for motor and visual control and speed, against which to compare the time cost of executive control.
Vigil Continuous Performance Test	Attention test designed to tap sustained attention. Single letters are presented masked by visual noises. Participants are instructed to press the spacebar as quickly as possible when they see a given letter.
Wilkins counting test	Attention test consisting of series of binaural auditory bleeps at different rates pre-recorded on cassette audiotapes. The task is to count the bleeps and report the number presented at the end of each series when instructed to do so.
	Memory tests
Autobiographical memory test	Psychological test consisting of two lists of 10 emotional cue words. Participants are required to retrieve a specific memory in response to each cue word.
Digit span backward and forward of the Wechsler Adult Intelligence	Memory test in which subjects are requested to either correctly repeat or recite back a span of up to16 digits (14 digits backwards). Higher scores are indicative of higher memory recall.
Operation Span Task	Psychological test frequently used to index working memory capacity. It involves remembering non-affective stimuli such as letters over short intervals while performing simple arithmetic tasks.
Wide Range Assessment of Memory and Learning	Measure of short-term memory, in which the experimenter read a list of 16 words four times and asks participants to recall as many words as possible after each reading.
	Tests of executive functions
Controlled Oral Word Association Test	It is a measure of a person's ability to make verbal associations to specified letters (verbal fluency) which is able to detect changes in word association fluency often found with various disorders
Hayling task	Test used to assess the capacity to inhibit cognitive prepotent responses. In the automatic condition, the experimenter read aloud each sentence to the participant. The participant have to listen to the sentence and to complete it with the appropriate word as quickly as possible. In the inhibition condition, participants are instructed to complete the sentence with an unrelated, nonsensical word as quickly as possible.
Word production task	In part 1, participants are presented with 10 category descriptions and are asked to generate items that belong to each category within 30 s. In part 2, participants are given 1 min to write as many words as possible starting with a given letter.
	Tests of miscellaneous measures of cognition
Emotional interference task	Psychological test in which participants judge whether a tone is high- or low-pitched while viewing neutral, pleasant, or unpleasant pictures. Slowed reaction times are thought to reflect increased allocation of attentional resources to emotional stimuli.
Measure of Awareness and Coping in Autobiographical Memory	Psychological test in which participants are asked to recall and describe their symptoms. Participants' symptom descriptions are then classified as specific, extended, or categoric. More specific descriptions are associated to higher meta-awareness.
Raven's standard progressive matrices	Standard intelligence test which comprises 5 sets in which subjects are asked to identify the missing item that completes a given pattern. Items within each set become increasingly difficult, requiring ever greater cognitive capacity to encode and analyze information.

relationship was found between enhanced selective attention and increases in self reported mindfulness levels (Polak, 2009).

Interestingly, all four case–control studies showed significantly higher levels of selective attention in long term meditators as compared with controls, although with some specific differences across trials. In the Chan and Woollacott's (2007) study no correlation was found between the congruency effect score and meditation experience as measured with the Global local letters task. However, meditation experience, as measured by meditation minutes/day, was associated with faster response time across all trial types reaching significance in the global condition ($p<0.05$). Additionally, Hodgins and Adair (2010) found that both meditators and non meditators had shorter RTs on valid rather than invalid cues of the Selective attention task. However meditators disengaged more quickly from incorrectly cued visual information and more flexibly re-directed attention to new information. Also, Van den Hurk, Giommi, Gielen, Speckens, and Barendregt (2010) observed that meditators showed a significantly smaller orienting network effect on RT data of the ANT than did controls and Moore and Malinowski (2009) found that higher selective attention abilities were both correlated with meditation experience and with self reported mindfulness levels. Similar to what we pointed out for case–control studies focusing on sustained attention it is worth mentioning, however, that results deriving from such studies do not allow to infer any causal relationship between MMP and enhanced selective attention, even though findings suggesting that meditation experience seems to be related to enhanced selective attention abilities could partially dampen such concerns.

3.3.3. Executive attention

Executive attention was investigated in 5 prospective and 4 case–control studies. Two studies, 1 of which using the ANT (Tang et al., 2007) and another one (Wenk-Sormaz, 2005) using the Stroop task (Stroop, 1935), reported significant improvements on executive attention measures in mindfulness groups as compared with control groups which were not mediated by changes in arousal (Wenk-Sormaz, 2005). In addition, Jha et al. (2007) found that at baseline expert concentrative meditators demonstrated improved conflict monitoring performance relative to novice meditators as measured with the ANT. However, no significant difference was observed following treatment. A possible explanation for the latter finding was suggested to be related to an improvement of the control group scores at time 2, possibly related to task exposure effects or alternatively to possible floor effects in RT performance (Jha et al., 2007). Note, however, that only one of such studies employed a randomized controlled design (Wenk-Sormaz, 2005) and evidence deriving from the remaining studies (Jha et al., 2007; Tang et al., 2007) should be considered with caution. In addition, at the opposite of previous findings, Polak (2009) and Anderson et al. (2007) did not observe any improvement following mindfulness training. A possible explanation for Polak's findings (Polak, 2009) could be related to the short duration of the trial (only two sessions) whereas the reason why Anderson et al. (2007) did not find any difference remains unclear.

Pertaining to case–control studies, Chan and Woollacott (2007) found a significant inverse correlation between meditation experience as measured by minutes of meditation/day and Stroop interference ($p<0.0005$). However, there were no significant differences between mindfulness and concentrative meditators. Similarly, Moore and Malinowski (2009) observed positive correlations between MMP and higher Stroop scores as well as higher self reported levels of mindfulness, and Van den Hurk et al. (2010) observed a trend towards significance for the association between Vipassana meditation practice and fewer error scores on the Stroop task ($p=0.07$). On the other hand, no difference in executive functions between meditators and controls was observed in Josefsson and Broberg's study (2010). However, it should be pointed out that such study included meditators with less experience as compared with other case–control studies.

3.3.4. Attention switching

Attention switching was explored in three prospective and 1 case–control study. None of the prospective studies observed any significant difference between active and control groups following mindfulness training (Anderson et al., 2007; Chambers et al., 2008; Heeren, Van Broeck, & Philippot, 2009), preliminarily leading to the hypothesis that attention switching is not affected by MMP, at least by short term training. However, results from Hodgins and Adair's (2010) study comparing expert meditators with non meditators by means of the Ambiguous image perspective-switching task showed that meditators had higher abilities to identify more alternative perspectives of ambiguous images and to identify the first perspective more quickly than did non-meditators, providing preliminary support for the notion that enhanced attention switching faculty could result from long term rather than short term MMP.

3.3.5. Further attentional abilities

In 2007, Slagter et al. (2007) were the first authors to investigate the effects of a 3 month Vipassana retreat on attentional blink, a process where if a second target stimulus (T2) of two target stimuli is presented within 500 ms of the first one (T1) in a rapid sequence of distracters, it is often not detected (Raymond, Shapiro, & Arnell, 1992), possibly as a result of a deficit in the ability to process two temporally close, meaningful stimuli (Shapiro, Arnell, & Raymond, 1997). The results of such study showed that the meditation group showed a significantly smaller attentional blink as compared with controls ($p<0.001$). Additionally, such reduction in attentional blink size was associated with a reduction in brain resource allocation to T1, as reflected by a smaller T1-elicited p3b amplitude (Slagter et al., 2007). Interestingly, such results were further replicated in a case–control study (van Leeuwen, Muller, & Melloni, 2009) comparing expert mindfulness meditators with age matched and younger controls. In such study, not only the magnitude of the blink was larger for the age-matched control as compared with the meditation group, but the meditation group, stemming from an older population, performed even better than the young control group, even though performance on the attentional blink has been shown to drop with age.

In addition, Hodgins and Adair (2010) compared expert mindfulness meditators to non meditators using the Change blindness flickering task (Rensink, O'Regan, & Clark, 1997) as a measure of non directed attention, finding that meditators identified a greater number of changes in flickering scenes than non-meditators and noticed changes more quickly than non meditators. However no significant benefits were observed on measures of non directed attention in patients randomly assigned to a MBSR intervention as compared with patients assigned to a waiting list (Anderson et al., 2007). Note, however, that changes in mindfulness predicted changes in object detection in participants to MBSR program but not in controls. On the other hand, no significant benefits were observed in patients with traumatic brain injuries following a shortened version of MBSR as compared with controls (Mcmillan et al., 2002). It is noteworthy, however, that, in the absence of replications, such findings should be considered with caution and deserve further investigation.

3.4. Effects of MMPs on memory

3.4.1. Working memory

The effects of MMPs on working memory were investigated in 3 prospective studies. Two of such studies investigated the effects of a 10 day and a 4 day mindfulness retreats respectively (Chambers et al., 2008; Zeidan, Johnson, Diamond, David, & Goolkasian, 2010) and

investigated the effects of mindfulness training on working memory by means of the digit span backward and forward of the Wechsler Adult Intelligence Scale (The Psychological Corporation, 1997). Both studies found a significant improvement in working memory capacity following the retreat. However, only in Chambers et al. (2008) focusing on a retreat with a longer duration, meditators performed significantly better than controls at post-test. In addition, Jha, Stanley, Kiyonaga, Wong, and Gelfand (2010) investigated the potential benefits of a mindfulness based mental fitness training modeled on MBSR to counteract the loss of working memory abilities prior to exposure to stressful events, using the Operation span (Ospan) task (Unsworth, Heitz, Schrock, & Engle, 2005), which involves memory of non affective stimuli such as letters over short intervals while performing simple arithmetic counts. Ospan scores showed a trend towards improvement from T1 to T2 in the meditators group with higher meditation practice ($p = 0.08$), whereas they deteriorated over time in the control group, and in the meditation group with low practice (Jha et al., 2010). In addition, only among those with higher meditation practice an overall increase in positive affects and a decrease in negative affects, as measured with the Positive and Negative Affective Scale (Watson, Clark, & Tellegen, 1988), were observed, pointing out to the importance of persistent practice to achieve better results. Similar to a number of studies mentioned above, however, it is worth mentioning that such studies were limited by a non randomized design which could introduce some biases and should therefore be considered with caution.

3.4.2. Memory specificity

One controlled and 2 randomized controlled studies investigated the effects of MBCT in comparison with a waiting list on the enhancements of memory specificity in formerly depressed patients with at least two prior depressive episodes (Hargus, Crane, Barnhofer, & Williams, 2010; Williams, Teasdale, Segal, & Soulsby, 2000) or in healthy subjects (Heeren et al., 2009). The importance of memory specificity relies on recent findings suggesting that patients with a history of major depression show difficulties in retrieving specific autobiographical memories and tend to recall categorical overgeneral memories. These difficulties, have, in turn, been related to impaired social problem solving and difficulties in generating specific simulations of future events, and are considered as markers of vulnerability to future depression and delayed recovery from episodes of emotional disorders. Interestingly, a significant effect of MBCT was observed both in healthy and in formerly depressed patients (Hargus et al., 2010; Heeren et al., 2009; Williams et al., 2000), such that patients addressed to the MBCT program increased their ability to provide specific memories as compared with controls at post test. Also, Hargus et al. (2010) found that, while there was no significant difference between the MBCT + TAU and TAU group in the specificity of relapse signatures at baseline assessment, recollection of the relapse signature became less specific over time in participants in the TAU group, suggesting a protective effect of mindfulness training from a deterioration of memory specificity in formerly depressed patients with a history of suicidality. A main limitation of such studies was, however, the nature of the control groups (waiting list), which did not allow to distinguish specific from non specific effects of MBCT, suggesting the necessity of further investigation.

3.4.3. Miscellaneous measures of memory

Only 2 studies (Mcmillan et al., 2002; Polak, 2009) investigated the effects of MMP on general measures of memory by means of either the Wide Range Assessment of Memory and Learning (Sheslow & Adams, 1990) or the Adult Memory and Information Processing Battery (Coughlan & Hollows, 1985), finding no significant support for possible benefits deriving from mindfulness training on these measures. Note however that critical issues concerning the short duration of one of such studies (2 days mindfulness induction) (Polak, 2009) and the population under examination, including only patients with traumatic brain injuries, in the other (Mcmillan et al., 2002) could explain why negative findings have been observed and point out the necessity of a more thorough investigation of the effects of adequate mindfulness training on measures of memory other than working memory and memory specificity.

3.5. Effects of MMPs on executive functions

Two controlled and 1 randomized controlled studies probed the effects of MMP on executive functions by means of tasks involving different measures of verbal fluency (Heeren et al., 2009; Wenk-Sormaz, 2005; Zeidan et al., 2010). One of such studies further used the Hayling task (Burgess & Shallice, 1996) and the go/stop paradigm (Dougherty, Mathias, & Marsh, 2003) to assess the capacity to inhibit cognitive prepotent responses (Heeren et al., 2009). In the first of such studies focusing on a brief mindfulness induction, Wenk-Sormaz (2005) found that, after the induction, meditators did not differ from non meditators when they were requested to provide habitual responses. However, they provided significantly more unusual responses as compared with controls when this was requested. In Heeren et al.'s (2009) study focusing on MBCT, each participant completed three separate verbal fluency tasks including a semantic, a phonemic and a verb's word fluency task. Results suggested that the mindfulness group, which initially showed similar performances as compared with a matched control group, reported significantly more correct items on all tasks after the intervention. Similarly, in Zeidan et al.'s (2010) study, subjects addressed to a 4 day intensive retreat showed significant improvements on measures of verbal fluency as measured with the Controlled Oral Word Association Test (Benton, 1989) as compared with controls.

Heeren et al. (2009) also found significant support for an effect of MBCT on the inhibition of cognitive prepotent responses. They observed that the mindfulness group, which initially showed similar performances as compared with the matched control group as measured with the Hayling task, reported significantly fewer errors after the intervention ($p < 0.001$). However, no significant difference between groups was observed in the go/stop paradigm, possibly reflecting a higher ability of meditators to reduce cognitive prepotent responses in comparison with motor behaviors.

3.6. Effects of MMPs on miscellaneous measures of cognition

Three further prospective studies investigated objective correlates of mindfulness training on miscellaneous measures of cognition. Ortner, Kilner, and Zelazo (2007) randomly addressed 68 subjects from a large urban university to a mindfulness meditation training, a relaxation training or a waiting list. They tested mindfulness training effects on the reduction of emotional interference during a cognitive task presented at either 1 s stimulus onset asynchrony (SOA) or 4 s SOA. While there were no differences across groups at T1, analyses of interference effects at T2 revealed that only the mindfulness meditation group showed reduced interference from unpleasant pictures from T1 to T2 for the 4 s SOA. Such findings suggest that MMP could help practitioners to disengage their attention from negative stimuli more rapidly than other control conditions. On the other hand there were no differences with regard to pleasant stimuli or unpleasant stimuli at 1 s SOA (Ortner et al., 2007). It is noteworthy, however, that both mindfulness and concentrative meditation practices resulted in positive changes in subjective and psychological well-being, although only MMP resulted in mindfulness levels' increases.

Of further interest is the finding that, although comparable at baseline, a group of formerly depressed patients randomly assigned to MBCT in adjunct to TAU as compared with subjects assigned to TAU only, displayed significant post treatment increases in meta-awareness (i.e. one's relationship with his/her own mental contents characterized by experiencing thoughts and emotions non conceptually as transient

mental events rather than as truths or as definitions of self; Hargus et al., 2010). At the opposite of previous findings, however, Tang et al. (2007) found only partial support for the notion that a 5 day mindfulness intervention could improve intelligence levels as measured by means of Raven standard progressive matrices over simple relaxation training ($p = 0.08$). It is worth mentioning, however, that because such findings still lack replications, and in some cases they do not allow to distinguish specific from non specific effects of MMP (Hargus et al., 2010) or the effects of mindfulness trainings of longer duration (Tang et al., 2007), they should be considered with particular caution. Nevertheless, they point out the importance of further higher quality research to determine the potential benefits resulting from mindfulness training on several domains of cognitive function.

4. Discussion

The aim of the present work was to review current evidence about effects of MMPs on objective measures of cognitive functions, including attention, memory, executive functions and further measures of cognition. Several meaningful results have been observed. First of all we hypothesized that even a moderately brief mindfulness training such as an 8 week meditation program or a short term intensive retreat could improve sustained and particularly selective and executive attention as well as attention switching in subjects with no prior meditation experience. Of note, reviewed findings provide preliminary evidence for such hypothesis. First of all, when mindfulness training was investigated by means of properly delivered meditation programs, significant benefits were observed following MMP in comparison with no treatment (Chambers et al., 2008; Jha et al., 2007) or relaxation conditions (Tang et al., 2007). The only exception was characterized by the apparent lack of benefits deriving from MMP in comparison with control conditions with respect to attention switching (Anderson et al., 2007; Chambers et al., 2008; Heeren et al., 2009). Such observation led some authors to suggest that attention switching could be relatively insensitive to the type of manipulations represented by mindfulness training (Cusens et al., 2010) or alternatively that it could be a marker of more advanced MMP.

A second hypothesis of our review was that long term MMP could be associated with further improvements on attentional measures mentioned above as well as with the development of unfocused sustained attention characterized by a more distributed attentional focus in comparison with early stages of practice. A number of case–control studies comparing expert mindfulness meditators with concentrative meditators and non meditators reported meaningful results in this direction. First of all, the majority of reviewed studies found significantly higher attentional abilities in long term mindfulness meditators as compared with matched controls on different domains of attention (Chan & Woollacott, 2007; Hodgins & Adair, 2010; Moore & Malinowski, 2009; Pagnoni & Cekic, 2007; Valentine & Sweet, 1999; Van den Hurk et al., 2010). Furthermore, a significant positive relationship was observed between meditation experience, defined either as meditation minutes/day (e.g. Chan & Woollacott, 2007) or as the total amount of meditation practice (e.g. Valentine & Sweet, 1999), and enhanced cognitive abilities and brain structural changes (Pagnoni & Cekic, 2007). Similarly, available evidence suggested that a significantly smaller attentional blink could be observed both following a mindfulness meditation retreat (Tang et al., 2007) and in expert meditators as compared with matched control subjects (van Leeuwen et al., 2009). Finally, it is worth mentioning that, when long term meditators, either described as long term mindfulness meditators (e.g. Valentine & Sweet, 1999) or as expert concentrative meditators after a mindfulness/open monitoring retreat (Jha et al., 2007), were compared with concentrative meditators or with MBSR meditators (who concurrently train concentrative and open monitoring skills), they showed significantly higher sustained attention abilities, especially when stimuli were unexpected (Valentine & Sweet, 1999). Overall, such findings provide preliminary evidence for the development of unfocused sustained attention as a result of long term mindfulness/open monitoring training.

Of note, the only hypothesis that was not supported by empirical evidence concerned the lack of improvements of executive attention in expert concentrative meditators following a mindfulness retreat in comparison with novice meditators addressed to MBSR or to a waiting list (Jha et al., 2007). Note, however, that long term meditators overall performed better than matched controls on measures of executive attention. On the basis of such finding, one could hypothesize that the development of executive attention occurs early during concentrative/mindfulness training or alternatively that is more specifically associated with concentrative rather than with mindfulness training. Accordingly, it could not show further improvements during pure mindfulness practice where attention is equally distributed across all external and internal stimuli (Lutz, Slagter, et al., 2008). However such hypothesis has yet to be verified within the context of experimental research.

We also predicted that MMPs could enhance memory, in particular working memory. Overall, reviewed findings preliminarily suggest that MMP could be related to enhanced working memory capacity as well as to a prevention of loss of working memory abilities prior to exposure to stressful stimuli (Chambers et al., 2008; Jha et al., 2010; Zeidan et al., 2010). In addition, Jha et al. (2010), along with a number of studies mentioned above (Chan & Woollacott, 2007; Pagnoni & Cekic, 2007; Valentine & Sweet, 1999), provided further evidence to suggest that the effects of mindfulness training could be related to the amount of meditation practice, providing additional evidence as to how it could not be the mere participation to a mindfulness meditation program that produces clinical changes but rather the quantity and quality of meditation practice one employs. Similarly, MMP was related to increased memory specificity, a psychological marker of mental well being. Increased memory specificity, in fact, can be considered as opposite to overgeneral memories, which have been related to impaired social problem solving (Goddard, Dritschel, & Burton, 1997), and are considered as markers of vulnerability to future depression (van Minnen, Wessel, Verhaak, & Smeenk, 2005) and delayed recovery from episodes of emotional disorders (Peeters, Wessel, Merckelbach, & Boon-Vermeeren, 2002). Finally, although less extensively investigated, executive functions, including verbal fluency and inhibition of cognitive responses, as well as further cognitive measures, such as meta-awareness and emotional interference from distracting stimuli, could be improved by mindfulness training as well. However, on account of the limited evidence about such topic and the number of shortcomings related to available studies such as the impossibility to distinguish between specific and non specific effects of MMP, such findings should be considered with caution and deserve further investigation.

4.1. Clinical implications

Despite the preliminary nature of these findings, it is worth mentioning that they could have a strong clinical impact. First of all, significant psychological benefits following mindfulness training are supposed to depend, at least partially, on the development of attentional control and other cognitive executive functions (Baer, 2003). As an example, the reduction of excessive elaborative processing of negative stimuli following MMPs, which presumably draws on limited processing resources (Ellis & Ashbrook, 1988), might otherwise be directed towards selecting and executing an optimal response to environmental contingencies. As a further example, subjects with low versus high working memory capacities are more likely to suffer from emotionally intrusive thoughts and are less successful at suppressing positive and negative emotions (Brewin & Smart, 2005; Schmeichel, Volokhov, & Demaree, 2008). However, working memory capacity is not an immutable individual factor, as it can be modified by mindfulness

training (Jha et al., 2010). Also, there is some evidence suggesting that MMP could enhance psychological well being (e.g. Anderson et al., 2007; Jha et al., 2010; Ortner et al., 2007) and that benefits deriving from mindfulness training could increase proportionally with daily or total length of practice (Chan & Woollacott, 2007; Jha et al., 2010; Pagnoni & Cekic, 2007; Valentine & Sweet, 1999).

Note, however, that specific categories of subjects, such as people with traumatic brain injuries, could be less likely to benefit from mindfulness training (Mcmillan et al., 2002). Indeed, although Mcmillan et al. (2002) was limited by the investigation of a modified version of mindfulness training, it points out the possibility that mindfulness training could be helpful in certain conditions but not in others. As an example, Zylowska et al. (2008) recently reported significant psychological benefits as well as enhanced cognitive abilities in subjects with attention deficit and hyperactive disorder following mindfulness training, suggesting possible cognitive benefits deriving from MMP in subjects with impaired attention. On the other hand, other authors have speculated that MMP could be more useful to prevent rather than to treat age related disorders such as Alzheimer's disease or cognitive decline usually associated with age (e.g. Pagnoni & Cekic, 2007). This further raises several challenges for future research on this topic. They include, for instance, the search for a specificity profile of different subcomponents of mindfulness to understand which meditation practices are best used for cultivating different types of cognitive (and emotional) skills as well as the need to understand how the individuals' unique cognitive and affective styles could be best matched to specific forms of meditation.

4.2. Limitation of current evidence

A substantial number of limitations should be considered before firm conclusions could be drawn from reviewed studies. First of all a high number of studies compared mindfulness training to a waiting list which does not account for non specific effects of mindfulness training. In other words, it is difficult to ascertain to what extent a different intervention such as simple relaxation could lead to similar outcomes. It is noteworthy, however, that studies comparing MMPs with relaxation, simple rest or different types of meditation practices (Chan & Woollacott, 2007; Ortner et al., 2007; Tang et al., 2007; Valentine & Sweet, 1999) have either reported significantly higher cognitive performances in mindfulness meditators as compared with controls or different patterns of cognitive abilities following different meditation trainings. Such findings suggest that it is unlikely that they could be simply due to non specific effects of training.

Second, a substantial heterogeneity has been observed on specific domains of cognition. A large number of reasons could explain such discrepancies. A possible explanation could be simply imputed to differences in neuropsychological tests employed. However, a more intriguing explanation could be related to the notion that psychological tests used in current trials could lack sufficient sensitivity to detect changes following mindfulness training. A large number of MMPs, in fact, is specifically concerned with apperception (i.e., perception of internal phenomena) rather than with perception of external phenomena (Cusens et al., 2010). Interestingly, such issue further points out the possibility that even subtle differences in meditation instructions could be related to significantly different neuropsychological findings. It also suggests that tests of somatosensory attention deserve future consideration. In addition, we have observed a substantial heterogeneity in the types of practices encompassed under the mindfulness "umbrella term" as well as in their daily and total duration. Taking into account that negative findings were frequently related to the investigation of modified and non standardized versions of mindfulness training, our results point out the necessity of a more accurate investigation of existing standard mindfulness protocols so as to reduce possible sources of discrepancies across studies.

Additionally, significant variations in study design should also be considered. In particular, it is worth mentioning that positive results were frequently observed in case–control studies, which are carried out at one time point and do not allow to infer a causal relationship between MMP and enhanced cognitive ability. Accordingly, such studies should be considered with caution, as they do not allow to rule out the possibility that, as an example, higher pre-meditation cognitive abilities could be specific of subjects more prone to meditate as compared with control subjects. Note, however, that positive findings in some prospective studies focusing on properly delivered MMPs as well as the observed positive correlation between enhanced cognitive abilities and the amount of MMP in a number of case–control studies could partially dampen such concerns. On the other hand, even results deriving from prospective controlled studies should be considered with caution. The majority of such studies, in fact, was limited by a non randomized design that do not allow to exclude the existence of subtle undetected differences between subjects addressed to MMP groups as compared with those addressed to control groups. Accordingly, further higher quality research is needed to overcome the limitations related to available studies.

Moreover, the inclusion of very short mindfulness inductions could raise concerns as to whether such brief trainings could be related to observable changes in cognitive functions as well. However, as Williams (2010) has recently pointed out, one could answer that authors of such studies "are not trying to analogize a full mindfulness treatment program, but to bring about very short term changes that would need much longer to consolidate if they were going to bring about long-term benefit" (p. 3). The inclusion of different patient populations including both clinical and non clinical populations should also be considered. In addition, our review indirectly point out the necessity of a more deep investigation of possible effects of MMPs on different domains of memory and on further executive functions such as problem solving, which have not been systematically investigated so far.

Finally, one could call into question the categorization of cognitive functions employed in the present review. Cognitive functions are known to be significantly related to each other (e.g. McVay & Kane, 2009; Redick & Engle, 2006) and every attempt to categorize cognitive functions as distinct abilities could represent a simple heuristic rather than an objective distinction. However, as explained above, our categorization of cognitive functions was only used for clarity purposes. Additionally, we have referred to some of the most validated scientific models of cognition which have been linked to specific neurobiological areas as well (e.g. Corbetta & Shulman, 2002; Mirsky et al., 1991; Posner & Petersen, 1990).

5. Conclusion

In conclusion, the results of the present review provide preliminary support for the notion that MMPs could provide significant benefits on several measures of cognition which seem specific for the phase of meditation training under investigation. However, further higher quality studies focusing on more standardized MMPs are needed to replicate available findings, to more deeply explore the effects of mindfulness training on further domains of cognition and to reduce discrepancies of findings deriving from systematic differences in mindfulness protocols.

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