Cogn Process (2018) 19:73–85
https://doi.org/10.1007/s10339-017-0844-3

RESEARCH REPORT

# Long-term meditation: the relationship between cognitive processes, thinking styles and mindfulness

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Received: 7 April 2016 / Accepted: 23 October 2017 / Published online: 7 November 2017


**Abstract** The aim of this study is to examine the relationship between meditation and cognitive functions. More in depth the purpose is to demonstrate that long-term meditation practice improves attention skills and cognitive flexibility. Eighteen long-term meditation practitioners were compared to a matched control group, who never practiced meditation. Each subject was tested, using computerized software (Presentation Software 9.90), which measured: attention, visual search abilities, working memory and Stroop's interference tasks. Furthermore, we examined the relationship between long-term meditation practice, mindfulness skills and thinking styles, namely styles of processing information. The results showed significant differences between the two groups, demonstrating that long-term meditation is linked to improvements of attentional functions, working memory and cognitive flexibility.

**Keywords** Meditation · Attention · Working memory · Cognitive flexibility · Thinking styles

Handling editor: Narayanan Srinivasan (University of Allahabad).
Reviewers: Joseph Glicksohn (Bar-Ilan University), Peter Malinowski (Liverpool John Moores University).

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## Introduction

Recently, the interest in meditation has grown and become a topic for scientific research (Knight 2004). Mainly there are two different perspectives, one that focuses the interests on therapeutic benefits (e.g., Chiesa and Serretti 2009), and another, using a neurophysiological approach, has demonstrated that extensive meditation practice can result in different benefits in terms of cognitive processes (e.g., attention, cognitive flexibility and creativity; Berkovich-Ohana et al. 2016; Colzato et al. 2015a, b; Moore and Malinowski 2009). Recent findings have illustrated that long-term meditation has an effect on mental processing, leading to functional as well as structural changes of the brain (Barinaga 2003; Davidson et al. 2003; Pagnoni and Cekic 2007).

Meditation can be conceptualized as a broad variety of complex practices which, by engaging emotional and attentional regulatory strategies, allows the cultivation of well-being and emotional balance (Lutz et al. 2008). Lutz et al. (2008), and more recently Lippelt et al. (2014) have narrowed down two different styles: *focused attention meditation* (FAM) and *open monitoring meditation* (OMM). The two techniques mainly differ in the attentional control that is needed. The FAM requires that the practitioner focuses his attention on a chosen object and sustain this focus; the ability to regulate attention increases with the length of practice, so the subject becomes gradually more able to control distractions and redirect the focus to the chosen object (Lutz et al. 2008). The capacity to reduce distractions and the development of monitoring ability are necessary for the transition into the OMM; the aim is to reach "reflexive awareness" of each experience and to recognize the nature of emotional and cognitive patterns (Lutz et al. 2008).

Despite the difficulty to conceptualize and evaluate the meditation process, recently, there has been a great interest in the link existing between this practice, mainly considered a Buddhist tradition, and the western way of seeing improvements in terms of cognitive processes and neurophysiological changes. For example, the neuropsychological hypothesis underlying the FAM is that specific neural systems are associated with each ability, e.g., sustained attention is associated with the activation of right frontal and parietal areas and the thalamus, while conflict monitoring with the dorsal anterior cingulate cortex and dorsolateral prefrontal cortex (Corbetta and Shulman 2002; Posner and Rothbart 2007; Weissman et al. 2006). The OM meditation, which does not imply a specific focus of attention, relies on brain regions implicated in vigilance and self-monitoring (Lutz et al. 2008). For example, given that OMM focuses on the cultivation of emotional awareness, recent neuroimaging studies suggest the involvement of a prefrontal regulation of limbic responses on emotional processes (Hariri et al. 2000). The OM meditation invites the practitioner in everyday life to accept and label each experience associating it with an emotional state; research has shown that simple verbal labeling of affective stimuli attenuates responses in the amygdala, demonstrating that OMM practice calls upon emotion regulation (Hariri et al. 2000). In particular, authors assume that FAM increases top-down control networks, facilitating the support for relevant information, while OMM weakens top-down control, inducing a more parallel processing mode. So far, we have presented the hypotheses that can explain the effects of long-term meditation practice on different cognitive processes. The following section will provide evidence supporting positive effects of the meditation practice on the ability to allocate attention (e.g., attentional blink tasks), cognitive flexibility (e.g., Stroop test) and executive functioning in general. For example, Slagter et al. (2007), using the attentional blink (AB) paradigm, investigated the effects of 3-month intensive meditation training (Vipassana, an OMM style), on the ability to allocate attention. This paradigm affirms that, in the presence of a sequence of visual stimuli in rapid succession in the same spatial position, a subject is able to identify the first target without problems, but has difficulty in identifying the second, if it is presented between 200 and 500 ms after the first (Petro and Keil 2015). Results showed that intensive training reduces the AB, suggesting that meditators were more efficient in allocating their attentional resources to both stimuli. The EEG patterns suggest that the improvement in AB task is due to less use of resources in finding the first target, as reflected by a smaller T1-elicited P3b (Slagter et al. 2007). Olivers and Nieuwenhuis (2005, 2006) hypothesized that this is due to the fact that observers are in a more diffuse mental state and may distribute their attention in a more flexible operating mode. Similar results were obtained by Van Leeuwen et al. (2009), who tested the performances of expert meditators in opposition to two groups of non-meditators, one age-matched and a younger control group. The findings showed a better performance of the experimental group, despite the age.

Testing a group of non-meditators after a single session of OM or FA meditation, before performing an AB task, researchers found that only after the OM meditation the subjects presented a better performance, which is assumed to weaken top-down control and suggests that this practice can induce cognitive changes in a minimum length of time (Colzato et al. 2015a, b). Another research that provides evidence that meditation promotes high-order cognitive processing, had the aim of evaluating the effects of short-term meditation, in particular mindfulness meditation (MM), on working memory, sustained attention, visual coding and verbal fluency (Zeidan et al. 2010). The findings showed that, even a brief practice of MM can improve the performance in different cognitive tasks, demonstrating that it can affect executive functioning in general (Zeidan et al. 2010).

So far, the literature has provided evidence that long- and short-term meditation can induce an enhancement of cognitive processes and a greater control of emotional reactivity. It has been pointed out that meditation can influence the executive attention network (Tang et al. 2009), but not many studies have focused on other processes. Meditation emphasizes self-regulation of attention; beyond the ability to sustain attention, self-regulating means that it is necessary to control and adapt different strategies to solve the conflict between competing stimulus dimensions (*inhibition*; Fan et al. 2003; Fabio and Towey 2017) and if attention wanders inhibition is the basis to *switch* the focus once again on the chosen object (Lee and Orsillo 2014). Based on the definition of mindfulness as: "paying attention in a particular way: on purpose, in the present moment, and non-judgmentally" (Kabat-Zinn 1994, p. 4), Lee and Orsillo (2014) conceptualized *inhibition* and *switching* as two core aspects of cognitive flexibility.

Cognitive flexibility can be interpreted as the ability to adapt processing strategies to the situation, responding adequately to unexpected conditions (Cañas et al. 2003). Individuals present a typical way of elaborating information and filtering stimuli (environmental, sociological, perceptual) that is influenced by different cognitive and thinking styles (Leng and Hoo 1997; Zhang 2006). Cognitive styles shape the way people manage different situations, and determine the preference for thinking strategies (Leng and Hoo 1997). Within the study of style constructs, Grigorenko and Sternberg (1995) affirm that the various concepts (e.g., cognitive style, learning style, mode of thinking and thinking style) fall into different macro-areas of research (cognition-centered, personality-centered and activity-centered). Each construct has been given different terms and categorizations, but within the cognition-centered studies, they refer specifically to "modes of thinking" or "hemispheric thinking style" (e.g., Albaili 1993; Hassan and Abed 1999; Zhang 2002a, b). The construction has its origin from the early studies on brain lateralization (Springer and Deutsch 1997; Yamaguchi et al. 2000) and research on individual differences (e.g., creativity; Torrance 1966). While in the early studies it was hypothesized that a specific thinking style was a sign of the dominance of one of the two hemispheres (Torrance 1981), research has suggested that they are much more integrated than it was believed. In an early study by Bennett and Trinder (1977) that assumed the relationship between cognitive styles and hemispheric laterality, it was hypothesized that meditation is characterized by an holistic cognitive style associated with the right hemisphere. Contrary to prediction, results relative to the distribution of alpha activity demonstrated that the hemispheres were found to be symmetrical. Zhang (2002a, b), analyzing the concept in terms of information processing, suggested the term "mode of thinking" to describe the different styles that do not necessarily reflect an asymmetry. There are three modes of thinking: logical–analytical thinking, characterized by a preference for a systematic approach (originally left-brain dominance); an holistic manner of processing information, in a synthesized and intuitive way (originally right-brained dominance); integrative mode of thinking that implies the use of a dynamic and interactive processing (originally whole-brained). Although individuals present a dominant mode of thinking, the use of both styles allows flexible ways of processing information within different contexts. In these terms the link between meditation and cognitive flexibility is still not clear; there is not much literature concerning relevant aspects of cognitive functioning, such as thinking styles. Some other studies have tried to fill in this blank, using tests that are specifically designed to evaluate cognitive flexibility finding positive effects for OMM and mindfulness (Colzato et al. 2015a, b; Lee and Orsillo 2014; Moore and Malinowski 2009).

In particular, in the wake of the first studies of Moore and Malinowski (2009), which evaluated meditators using measures of Stroop interference, it was found that attentional performance and cognitive flexibility are positively related to meditation practice and levels of mindfulness. Recently, Lee and Orsillo (2014), using a specific population that it supposed to have low levels of cognitive flexibility, found that people with generalized anxiety disorder (GAD) who practiced mindfulness and relaxation had more efficient emotional Stroop, facilitating conflict monitoring/inhibition in cognitive flexibility.

Given that the literature has mainly emphasized the effects of meditation on attention, in the current research we thus hypothesized that long-term meditation influences both attentional skills and cognitive flexibility. Long-term meditation practitioners were evaluated on many functional cognitive processes, namely attention functions and cognitive flexibility (sustained attention, inhibition, switching), working memory and visual search abilities. Furthermore, other than testing the impact of meditation on mindfulness skills, the novelty of the present study was to evaluate the preference toward specific learning and thinking styles (logical–analytical, holistic–intuitive and integrated). We hypothesized that meditation can influence the way people use different thinking styles, assuming that meditators are able to modulate modes of thinking based on what is needed in different contexts, thus adopting a dynamic style (integrated).

## Methods

### Participants and procedure

Participants ($n = 36$) were comprised of two different groups: an experimental group (long-term meditators) and a control group (non-meditators). The experimental group was composed of eighteen long-term meditators (age, $M = 45.72$, SD = 7.3) with more than 6 years of practice ($M = 8.77$; SD = 2.23) recruited from two meditation centers. Four participants were selected from a center in Messina (Sicily), and the rest from a center in Reggio Calabria. In the centers, the predominant style of meditation was the FAM; in particular among the different techniques that were used, most of the participants were confident with the Buddhist meditation (samatha), the kundalini meditation and the mantra meditation. Table 1 reports the characteristics of each participant.

The control group was composed of 18 participants (age, $M = 44.9$, SD = 6.21) who never practiced meditation. The groups were matched by chronological and mental age (assessed using the Raven's Advanced Progressive Matrices; Raven 1938), gender ($n = 9$ males, $n = 9$ females for each group) and education level (total years, $M = 15.4$ SD = 4.1). Participants were all Caucasian.

The Human Ethics Committee of the Cognitive Science, Education and Cultural Studies of the University of Messina approved the study protocol; all participants volunteered willingly (without remuneration) to the research after being informed that the study was an investigation of the effects of meditation on cognitive processes; therefore, they gave a written consent.

Using a demographic questionnaire, we obtained the personal data, namely age, gender, educational level and occupation; moreover, the meditators had to specify for how long they practiced meditation (average weekly practice of 14 h). After explaining the procedure, the two groups completed a series of tests which were presented in a random order and administrated individually in isolated areas.

**Table 1** Characteristics of the meditators

| Meditators | Age | Gender | Meditation centers | Years of practice | Type of practices |
|---|---|---|---|---|---|
| Participant 1 | 52 | M | Reggio Calabria | 12 | Buddhist and mantra meditation |
| Participant 2 | 38 | M | Reggio Calabria | 6.5 | Buddhist meditation |
| Participant 3 | 44 | F | Reggio Calabria | 9 | Buddhist meditation |
| Participant 4 | 52 | F | Reggio Calabria | 7 | Mantra and sound meditation |
| Participant 5 | 51 | F | Reggio Calabria | 8 | Mantra meditation |
| Participant 6 | 52 | M | Reggio Calabria | 10 | Kundalini meditation |
| Participant 7 | 39 | F | Reggio Calabria | 6 | Mantra meditation and pranayama |
| Participant 8 | 46 | F | Reggio Calabria | 9 | Buddhist meditation |
| Participant 9 | 52 | M | Reggio Calabria | 11 | Kundalini and mantra meditation |
| Participant 10 | 38 | M | Reggio Calabria | 9.5 | Buddhist and Mantra Meditation |
| Participant 11 | 46 | F | Reggio Calabria | 9 | Mantra and sound meditation |
| Participant 12 | 39 | M | Reggio Calabria | 7 | Mantra meditation |
| Participant 13 | 52 | F | Reggio Calabria | 8 | Buddhist meditation |
| Participant 14 | 38 | M | Reggio Calabria | 7 | Kundalini meditation |
| Participant 15 | 51 | M | Messina | 15 | Buddhist meditation |
| Participant 16 | 52 | F | Messina | 7.5 | Buddhist meditation |
| Participant 17 | 47 | F | Messina | 7 | Buddhist meditation |
| Participant 18 | 41 | M | Messina | 9.5 | Buddhist meditation |

## Measures

*Stroop's test (ST)*

The ST (Stroop 1935) was created to evaluate selective attention and cognitive flexibility; more in depth it assesses the ability to allocate and shift attention and to inhibit task-irrelevant information, seeing that there is a difficulty in stopping the automatic processes. The computerized color-word Stroop task (MacLeod 1991) consists in 12 alternating blocks of color identification trials or incongruent color/word blocks. In the color identification trials, participants viewed a series of ten stimuli (XXXX) and were instructed to identify the color by pressing the appropriate buttons associated with each color. In the color-word incongruent blocks, subjects viewed a series of ten color names presented in an incongruent font color (e.g., red written in green) and were asked to identify the font color. Each stimulus was displayed for 1900 ms with a 100-ms interstimulus interval; a 12-s rest interval occurred half-way through the task.

*Visual search (VS)*

The VS test measures the ability to focus attention on relevant stimuli, ignoring the irrelevant ones, i.e., selective attention. The VS task requires participants to determine the presence of a target (e.g., a letter, a shape or an image) among a number of distracting stimuli. Sessions in which at least one feature always differentiates targets from distractors, called *feature* searches, have been used in the present study. Conditions differ for the presence or absence of the target; therefore, the subject must identify the target as quickly as possible. Visual search is widely thought to involve both parallel and serial processes (Wolfe 1994). In the feature search conditions, theories propose that observers may search for groups of items at a time, the size of which varies with search difficulty and practice (the *group scanning hypothesis*: Treisman and Gormican 1988). Some authors claim the importance of attentional control mechanisms such as the activation and inhibition of irrelevant information (Treisman and Sato 1990).

*N-back task*

This test measures executive control relating to the update of information in working memory (Shimamura 2000). Cognitive control is expressed as the ability to direct behavior in a flexible way according to different situations; Miller and Cohen (2001) define it as the brain's ability to represent, maintain and update the rules that guide behavior in ways appropriate to the context. The representations of information that guides behavior must be activated and maintained in working memory, so that you can obtain the archived goal and respond to external stimuli (Lenartowicz et al. 2010).

The N-back task requires participants to pay attention to a stream of stimuli (e.g., letters) and track the location of a target indicating a match when the current stimulus is the same as it was *n* times back in the sequence (Kane et al. 2007). For example 2-Back means that the subject must indicate a match when the stimulus presented two stimuli ago is the same. The request is to click the left mouse button when the letter that the subject sees is equal to the one that was presented before. In the event that the letter is not identical to the previous one, the subject must not press any button, but continue to store the last letter submitted. The test is repeated several times, but with some variations. The second time the subject has to press the left mouse button when the letter displayed is equal to the one shown two positions before; the third time the subject has to press the left mouse button when the letter displayed is equal to the one shown three positions before. Each block contains a series of letters constituted by 20 elements, for a total of 60 items.

*Backward masking (BM)*

The BM is a task that is used to investigate early stages of human information processing. At least three fundamental mechanisms underlie visual BM task performance: integration, inhibition and attentional shifting (Breitmeyer 1984; Breitmeyer and Ganz 1976; Michaels and Turvey 1979; Turvey 1973). Visual masking occurs when there is a reduction in visibility of an object (target) caused by the presentation of a second object designed as mask (Breitmeyer and Ogmen 2000). Backward masking means that the mask is presented after the target; the wider effect occurs, not when the stimulus and mask are presented simultaneously, but when you insert a short interval of time between the presentation of the target and the mask. A major factor in this type of test is the focus. In fact, there is no effect on masking if the attention is immediately focused on the target stimulus, but if the focus of attention on the object is too slow, the mask will be more visible. In this study, the test was divided into two blocks. In the first block, the subject had to press the left mouse button every time he saw the word “ONE” appear among other words, one after another. The participants saw, at the center of the screen, different white words presented on a black background. The non-target stimuli (words with more than three letters) had to be ignored. The subsequent phase represented the real test; the task was to identify the word “ONE” by pressing the left mouse button, even if it was presented for the same amount of time, after it’s appearance it was masked by three “X,” increasing the difficulty of viewing the target.

*Attentional blink (AB)*

Visual selective attention was evaluated through the AB task, giving a measure of the temporal aspects of attention. The paradigm affirms that, in the presence of a sequence of visual stimuli in rapid succession in the same spatial position, a subject is able to identify the first target without problems, but has difficulty in identifying the second, if it is presented between 200 and 500 ms after the first. Participants were asked to identify two targets within a rapid serial visual presentation (RSVP), in which the stimuli are presented for a short period of time in the same place in rapid succession.

There is a refractory period during which the attention is not available to process the second target if it occurs between 200 and 500 ms after the first; if it is presented later in the RSVP stream, it is usually easily identified. The test consists of ten series, each containing seven sequences, for a total of 70 sequences. At the beginning of each test, a red cross of $0.57° \times 0.57°$ of visual angle appears in the middle of the screen for a duration of 1000 ms. After the presentation of the cross, the monitor displays a RSVP of 10–15 letters, each measuring $0.86° \times 0.86°$. The letters were randomly chosen from the alphabet (with the exclusion of I, O, Q, S, X and Z), and the subsequent letter was never the same. The letters were presented for 100 ms; moreover, two letters were replaced by two numbers randomly chosen from 1 to 9. The occurrence of T1 in the stimulus stream was varied randomly between positions; the distance between the first item (T1) and the second (T2) was systematically varied from 1 to 7 time intervals (lag), corresponding to lags of 100, 200, 300, 400, 500, 600 and 700 ms, and the second item (T2) was presented two lags from the end of the series. The participants were asked to look carefully at the RSVP and identify both the stimulus T1 and T2 and to report every time they saw the target on the correspondent diagram that summarized the 70 trials, without time limits. Participants were asked to give an answer even when they were not sure of their response.

*Style of learning and thinking*

The style of learning and thinking (SOLAT) is a test that measures individual differences in thinking styles (Torrance et al. 1988). Torrance (1982) interpreted the concept of cerebral hemisphericity as a psychological dimension, which reflects the tendency of a person to rely on processes that imply one or another cerebral hemisphere (in terms of functional aspects). The self-administrated test allows the evaluation of hemisphere dominance, giving profiles that describe different styles of processing information (Torrance 1982).

People with “left-dominant profile” are inclined to apply sequential and logical–analytical strategies, with a tendency to be logical and conformist (Fitzgerald and Hattie 1993). The “right-dominant profile” refers to people who are unconventional, use intuitive strategies and prefer unstructured tasks (Torrance 1982). The “integrated profile” is typical of those who tend to use the two different strategies when needed (Fabri et al. 2007). Despite the fact that in origin the concept referred to “hemispheric specificity,” later research has failed to associate the three dimensions of the SOLAT with a specific hemispheric dominance (e.g., Zalewski et al. 1992).

More recently, some authors considered these concepts in terms of "modes of thinking" or "hemispheric thinking style" (e.g., Albaili 1993; Hassan and Abed 1999; Zhang 2002a, b), abandoning the association with a physical side. Zhang (2002a, b) refers to the three styles: logical–analytical, holistic–intuitive and integrated.

The Italian version (Antonietti et al. 2005) is composed of 28 items, containing two separate statements, one for the left style and one for the right. The subjects may choose which statement is more suitable, while having the possibility of selecting both. The instrument provides three different scores (SOLAT-L, SOLAT-R and SOLAT-I). Italian SOLAT version showed a quite adequate internal-consistency reliability ($\alpha$ = .69) and a good fit of global model (Person Separation Index = .71).

*Kentucky inventory of mindfulness skills (KIMS)*

The KIMS is a 39-item self-report used for the assessment of mindfulness skills (Baer et al. 2004) that can be used to evaluate population with or without meditation experience. KIMS was designed to assess mindfulness based on overall experience in every day life, through four dimensions with the correspondent subscales: observation, description, acting with awareness and acceptance without judgment. The observing skill refers to the ability to attend to different stimuli including internal or external phenomena. The second subscale refers to the ability of describing observed phenomena using nonjudgmental words. Acting with awareness refers to the tendency of fully engaging every task and activity. The last ability refers to accepting events or experiences without judging them. Items are rated on a five-point Likert scale ranging from 1 (*never or very rarely true*) to 5 (*almost always or always true*); higher scores indicate a greater level of awareness.

The KIMS was first used on the Italian population by Capovilla et al. (2009), finding that subscales show a good range of internal consistency (Cronbach's alpha), with scores that vary between $\alpha$ = .76 and $\alpha$ = .88.

### Statistical analysis

The data analysis was completed using the IBM SPSS Statistics, Version 20.0. Analyses of variance (ANOVA) and repeated-measures ANOVAs were performed, assigning groups as independent variables and each of the measured parameters as dependent variables. With reference to the reaction time (RT) parameters that showed a distribution with indexes of asymmetry and kurtosis close to zero, the data were directly analyzed, while in the case of an asymmetric distribution, analyses were performed on the log-transformed data.

Pearson's correlation test was used to assess the association between different cognitive skills, mindfulness skills and years of practice. The *alpha* level was set to $p < .05$ for all statistical tests. In case of significant effects, the effect size of the test was reported. The effect sizes were computed and categorized according to Cohen (1988).

## Results

### Stroop's test

With reference to the ST, two parameters were analyzed: correct responses (CRs) and mean RTs (see Table 2). Repeated-measures ANOVA 2 (groups: non-meditators vs meditators) × 2 (conditions: congruent color-word vs incongruent color-word) was performed, with group as a between-subject factor and the two conditions as a within-subject factor. Groups shows no significant effect, while the interaction groups x conditions revealed a significant effect, $F(1, 102) = 2.2$, $p < 0.05$, $d = .78$. This means that meditators, in the CRs, are less influenced by the Stroop interference.

With reference to the RTs, groups showed significant effect, $F(1, 34) = 2.96$, $p = 0.05$, $d = .78$. This means that meditators present lower RT's than the control group in both the conditions. Despite the absence of significance in the interaction groups × conditions, results reveal lower RTs among meditators, especially for the incongruent task condition. *T* test for the incongruent color-word condition (both

**Table 2** Mean reaction times (in ms) and correct responses (in %) for each condition of the ST and VS

| | Meditators ($n$ = 18) | | Non-meditators ($n$ = 18) | |
|---|---|---|---|---|
| | *M* (SD) | % (SD) | *M* (SD) | % (SD) |
| Stroop test | | | | |
| Congruent color-word condition | 1118.09 (307.81) | 98 (0.06) | 1628.21 (737.3) | 98 (0.03) |
| Incongruent color-word condition | 1946.16 (1779.71) | 55 (0.40) | 2260.73 (1425.99) | 33 (0.35) |
| Visual search | | | | |
| Target | 820.47 (225.19) | 91 (0.1) | 1118.84 (470.12) | 94 (0.07) |
| Non-target | 1204.78 (458.71) | 100 (0) | 1409.02 (523.68) | 98.5 (0.01) |

for CRs and RTs) also shows significant difference, respectively: $t(35) = 2.82$, $p < .05$, $t(35) = 4.12$, $p < .01$.

### Visual search

Two parameters were analyzed: CRs and mean RTs of the correct trials. The CRs refer to both the situation of finding or not finding the target. ANOVAs were performed assigning groups as independent variables. Given the simplicity of the task, results show very high rates of correct answers, exhibiting a ceiling effect. With reference to the RTs, groups revealed a significant effect, $F(1,34) = 3.96$, $p = 0.05$, $d = .77$. Meditators obtain a better performance, presenting lower RTs (see Table 2).

### N-back task

The test consists of three conditions, each with four parameters. There are four types of possible responses: *hit*, *other*, *miss* and *false alarms*. Table 3 shows means and standard deviations for each factor. ANOVAs were conducted to examine any group differences. Despite the fact that the trend shows a greater number of correct answers for the group of meditators, with reference to the *hit* parameter (individuation of the target), there are no differences between the two groups. Instead, meditators are able to ignore more frequently the not-target stimulus (*other responses*), $F(1, 34) = 3.8$, $p = 0.05$, $d = .77$; this means that the meditators have a higher level of correct answers, especially in the third condition that requires a greater cognitive effort. The third parameter is related to the omissions (*miss responses*); the analysis revealed that meditators have a lower number of omissions compared to the control group, but the differences are not statistically significant. With reference to the *false alarms*, there are significant differences between the two groups, with meditators presenting a lower number of false alarms, $F(1, 34) = 3.2$, $p = 0.05$, $d = .79$. This means that meditators, even when the task becomes more difficult, are able to update efficiently the information in working memory, also presenting higher attentional skills; in fact, they recognize the target more frequently and also commit fewer false alarms.

No differences emerged in the RTs of the two groups.

### Backward masking

BM may be divided into two phases: recognition without masking and recognition in the presence of the mask. Repeated-measures ANOVA 2 (groups: non-meditators vs. meditators) × 2 (conditions of the backward masking) was performed, with group as a between-subject factor and the two conditions as a within-subject factor. We analyzed RTs of correct answers and the performance with reference to the four types of responses (*hit*, *other*, *miss* and *false alarms)*. Table 4 shows means and standard deviations. Despite the fact that the data reveal a better performance for the group of meditators, with higher correct responses and lower RTs, the differences between groups are not statistically significant.

**Table 3** Means and standard deviations related to correct responses and reaction times (in ms) of the N-back task

| N-back task | Meditators ($n = 18$) | | | Non-meditators ($n = 18$) | | |
|---|---|---|---|---|---|---|
| | | | TR | | | TR |
| | *M* | SD | *M* (SD) | *M* | SD | *M* (SD) |
| N-back 1 | | | 604.22 (168.77) | | | 634.6 (303.96) |
| Hit | 4.66 | 0.88 | | 4.5 | 0.67 | |
| Other | 14.58 | 0.66 | | 14 | 1.53 | |
| Miss | 0.33 | 0.88 | | 0.5 | 0.67 | |
| False alarm | 0.41 | 0.66 | | 0.91 | 1.5 | |
| N-back 2 | | | 585.73 (230.52) | | | 570.62 (238.19) |
| Hit | 3.75 | 1.81 | | 2.91 | 1.37 | |
| Other | 13.66 | 1.49 | | 13.16 | 1.94 | |
| Miss | 1.25 | 1.81 | | 2.08 | 1.37 | |
| False alarm | 1.33 | 1.49 | | 1.83 | 1.94 | |
| N-back 3 | | | 633.61 (290.57) | | | 581.5 (287.4) |
| Hit | 2.66 | 1.43 | | 1.83 | 1.11 | |
| Other | 13.91 | 1.16 | | 12.66 | 1.96 | |
| Miss | 2.33 | 1.43 | | 3.08 | 1.24 | |
| False alarm | 1.08 | 1.16 | | 2.33 | 1.96 | |

**Table 4** Means and standard deviations related to correct responses and reaction times (in ms) of the BM

| Backward masking | Meditators ($n = 18$) | | | Non-meditators ($n = 18$) | | |
|---|---|---|---|---|---|---|
| | | | TR | | | TR |
| | *M* | SD | *M* (SD) | *M* | SD | *M* (SD) |
| BM 1 | | | 719.76 (233.49) | | | 750.91 (202.69) |
| Hit | 2 | 0 | | 2 | 0 | |
| Other | 7.75 | 0.62 | | 7.83 | 0.38 | |
| Miss | 0 | 0 | | 0 | 0 | |
| False alarm | 0.25 | 0.62 | | 0.16 | 0.38 | |
| BM 2 | | | 384.49 (265.25) | | | 471.43 (216.63) |
| Hit | 1.08 | 0.79 | | 1.41 | 0.66 | |
| Other | 7 | 1.12 | | 6.41 | 1.16 | |
| Miss | 0.75 | 0.86 | | 0.58 | 0.66 | |
| False alarm | 1.16 | 1.02 | | 1.58 | 1.16 | |

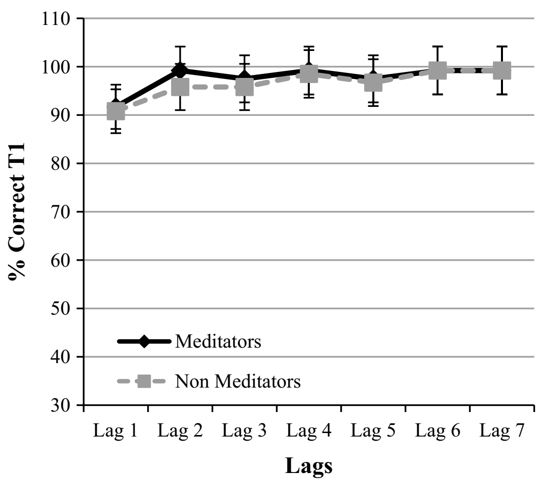


**Fig. 1** Performance of the two groups referred to T1 for each lag of the attentional blink

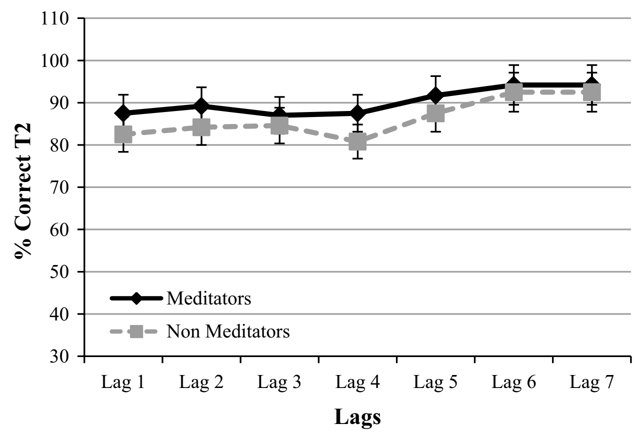


**Fig. 2** Performance of the two groups referred to T2 for each lag of the attentional blink

## Attentional blink

Repeated-measures multivariate analysis of variance (MANOVA) 2 (groups: non-meditators vs. meditators) × 2 (target sequence: T1 and T2) × 7 (time intervals: lag 1, 2, 3, 4, 5, 6, 7) was performed, with groups as a between-subject factor and targets (1 and 2) and the seven intervals of time (lag) as a within-subject factor. The paradigm supposes that people have greater difficulty to locate the second target, while the first is easily recognizable. As expected, the proportion of correct responses to T1 was high with no differences between the two groups and the target sequence was significant, $F(1, 34) = 46.9$, $p < 0.01$, $d = .98$. As for the time intervals (lags), results show the classical lag effect, with a dropdown in performance with lag 2, 3, 4 and 5; after 500 ms the performance was optimal once again (see Figs. 1, 2). With reference to the interaction target sequence x lag, there is a significant effect, $F(6, 102) = 2.8$, $p < 0.005$, $d = .93$. Bonferroni post hoc comparisons ($t$ test, $p < .01$) were carried out only on the T2 showing significant effects between lag 1 and lags 2, 3, 4, 5 and between lag 6 and lags 2, 3, 4, and 5. With reference to the interaction groups × lag, there is a significant effect, $F(1, 102) = 21.34$, $p < 0.01$, $d = .77$; post hoc comparisons (Bonferroni) on T2 were carried out for the interaction effect. The performances were significantly worse in the lags 2 and 3 for non-meditators as opposed to meditators. The general trend reveals that the group of meditators presents a better performance through the task; in particular, the AB was smaller between the critical lags (2 and 5). This means that meditators display a more parallel processing mode, increasing accuracy, with a more efficient distribution of attentional resources over the two targets.

**Table 5** Means and standard deviations related to each subscale of the SOLAT and the KIMS

| | Meditators ($n = 18$) | | Non-meditators ($n = 18$) | |
|---|---|---|---|---|
| | *M* | SD | *M* | SD |
| Style of learning and thinking | | | | |
| LH-dominant profile | 6.91 | 4.75 | 12.75 | 4.91 |
| RH-dominant profile | 12.16 | 4.23 | 10.58 | 5.19 |
| Integrated profile | 8.91 | 6.45 | 4.66 | 3.7 |
| Kentucky inventory of mindfulness skills | | | | |
| Observation | 51.33 | 6.03 | 36.08 | 5.35 |
| Description | 32.91 | 4.5 | 32.16 | 3.9 |
| Acting with awareness | 35 | 6.87 | 38.27 | 5.47 |
| Acceptance without judgment | 30.25 | 3.25 | 29.08 | 4.64 |

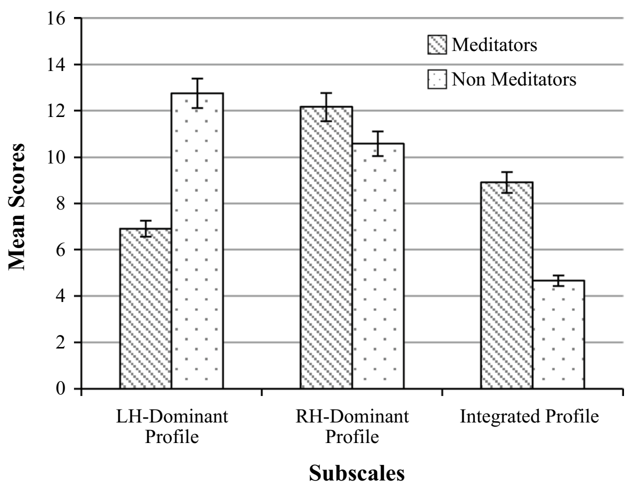


**Fig. 3** Mean scores for the groups related to each subscale of the style of learning and thinking. Error bars represent 95% confidence intervals

## Style of learning and thinking

With reference to the styles of learning and thinking, results show significant differences between the two groups; in particular, the meditators present higher scores for SOLAT-I, $F(1, 22) = 7.9$, $p < 0.01$, $d = .87$ (see Table 5).

Figure 3 shows that the group of non-meditators has a dominant left index profile (as normal population distribution), indicating a preference for structured tasks to be solved by following a systematic method, while, as expected, results reveal that the integrated profile is predominant in the meditators group, meaning that the mental exercise that is associated with the meditation practice can lead to greater dynamic modes of thinking, namely the ability to modulate different strategies in specific situations.

## Kentucky inventory of mindfulness skills

ANOVA 2 (groups: non-meditators vs. meditators) × 4 (subscales: *observation*, *description*, *acting with awareness* and *acceptance without judgment*) was performed to analyze mindfulness skills.

Results for the four subscales are summarized in Table 5. Results show a significant difference between the two groups for the *observation* subscale, $F(1, 34) = 42.9$, $p < 0.01$, $d = .88$. This means that meditators present a higher level of the observation skill, indicating that they pay more attention to body changes in terms of sensations and emotions, as well as external phenomena.

## Correlations between cognitive performances, mindfulness skills and years of practice

With reference to the relationship between the different cognitive skills, results show positive correlations with most of the examined variables, which vary between $r = .32$, $p < .01$ and $r = .62$, $p < .01$ (see Table 6 for the most important correlations). For example, positive correlations were found between the KIMS *observation* subscale and SOLAT-I ($r = .62$, $p < .01$) and negative correlations were found

**Table 6** Correlation matrix referred to the most significant cognitive parameters and the years of practice of the meditators

| Variables | KIMS observation | SOLAT-I | Stroop test | | Visual search RT | N-back task | | Attentional blink | |
|---|---|---|---|---|---|---|---|---|---|
| | | | RT | CR | | Other responses | False alarms | Lag 3 | Lag 4 |
| KIMS | | | | | | | | | |
| Observation | – | .62** | .51* | .56** | .08 | .32* | – .36** | .41* | .53** |
| SOLAT | | | | | | | | | |
| SOLAT-I | .62** | – | .32* | .36* | .12 | .51** | – .36* | .61** | .54** |
| Mean years of practice | .62** | .59** | .4* | .43** | .21 | .37* | – .32* | .36** | .43** |

* $p < .05$; ** $p < .01$

with the N-back task *false alarms* ($r = -.36$, $p < .05$). This indicates that high levels of mindfulness skills, in particular observational skills, are correlated with learning and thinking styles (SOLAT-I) and are linked to the efficiency in updating information in working memory. Most of the cognitive variables are correlated, with the exception of the VS parameters; this is probably due to the great simplicity of the task itself. The same pattern is found when examining the relationship with the meditation expertise (in terms of years of practice); results demonstrate that there is a positive correlation with most of the cognitive variables, which vary between $r = .36$, $p < .01$ and $r = .62$, $p < .01$. This means that greater expertise is associated with a better performance.

## Discussion

The present study investigated the relationship between meditation and different cognitive processes. The aim was to confirm that long-term practice can increase attentional skills, and to evaluate the effect on working memory, visual search abilities and cognitive flexibility. Furthermore, the two groups (meditators vs non-meditators) were compared on self-reported mindfulness and thinking styles, expecting higher levels of the first and that meditators present dynamic modes of thinking (integration of different modes). In line with previous reports, results demonstrate significant differences between the two groups, indicating that there is a link between long-term meditation practice and some high-order cognitive processes.

As has been pointed out, attention skills are fundamental in the practice of meditation. Within the different types of meditation, attentional regularity strategies are essential (Lutz et al. 2008); for instance, the FA meditation focuses on attentional control, implying different processes, such as sustained attention, inhibition and switching (Lutz et al. 2008). For this reason, many studies have focused mainly on the beneficial effect of meditation on the ability to allocate attention over time (Colzato et al. 2015a, b; Slagter et al. 2007). Using the AB paradigm, our observations are in line with previous reports showing that long-term practice is associated with smaller ABs (Colzato et al. 2015a, b; Slagter et al. 2007; Van Leeuwen et al. 2009). Comparing the two groups, there were no differences in the performance related to the first target, while non-meditators had greater difficulty recognizing the second target. Meditators presented better ABs, especially within the critical lags, demonstrating the ability to display a more parallel way of processing and distributing attention in a more functional way. Although there are evident limitations for cross-sectional studies, data suggest possible effects that are corroborated by a longitudinal test–retest design that uses the electroencephalography (EEG) to investigate the effects of meditation on the distribution of attentional resources. Slagter et al. (2007) found that after 3 months of practice, participants showed a significant reduction in the size of the AB, confirming previous results.

Furthermore, to evaluate in more detail the two mechanisms that govern the process of visual attention tasks, namely the activation and inhibition of irrelevant information, we used another test, the VS. This confirmed significant differences between the two groups, with meditators obtaining lower RTs throughout the different tasks and therefore better performances in the visual attention abilities.

Meditation implies self-regulation; this means the ability to sustain attention on a intended object as supported by two complementary components: resolving conflicts among stimuli (*inhibition*) and the ability to redirect the focus on the intended object if attention wanders (*switching*); both abilities can be seen as core aspects of cognitive flexibility (Lee and Orsillo 2014). Few studies have analyzed cognitive flexibility alone, while it has been associated with other processes. For example, Moore and Malinowski (2009) evaluated the link between meditation, self-reported mindfulness and different cognitive processes. Following the idea that cognitive flexibility implies the ability to interrupt or de-automate automatic responses, they used a well-established measure: the ST. This test provides evidence of the difficulty to suppress irrelevant information and interrupt automatic processes (Stroop effect). The authors found that meditators performed significantly better than non-meditators on all measures of attention, and displayed decreased Stroop interference; furthermore, mindfulness skills were higher for the meditators with positive correlations to the attentional measures (Moore and Malinowski 2009). Consistent with previous research, the results in the present study show better performances in the ST, in terms of CRs and in the RTs, demonstrating less influence of Stroop interference. Moreover, positive correlations were found between both the parameters of the ST and the levels of self-reported mindfulness (observational skills). Previous research had obtained similar results even with short-term practice: Only 12 min of MM seems to influence the way people respond to the Stroop task, reducing habitual responding (Zeidan and Faust 2008). Different results were obtained in a longitudinal study that failed to find positive effects on attentional processes after an 8-week mindfulness program as assessed by various measures of attention including Stroop interference (Anderson et al. 2007).

The literature presents extensive evidence that the practice of meditation leads also to positive effects in terms of well-being, emotional self-regulation and specific cognitive functions (Tang et al. 2007; Wallace and Shapiro 2006); even so, besides attentional skills, to our knowledge not many studies have focused on different aspects of cognition, such as executive functioning and visuospatial processes. In a previous study that had the aim of evaluating the effect of short-term meditation on mood and on several cognitive tasks, Zeidan et al. (2010) compared a group of subjects who were involved in sessions of brief mindfulness training with a control group who was exposed to an alternative task, finding that even brief meditation can enhance the ability to sustain attention and improve visuospatial processing, working memory and executive functioning (Zeidan et al. 2010). These results are convergent with the findings in the present study; along with the extended evaluation of the attentional skills, we also examined visual processes and working memory abilities. Our findings provide evidence that long-term meditation can influence working memory, in terms of both accuracy in discrimination and the ability to maintain it over time. The performance of meditators was significantly better, especially when related to two of the four conditions of the N-back task; meditators are able to ignore the not-target stimulus (other responses), meaning that they obtain higher levels of correct answers, which is confirmed by fewer false alarms: Meditators were able to reduce incorrect answers, even when the task increases in difficulty. These results demonstrate the ability to efficiently update information in working memory, maintaining focus for the time necessary to retrieve and refresh information. The presence of higher RTs for the experimental group suggests the use of strategies, which even if they decrease the response velocity, increase the probability of giving the correct answer.

Contrary to predictions, though results were higher for the meditators, we did not find significant evidence of differences between the two groups when compared for visual process abilities. While different visual attention tasks have provided extensive evidence to suggest that meditators perform better at allocating attention over time, conversely the use of the BM enabled the analysis of earlier pre-attentive levels of visual processing. Presently, there is no agreement in the literature as to which attentional processes the test measures; indeed, masking is not a unitary phenomenon (Breitmeyer and Ogmen 2000). Some authors affirm that it refers to early stages of human information processing, others to top-down processes (Breitmeyer 1984); nevertheless, the influence solely of attention in visual masking cannot explain the large extent of theories that have been proposed throughout the years (Breitmeyer and Ogmen 2000). No differences were found between meditators and non-meditators for the performances of the BM; these results are interpreted according to theories claiming that the BM is a measure of early stages of visual processes (e.g., Turvey 1973). Therefore, it is probable that the nature of the task does not allow for an evaluation of mechanisms of attentional engagement and disengagement (as the AB task does), and meditation may influence attention more than the early stages of information processing.

A further goal of the present study was to evaluate the effect of meditation practice on different aspects of mindfulness skills. Results reveal that the meditators obtain higher scores especially for the *observation* subscale, suggesting the ability to pay attention to different stimuli including internal or external phenomena. These results are in line with the definition of meditation itself as a family of regulatory strategies that should allow the accomplishment of self-monitoring and meta-awareness, defined as the ability to reflect or be aware of ongoing thoughts or mental states (Smallwood et al. 2007). Other studies have investigated this aspect, focusing on the relationship between meditation, self-reported mindfulness and cognitive flexibility, finding higher levels of mindfulness skills that were also positively correlated with all attention measures (Moore and Malinowski 2009). Importantly, in the present study, results show positive correlations between the *observation* subscale and the performances in most of the cognitive parameters, indicating a relationship between meditation skills, attentional performance and cognitive flexibility. It is likely that no other difference emerged because of the prevalence of FA techniques used by the participants, which are characterized by self-monitoring and regulation of attention; it is probable that we would have found a major difference in the remaining subscales for OM meditators.

While only longitudinal studies that examine the changes over time may fully resolve the uncertainties and the limitations of cross-sectional designs, extensive data provide evidence that meditation can have an effect on different executive processes, namely attentional processes, working memory and cognitive flexibility in general. As has been pointed out, the novelty of this study was to evaluate, apart from different cognitive functions, the link between meditation and thinking styles. We hypothesized that long-term practice could have an effect on the way people rely on different thinking styles, in terms of preferences in using different strategies, such as logical–analytical, holistic–intuitive and the integration of both. The preference for both modes of thinking has been interpreted as the capacity of processing information in an interactive and dynamic way (Zhang 2006). Even if recent evidence using Torrance's model has mistakenly used the term brain dominance (e.g., Zalewski et al. 1992), researchers have proved that the SOLAT is a good measure of preferred mode of thinking and processing information (Antonietti et al. 2007; Zalewski et al. 1992; Zhang 2002a). Results show that non-meditators present a left-dominant profile; even if for the right-dominant profile results do not evidence a statistical difference, the group of meditators show a preference for an holistic manner of processing information and intuitive strategies (right-dominant profile). This result is in line with the idea that the holistic mode of thinking is creativity-generating (Zhang 2006; Zhang and Sternberg 2006), and is widely known that meditation practice leads to a creative mode of cognition (Glicksohn 1998; Horan 2009). As expected, meditators exhibit higher scores for the integrated profile, meaning that the mental training associated with meditation can improve cognitive flexibility in terms of the ability to use different thinking strategies when needed.

Bearing in mind the major limitation of the present study, that is the cross-sectional design, there is consistent evidence that long-term meditation can have an influence on many aspects of cognitive processes; as hypothesized, meditation training can improve attentional performance, working memory and enhance cognitive flexibility, namely the ability to modulate different strategies in specific situations.

**Acknowledgements** The authors would like to thank Romeo, Z., Ciccocioppi, L. and Scalici, F. for their assistance in data collection.

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