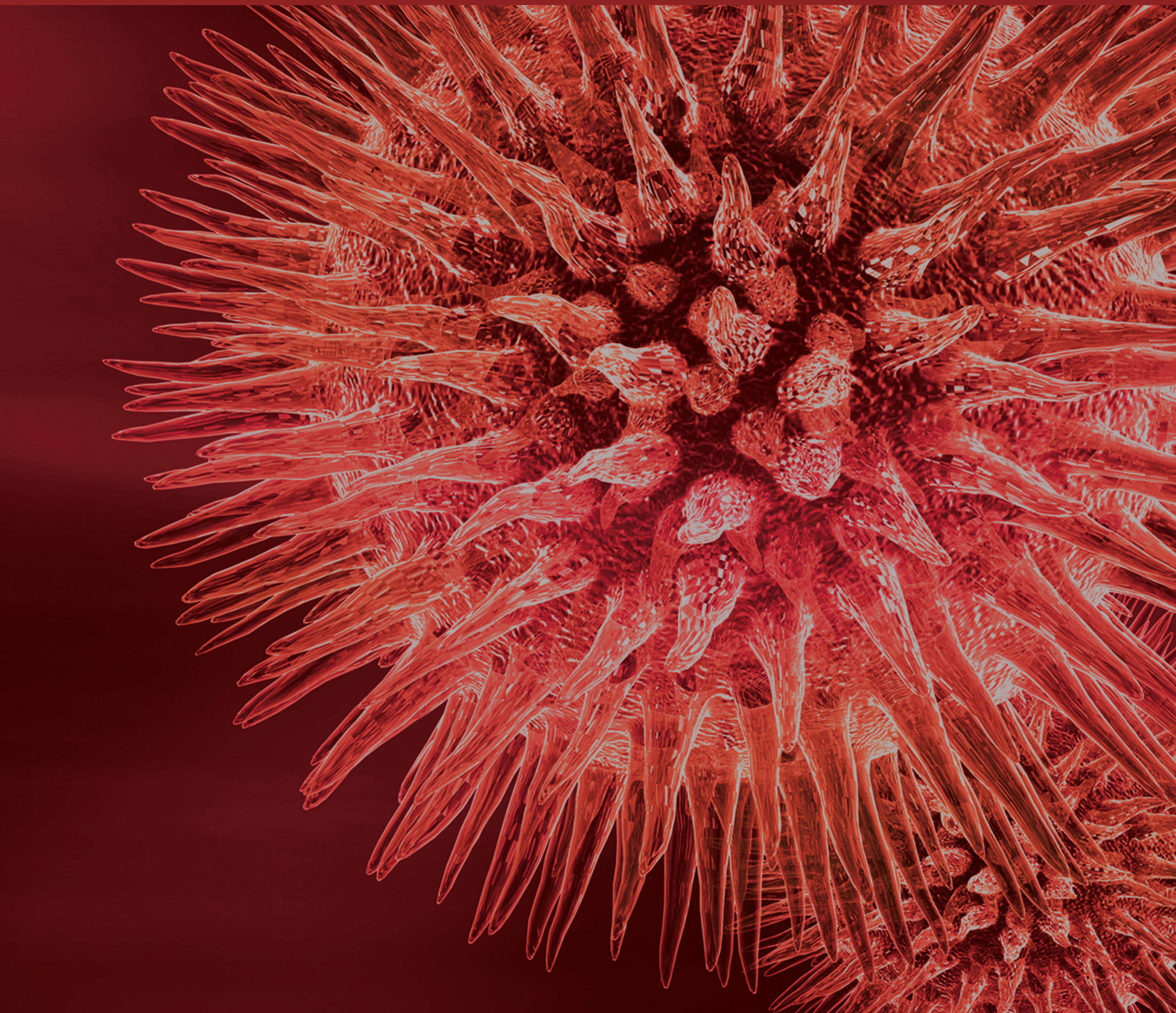
BioMed Research International

Physiological Effects of Mind and Body Practices

Guest Editors: Shirley Telles, Patricia Gerbarg, and Elisa H. Kozasa



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Editorial

Physiological Effects of Mind and Body Practices

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Mind-body practices originated in ancient cultures to enhance physical, mental, and spiritual wellbeing. Interest in their use in treatment stems from increasing awareness of their therapeutic potential and from the need for approaches that are cost-effective and have lower risks for adverse effects compared to pharmacological and other conventional interventions [1–3]. Rigorous research is needed to identify effective mind-body techniques and their mechanisms of action, if they are to be integrated into mainstream medicine [4].

The quality of evidence for mind-body practices varies widely. Scales for rating the quality of research are based on pharmacological studies. Very often the research design applicable to conventional medicine does not apply to mind-body practices. The diversity and complexity of interventions further confound efforts at conventional meta-analysis. Current studies are developing better control interventions and implementing more rigorous methods [2]. The National Center for Complementary and Alternative Medicine (NCCAM) [5] states that "*Developing insight into biological, physiological effects and mechanisms of action of mind and body interventions is critically important in developing translational research tools to design and execute maximally informative clinical research.*" For evaluating mind-body research, modifications of the original CONSORT statement have been proposed and are being evaluated [6].

Studies of mind-body practices suggest numerous mechanisms of action at multiple levels, including gene expression at the cellular level; interactions among central brain regions with neuroplastic changes; and top-down and bottom-up feedback loops between the brain and the body, particularly via the nervous system, interoceptive communication, and circulating neurohormones [7–10]. Prominent among proposed mechanisms are the following: (a) repatterning of primary interoceptive and higher order homeostatic mechanisms; (b) improved central regulation of autonomic, psychologic, neurologic, immunologic, cardiorespiratory, and gastrointestinal functions; (c) reorganization within cortical and subcortical structures, interconnectivity adjustments among central regulatory networks, neurotransmitter changes, improved emotion regulation by higher centers, better interhemispheric balance, and enhanced cognitive function; and (d) modulation of epigenetic factors, such as growth factors or hormones, as well as extensive up- and downregulation of genes [11–13].

The manuscripts in this special issue include both research studies and reviews. For example, effects of mind and body practices on specific higher brain functions such as creativity are explored and with objective markers (pro-NGF levels). A study of 1297 adolescents documents the impact of mind and body practices on academic performance and cardiometabolic risk factors. In young musicians the effects of Qigong are reported to be an enhancement of proprioception and a reduction of anxiety-induced physiological changes. While these three studies focus on higher brain functions and proprioception, additional trials emphasize autonomic changes occurring with mind and body practices. For example, the effects of guided imagery on heart rate variability in students performing spaceflight emergency tasks are evaluated. In another study physiological feedback is matched with self-reported stress while participants perform short tasks. These studies involve healthy volunteers. A single clinical study examines the effect of mindfulness meditation on mood, quality of life and attention in adults with ADHD.

All four review articles are on meditation. An activation likelihood estimation (ALE) reports a co-ordinate based meta-analysis of neuro-imaging studies in meditations of different types. Another review examines the electrophysiological changes in different meditations based on evoked and event-related potentials. Two other reviews looked at the physiological and cognitive effects of meditation, considered as a 'journey without a goal'; and the psychological and neural effects of mindfulness practice underlying its positive impact on health. An interesting comparative review explores the impact different meditation traditions have on the autonomic nervous system and on phasic or tonic changes in attention.

Identifying mind-body practices that show physiological or clear clinical benefits with appropriate biomarkers may lead to the refinement of certain techniques so that they become more efficient, less time-consuming, more effective, and better suited for the treatment of specific conditions. Also, mind-body practices can be used as noninvasive probes to explore fundamental neurophysiological processes and anatomic networks using brain imaging and other advanced technologies. Understanding the physiological changes, clinical benefits, adverse effects and contraindications associated with these practices will support the inclusion of mind-body treatments in mainstream medicine.

By highlighting studies with biological markers and physiological measures, this special issue is intended to further the understanding of mechanisms underlying the diverse effects of mind and body techniques.

Shirley Telles
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Research Article

Mindfulness Meditation Improves Mood, Quality of Life, and Attention in Adults with Attention Deficit Hyperactivity Disorder

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Objective. Adults with attention deficit hyperactivity disorder (ADHD) display affective problems and impaired attention. Mood in ADHD can be improved by mindful awareness practices (MAP), but results are mixed regarding the enhancement of attentional performance. Here we evaluated MAP-induced changes in quality of life (QoL), mood, and attention in adult ADHD patients and controls using more measures of attention than prior studies. *Methods*. Twenty-one ADHD patients and 8 healthy controls underwent 8 weekly MAP sessions; 22 similar patients and 9 controls did not undergo the intervention. Mood and QoL were assessed using validated questionnaires, and attention was evaluated using the Attentional Network Test (ANT) and the Conners Continuous Performance Test (CPT II), before and after intervention. *Results*. MAP enhanced sustained attention (ANT) and detectability (CPT II) and improved mood and QoL of patients and controls. *Conclusion*. MAP is a complementary intervention that improves affect and attention of adults with ADHD and controls.

1. Introduction

The term "mindfulness" has been used to refer to a wide range of phenomena, such as mindfulness as a state, mindfulness as a trait, and mindfulness as a type of training or practice [1], as will be employed here. Interventions based on mindfulness training, such as *mindful awareness practices* (*MAP*), involve intentionally bringing one's attention to one's internal and external experiences in the present moment, and they often involve meditation exercises [2, 3].

Mindfulness-based interventions are considered a type of cognitive training [4] and involve developing strategies that improve attention [5], affective self-regulation [6], and well-being and quality of life [7, 8] in healthy populations [9–11]. Using functional magnetic resonance imaging this type of practice has been shown to improve cognitive control [12] and to establish a stable pattern of deactivation in brain regions related to a mindfulness state [13]. MAP are also beneficial for many clinical conditions, such as anxiety disorders, depression, stress-related physical symptoms, fibromyalgia, chronic pain [14], and attention deficit hyperactivity disorder (ADHD) [4–15]; for a review see [16].

ADHD is characterized by symptoms of inattention, impulsivity, hyperactivity, and affective problems [17–19]. The disorder begins in childhood and can persist until adulthood [17–19] in approximately 50% of patients, and it affects approximately 2–4% of the adult population; see [20].

Regarding affect, ADHD is associated with a lower quality of life [21–23], decreased mood and arousal, and low motivation, all of which can be associated with impaired attentional performance [24, 25] because they relate to cognitive control (conflict resolution, planning, inhibitory control, and error correction) and emotional regulation [26]. In this context, MAP could improve the cognitive/affective processes [6, 27, 28] that are impaired in adults with ADHD [29, 30].

Adults with ADHD show impairment in attentional performance processes considering the influential model of Posner and Petersen [31, 32]. According to these authors, the attention system consists of three functional and anatomically different networks: alerting, the process involved in becoming and staying attentive to one's surroundings, which is closely linked to the concept of sustained attention or vigilance; orienting, or directing attention toward the location or modality of a specific stimulus; and executive attention, which is recruited when there is a conflict among multiple attention cues [31, 32]. These attentional subsystems are classically evaluated using the *Attentional Network Test* (*ANT* [33]). This is a computerized behavioral test that consists of the combination of cued reaction time [34] and the flanker task [35]. Briefly, the ANT involves determining whether arrows presented onscreen are pointing left or right. By measuring how reaction times are influenced by alerting cues, spatial cues, and flanking stimuli (a central arrow was flanked by two arrows pointing either in the same direction or in the opposite direction as the central arrow), the test measures the three attentional networks cited above. This task has determined that executive attention is impaired in adults with ADHD (see [36]), although other studies have shown no impairment [25]. Because a large body of data has shown that performance in this task is clearly related to different brain systems and regions that regulate attention, impairment can indicate physiological changes in brain functioning (see [31, 32]) that cannot be tapped by alterations on subjective measures such as questionnaires.

Another type of computerized attentional test that is widely used to characterize ADHD-induced attentional deficits is *Conner's Continuous Performance Test* (*CPT II* [37]). This test involves a motor response to a series of visual stimuli (letters of the alphabet) and the inhibition of this response to one type of stimulus (the letter x). This test can be used to measure sustained attention (the ability to sustain a consistent focus on continuous activities or stimuli), impulsivity, and selective attention (the ability to focus on relevant stimuli and ignore competing stimuli, a concept related to distractibility). Compared with controls, adults with ADHD make more omission errors on this task [30, 38, 39], present more variability in their mean reaction time [38] and the standard deviation of reaction time [30], are worse at discriminating between target and nontarget stimuli [30], and make more commission errors because of impulsivity or lack of motor inhibition [38–40]. Using measures obtained from the ANT that complement the CPT II, one study showed that adults with ADHD make more omission errors, have lower accuracy and vigilance scores, and present greater variability in responses compared with controls [25]. As with the ANT there are many studies that have associated performance in this test with alterations in specific brain systems. Tana et al. [41], for instance, have shown that performance in this task involves networks consistent with existing models of visual object processing and attentional control. Regarding frontal activation, there was a strong activation in the anterior cingulated cortex, which is particularly important for attentional processing in that it modulates focusing of attention, motor response selection, and error detection. Hence, performance in the ANT and CPT II indicates physiological changes in brain functioning.

The most *accepted* treatment for ADHD according to international guidelines (*NICE Clinical Guideline 072*) is methylphenidate, which improves symptoms. However, other treatments are being sought for a number of reasons: some patients experience side effects that preclude methylphenidate use; others experience only a 30% reduction in symptoms [42]; such stimulants are less effective in adults than in children (see [20]) and some patients are not willing to undergo pharmacological treatment (see [15]). Because many patients undergoing this type of pharmacological treatment still experience functional deficits related to decreases in self-monitoring, attention, and mood, interventions such as MAP that tackle these problems could be used as adjuvant treatments [4, 28].

To our knowledge, however, only two studies [15, 43] have investigated the affective and attentional effects of MAP in adults with ADHD. Zylowska et al. [15] adapted an eight-week group MAP program for this type of patients and showed improvements in ADHD symptoms, executive control (measured using the ANT), and subjective cognitive flexibility and self-regulation. However, that study had no control group, so a practice effect cannot be ruled out. Additionally, the intervention-induced benefits on subjective measures of mood were due to the social interactions of participating in the group sessions. In effect, Mitchell et al. [43], who included a nonintervention group and used the same MAP protocol employed by Zylowska et al. [15], found no evidence of improved attentional performance. They did, however, show that mood benefitted from MAP use. A possible explanation for these conflicting attentional effects is that the type of pharmacological treatment that the patients received was not controlled in these studies, which is important when considering that methylphenidate, the most widely used medication for this disorder, has acute effects on attentional performance [44]. Furthermore, these studies did not include healthy controls, so they could not indicate the measures on which the ADHD patients were impaired in relation to healthy individuals, nor could they establish whether the effects of MAP are differently effective in ADHD patients and in nonclinical populations.

Because meditation has also been shown to improve cognitive efficiency during attentional tasks in the form of less activation in various brain areas [45], it would make sense that practices such as MAP would lead to enhanced attentional performance. Hence, we aimed to investigate the effect of the MAP protocol developed by Zylowska et al. [15] on mood and quality of life (using validated questionnaires), as well as attention (using the ANT and CPT II) in a larger sample of adult ADHD patients of both sexes. We controlled for any acute effects of methylphenidate asking participants on the drug to abstain from their daily dose for 24 h before the study. We also controlled for practice effects by including a control ADHD group that did not participate in the MAP sessions (the nonintervention group). Additionally, to compare the effects of MAP in healthy controls and ADHD patients, two groups of healthy controls were evaluated, one of which participated in MAP and another did not. Based on previous publications [9–11, 15, 43], we hypothesized that MAP would exert positive effects on attentional performance as a proxy for more efficient brain activation during attention tasks [12, 13, 31, 32, 41, 45] in controls and ADHD patients; we also believed that mood would improve in both types of participants. Additionally, we hypothesized that the adults with ADHD would benefit more from the intervention because they have more affective problems and symptoms of inattention and thus would have more room for improvement. We also expected MAP to improve quality of life in patients as a result of better mood and attentional performance, as has been shown for nonclinical samples [7, 8].

2. Methods

2.1. Participants. All the participants were selected according to the following eligibility criteria: age between 18 and 45 years, more than 11 years of education, normal or corrected vision, nonverbal intelligence quotient (IQ) within normal range [46] (adapted for local use; see Campos [47]), no prior experience with meditation practices, and for whom Portuguese was the native language. Candidates diagnosed with neurological disorders, psychosis, obsessive-compulsive disorder, and Tourette syndrome or who were being treated with psychoactive drugs for reasons other than ADHD were not included in the sample. Participants were also excluded if they scored more than 30 on the Beck Depression Inventory (BDI [48], adapted for local use by Cunha [49]), which indicates severe depression [50] and scored more than the mean plus one standard deviation (see Andrade et al. [51] on the Trait Anxiety Questionnaire of the State-Trait Anxiety Inventory [52], adapted for local use by Biaggio and Natalício [53]).

2.1.1. ADHD Patients. The patients were all diagnosed with ADHD using the Structured Clinical Interview of the DSM-IV and fulfilled the diagnostic criteria of the *DSM-IV-TR* [54]. The diagnosis was made by a psychiatrist who specialized in ADHD. The Adult Self-Report Scale (ASRS; Kessler et al. [55], adapted for local use by Mattos et al. [56]) was used to classify and quantify ADHD symptoms. Some of the patients were recruited by physicians from an adult ADHD diagnosis and treatment program (*Programa Déficit de Atenção e Hiperatividade* (PRODATH) of the Psychiatric Institute of the Universidade de São Paulo (FMUSP)). Other ADHD patients responded to calls for participants in the media.

2.1.2. Healthy Participants. The healthy controls did not fulfill criteria for ADHD but met the other eligibility criteria described above. None of the controls took psychoactive medication during the study.

2.2. Procedure. The study was approved by the Ethics Committee of the Universidade Federal de São Paulo and the Universidade de São Paulo (CAAE 20530613.3.3001.0068) and registered at the ClinicalTrials.gov website (Identifier NCT01738334) and at the Registro Brasileiro de Ensaios Clínicos website (Identifier RBR-8dmcnj). All the participants provided informed consent. Information about the included and excluded patients can be found at the beginning of the Results.

Not all of those who were interviewed were willing to participate in MAP, and we were unable to recruit a sufficient number of participants to allow a randomized study. Hence, ours was a quasiexperimental pretest-posttest design with nonequivalent groups in which participants could self-select whether they would or would not participate in the MAP intervention.

Testing took place in the mornings in two one-hour sessions separated by approximately 10 weeks (baseline and endpoint). During this interval, the participants either participated in the eight-week MAP program or underwent no intervention (see details below). Patients treated with methylphenidate took their daily doses in the morning; on testing days they were asked to take their medication only after the experiment. Note that methylphenidate has a relatively short elimination half-life irrespective of its formulation, so that 24 h after their last dose the participants should be free of acute effects of this drug [57].

Affect was measured using validated questionnaires (symptoms of ADHD, mood, and quality of life; see below). The attentional tests administered were the ANT and the CPT II. The tests and questionnaires were administered in a fixed order and were followed by other measures in part of the sample in the preintervention session (a study that investigated ADHD effects on different types of executive functions, Bueno et al. [58]).

Following Zylowska et al.'s [15, 59] protocol, the mindful awareness practices involved weekly two-hour-long group sessions during eight weeks, as well as daily exercises to be performed at home. MAP was conducted on different days for the ADHD patients and the healthy controls.

2.3. Mindful Awareness Practices (MAP). The eight-week group program was adapted from clinical models of mindfulness training [60, 61] by Zylowska et al. [15] and Zylowska [59] to address ADHD-related psychoeducational issues regarding clinical, neurobiological, and etiological symptoms. The material was translated into Portuguese with the permission of the authors, adapted for use in Brazil for both ADHD patients and healthy controls, and was administered by the same highly experienced MAP practitioner. The patients and controls formed separate groups, and the program involved daily exercises to be performed at home (formal meditation and mindfulness in daily living). Each session lasted two and a half hours. Meditation was performed in a seated position, with an emphasis on daily mindfulness. Each session began with a short opening meditation, followed by a discussion about the daily home exercises. After this, new exercises were introduced and practiced by the group in each session, followed by a discussion. Each session ended with a review of the home practice exercises for the following week and a group meditation. All the participants received three CDs to help them with the home meditation practices, which were to be conducted at home for five minutes on weeks one and two, 10 min on weeks three to five, and 15 min on weeks six to eight [15]. The participants kept a diary detailing their meditation at home which allowed us to measure the frequency of the home exercises. At the end of the program, the participants were asked to rate their level of satisfaction with the intervention on a 10-point scale (0 = *totally unsatisfied*; 10 = *totally satisfied*).

2.4. Cognitive and Subjective Ratings

2.4.1. Subjective Rating Questionnaires

Adult ADHD Self-Report Scale (ASRS [55], Adapted for Local Use by Mattos et al. [56]). This questionnaire consists of 18 items evaluated on a five-point scale ranging from *never* (no symptoms) to *very often* (maximum symptoms). Half of the items evaluate the intensity of usual symptoms of inattention, and the other items evaluate hyperactivity/impulsivity symptoms.

Beck Depression Inventory (BDI [49], Adapted for Local Use by Cunha [49]). This is a scale that contains 21 statements regarding symptoms and attitudes related to depression. Each statement is rated on a four-point scale ranging from *neutral* to *maximum severity*. Respondents were asked to rate how they felt in the previous week.

State-Trait Anxiety Inventory (STAI-T [52], Adapted for Local Use by Biaggio and Natalício [53]). This is a self-evaluation scale that contains 20 statements pertaining to anxiety symptoms rated on a four-point scale (1 = *never*; 4 = *always*).

Positive and Negative Affect Schedule—Expanded form (PANAS-X [62], Adapted for Local Use by Peluso [63]). This questionnaire consists of a list of 60 different feelings and emotions. Respondents were asked to rate the extent to which they had these moods during the past week using a five-point scale (1 = *very little or not at all*; 5 = *extremely*). Combinations of these ratings yield two higher-level dimensions (positive affect and negative affect, including 10 feelings each) and 11 lower-order affective levels: fear, sadness, guilt, hostility, shyness, fatigue, surprise, joviality, self-assurance, attentiveness, and serenity. The scores for each dimension were calculated by adding the ratings of all emotions included in each level and dividing the total by the number of emotions in each dimension, so that scores ranged from 1 to 5.

Adult ADHD Quality of Life Questionnaire (AAQoL [64], Adapted for Local Use by Mattos et al. [23]). This scale consists of 29 items rated on a five-point Likert scale (*0 = not at all/never; 5 = extremely/very often; each point receives a score of 25*) that evaluate the level of difficulty in performing activities of daily life grouped into four different areas: life productivity (11 items), psychological health (6 items), life outlook (7 items), and relationships (5 items). Scores for negatively worded items were reversed. Item scores were summed and divided by item count to generate scores for each area and the total score (29 items) and then transformed into 100-point scales. Higher scores indicate better quality of life.

2.5. Attentional Tests

2.5.1. Attentional Network Test (ANT [33]). This task was carried out exactly as described in the original work by Fan et al. [33] and took approximately 25 min. Briefly, each trial began with the presentation of a fixation point on the computer screen on which participants were instructed to fix their eyes throughout the trial. After 400 to 1600 ms, an asterisk (cue) could be presented for 100 ms to direct attention to certain areas of the screen that did or did not coincide with the area in which the targets were presented. There were four cue manipulations (see below). Four hundred milliseconds after trials with cues, the target stimulus was presented. This target stimulus was a central arrow presented in a horizontal row including two flanker arrows to either side of the target. These arrows could point either left or right. The participants' task was to indicate the direction in which the central arrow was pointing by using the right or left button of the mouse. These flankers could point in the same direction as the target arrows (congruent condition, which facilitates responses) or in the opposite direction (incongruent condition, which makes the correct response more difficult). The target stimulus remained onscreen for a maximum of 1700 ms or until the participants responded. There was also a control condition that used lines as targets instead of arrows.

Four types of cues conditions influenced task difficulty: no cue, a condition in which only the fixation point was presented and remained on the screen; central cue, in which an asterisk was presented at the same location as the fixation point (this cue involves alerting because it orients the attention to one location); double cue, in which asterisks were presented simultaneously above and below the fixation point (alerting is involved, but the spatial location is broader than in the following condition); and spatial cue, in which the asterisk always occurred in the same spatial location as the target (both alerting and orienting are involved).

The dependent measures were the difference in hit reaction times (RT), that is, when correct responses were given, between the trials in which there were no cue and a double cue (as a measure of alerting), the difference in hit RT between the trials in which there were a central cue and a spatial cue (orienting), and the difference in hit RT between the trials in which there were congruent and incongruent flankers (as a measure of executive control/conflict). Additionally, we analyzed other measures that are typical of the CPT II [37] following Lundervold et al. [25]: (a) reaction time and accuracy: the mean hit RT and the number of hits and omission errors; (b) variability in response: the standard error of the mean hit RT (hit RT SE) and variability SE: the standard deviation of the 3 standard error values calculated for each block; (c) sustained attention/vigilance for interstimulus intervals (ISI) of 400 ms: the slope of the change in RT and in the standard error of the RT between blocks (hit RT block change and hit SE block change, resp.).

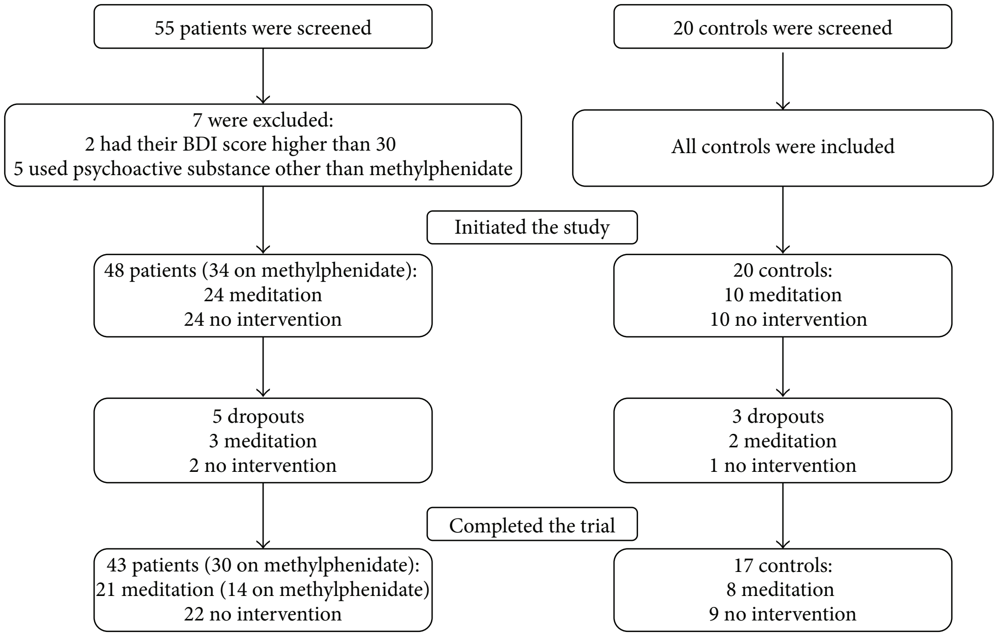

Figure 1: Flowchart of the participants (patients with ADHD and controls).

Before the participants began the task, they underwent a training session involving 24 trials. The task consisted of three blocks with 96 trials each, separated by a short interval. In each block, the following conditions were randomized: 4 cue conditions × 2 target locations × 2 target directions × 3 flanker conditions × 2 repetitions.

2.5.2. Conner's Continuous Performance Test (CPT II [37]). This task lasts 14 min and consists of 6 blocks in which all letters of the alphabet are presented individually in random order on a computer screen for 250 ms each, with random ISIs of 1, 2, or 4 s. Participants are instructed to press a key whenever a letter is presented, except in the case of the letter x (presented 36 times among the 324 letters presented), for which they should inhibit the motor response. The following measures were recorded: the number of omission and commission errors, the mean hit RT, the variability of standard error (variability of SE), the standard error of the mean hit RT (hit RT SE), detectability (d'), response style (β), perseverative responses (reaction time less than 100 ms), the slope of the change in RT and in the standard error of RT between blocks (hit RT block change and hit SE block change, resp.), and the slope of change in RT and in the standard error of RT as a function of the ISI (hit RT ISI change and hit SE ISI change, resp.).

2.6. Statistical Analyses. The level of significance was $P \leq 0.05$. We used general linear models (GLM) followed by Tukey's honest significant difference test (HSD) for unequal size samples when factors interacted. The factors and levels will be detailed in the Results. Only significant GLM and *post hoc* effects will be described below. When two or more factors interacted, only the higher-order effects will be described. For measures that showed interactions between intervention and session (there were no interactions of these factors with health status; see below) the magnitude of effects was determined through effect-size calculations (Hedges g [65]) following the general rules of thumb to classify effects sizes as small (<0.5), medium (between 0.5 and 0.8), and large (>0.8). These calculations were conducted using change scores (the mean post- minus preintervention scores of participants who underwent MAP and those who did not, divided by the pooled change-score standard deviation), following Mitchell et al. [43]. To assess whether MAP-associated alterations in mood/ADHD symptoms were related to attentional enhancement, we calculated the Pearson product moment correlations between the change scores for attentional measures that benefitted from the MAP and change scores in depression, anxiety, and ADHD symptoms (ASRS).

3. Results

We screened 55 patients, and seven were excluded (two because their BDI scores were higher than 30 and five because they used psychoactive substances other than methylphenidate). All 20 screened controls were included in the study. Our final sample consisted of 48 patients (34 on methylphenidate) and 20 controls (see the flowchart in Figure 1). Twenty-one patients (11 men) and eight controls (3 men) showed interest in participating in the MAP program. The subjects who did not undergo the MAP intervention between the two testing sessions included 22 ADHD patients (12 men) and nine controls (4 men). Thirteen of the patients had never been medicated for ADHD either by choice or because their condition had not been previously identified; seven of those patients participated in the MAP program. The remainder of the patients used methylphenidate in stable doses for 2 to 60 months (mean ± SD: 16.9 ± 19.8 months), fourteen of whom took part in the MAP.

Two ADHD participants and two healthy controls allocated to the MAP intervention dropped out of the study for personal reasons. Their data were excluded from the analyses. Three control participants (two from the MAP group) did not attend the reevaluation after the intervention period, and their data were excluded. Our final sample consisted of twenty-one ADHD patients (11 men) and eight controls (3 men) who participated in MAP and twenty-two ADHD patients (12 men) and nine controls (4 men) who underwent no intervention. No adverse events associated with MAP were brought to the experimenters' attention. The doses of methylphenidate of the patients taking medication did not change during the study. Fourteen patients (8 men) taking medication were in the intervention group, and sixteen (10 men) were in the nonintervention group.

3.1. Comparison of the Demographical Variables and Nonverbal IQ (Preintervention) of Patients and Controls (Table 1). Demographic information was analyzed using group as factor (ADHD patients who participated in MAP, ADHD patients who did not participate in MAP, healthy controls who participated in MAP, and healthy controls who did not participate in MAP). There were no differences between groups in demographic variables and IQ (all P values > 0.16). Therefore, differences in attentional performance and subjective measures could not be attributed to these characteristics.

3.2. Home Practice and Satisfaction with MAP. See Table 1.

3.3. Effects of the MAP Intervention on Subjective Measures (Table 2). For each dependent measure, GLMs were used which included session (baseline = before the eight-week intervention or nonintervention period; endpoint = after that period) as a within-subject repeated measure factor; health status (ADHD patients or healthy controls) and intervention (MAP or no intervention) were used as between-subjects factors. We focused on the following effects: the interactions of intervention (MAP and no intervention) and session (baseline and endpoint) to determine whether participants willing to participate in MAP differed at baseline from those who were not and whether at the endpoint session measures were improved by MAP; the main effect of session to determine practice effects; the main effects of health status to show the measures in which patients and controls differed; and the interaction of health status, intervention, and session to determine if the MAP was differently effective in patients and controls.

Regarding the questionnaires used in this study, overall, the patients reported more symptoms of ADHD, depression, anxiety, negative mood, and worse quality of life compared with controls. Most of the variables under investigation were sensitive to the MAP intervention, and in the majority of cases this factor interacted with session. With a single exception (subjective inattention on the ASRS), there were no baseline differences between the participants who did and did not participate in MAP. At the endpoint, positive mood and quality of life increased and negative symptoms decreased in the participants who underwent MAP, both in relation to baseline and compared with the participants in the nonintervention condition. There were no interactions between health status, session, and intervention (P values > 0.08), indicating that there were no significant differences between the ADHD patients and controls. This information will be detailed below.

The analysis of the ADHD symptoms evaluated by ASRS (Table 2) showed health status effects for inattention ($F_{(1,56)} = 137.41$; $P < 0.001$) and hyperactivity-impulsivity ($F_{(1,56)} = 32.87$; $P < 0.001$), with ADHD patients reporting more symptoms than the controls did. In both cases, there was also an interaction between intervention and session. For inattention ($F_{(1,56)} = 20.23$; $P < 0.001$), the interaction was explained by the fact that, before the intervention, the participants who were willing to undergo MAP had more symptoms than those who were not willing to do so, while the opposite was true after the intervention (P values < 0.05); there were no session differences among the participants who did not participate in MAP, while symptoms decreased among those who participated in MAP ($P < 0.01$). Inattention was the only measure that indicated a difference at baseline between those who were willing to participate in MAP and those who were not. The effect size on change scores for those who did and did not participate in MAP was large ($g = -1.3$). Figure 2 shows the effect sizes of all the measures for which there was an interaction between session and intervention.

For hyperactivity-impulsivity scores, there was also an interaction between session and intervention ($F_{(1,56)} = 7.83$; $P = 0.01$). At baseline, there were no significant differences between intervention groups. Additionally, there were no significant differences between the participants who did not undergo MAP. Conversely, at the endpoint, those who participated in MAP reported fewer symptoms compared with their baseline scores and with those who did not participate in MAP ($P < 0.01$). The effect size on the change scores for those who participated in MAP and those who did not was large ($g = -0.8$).

For the depression and anxiety scores obtained from the BDI and STAI-T, respectively (Table 2), we found the same pattern of GLM and *post hoc* effects that we found for hyperactivity-impulsivity symptoms on the ASRS. There was a main effect of health status, indicating that the ADHD patients showed more symptoms on the BDI ($F_{(1,56)} = 11.83$; $P < 0.001$) and STAI-T ($F_{(1,56)} = 27.26$; $P < 0.001$). We also found an interaction between session and intervention for the BDI ($F_{(1,56)} = 5.79$; $P = 0.02$) and STAI-T ($F_{(1,56)} = 5.59$; $P = 0.02$), which indicated no significant difference between conditions at baseline and a MAP-related improvement at endpoint compared with baseline and with the participants who did not undergo intervention (P values < 0.05), with no significant differences between sessions in the nonintervention condition. Effect sizes for the BDI and STAI-T measure considering the change scores of those who participated in MAP and those did not were medium ($g = -0.7$) and large ($g = -0.8$), respectively.

Regarding the PANAS-X (Table 2), there was a main effect of health status for most variables, which indicated worse mood in the ADHD patients (negativeaffect: $F_{(1,56)} = 9.54$,

Table 1: Mean (standard deviation) of demographic information per group (control and patients with attention deficit hyperactivity disorder (ADHD) submitted to mindful awareness practices (MAP) or to no intervention) and statistical comparison between them, times of at-home practice, and rating of satisfaction with the programme in the groups submitted to the MAP.

Variable	MAP control (N = 8)	No intervention control (N = 9)	MAP ADHD (N = 21)	No intervention ADHD (N = 22)	P
Demographics					
Gender (men/women)	3/5	4/5	11/10	12/10	
Age (years)	26.9 (3.9)	28.7 (5.5)	31.2 (7.5)	31.7 (7.8)	0.32
Education (years)	16.0 (2.8)	15.9 (2.0)	14.6 (2.4)	15.1 (3.2)	0.53
IQ Raven (number correct)	54.4 (1.7)	52.2 (7.4)	52.6 (3.7)	49.4 (7.4)	0.16
At-home practices (min)*					
Week 1	15.6 (11.2)		32.9 (17.6)		
Week 2	21.3 (7.9)		19.8 (14.1)		
Week 3	31.3 (18.1)		48.1 (27.3)		
Week 4	37.5 (10.4)		52.9 (48.8)		
Week 5	45.0 (10.7)		50.5 (42.8)		
Week 6	54.4 (15.9)		49.7 (50.7)		
Week 7	45.0 (16.0)		42.9 (57.6)		
Week 8	48.8 (10.6)		33.6 (20.6)		
Satisfaction (1–10 score)	9.3 (0.9)		9.3 (0.9)		0.82

*No effect of health status or interaction with week, but there was an effect of week [F (7, 189) = 4.35; P < 0.001]: practice in weeks 3–8 > weeks 1-2 (P < 0.001).

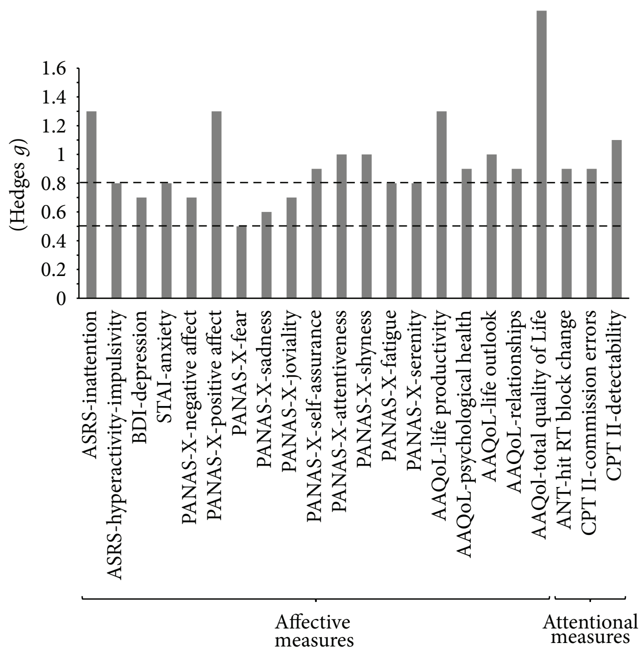

Figure 2: Effect sizes (Hedges g) of affective and attentional measures for variables for which there was an interaction of session and intervention factors considering change scores (post- minus preintervention period). Dotted lines indicate medium effect sizes ($g > 0.5$) and large effect sizes ($g > 0.8$). ASRS: Adult Self-Report Scale, BDI: Beck Depression Inventory, STAI: trait anxiety of the State-Trait Anxiety Inventory, PANAS-X: Positive and Negative Affect Schedule—Expanded Form, AAQoL: Adult ADHD Quality of Life Questionnaire, ANT: Attentional Network Task, CPT II: Conner's Continuous Performance Test, and Hit RT: reaction time of correct responses.

$P < 0.001$; positive affect: $F_{(1,56)} = 4.88$, $P = 0.03$; sadness: $F_{(1,56)} = 4.95$, $P = 0.03$; joviality: $F_{(1,56)} = 10.08$, $P < 0.001$; self-assurance: $F_{(1,56)} = 4.72$, $P = 0.03$; attentiveness: $F_{(1,56)} = 15.80$, $P < 0.001$; fatigue: $F_{(1,56)} = 4.41$, $P = 0.04$; and serenity: $F_{(1,56)} = 14.05$, $P < 0.001$). For these same variables, plus shyness and fear, we also found interactions between session and intervention (negative affect: $F_{(1,56)} = 7.49$, $P = 0.01$; $g = -0.7$; positive affect: $F_{(1,56)} = 18.13$, $P < 0.001$; $g = 1.3$; sadness: $F_{(1,56)} = 7.92$, $P = 0.01$; $g = -0.6$; joviality: $F_{(1,56)} = 7.82$, $P = 0.01$; $g = 0.7$; self-assurance: $F_{(1,56)} = 9.05$, $P < 0.001$; $g = 0.9$; attentiveness: $F_{(1,56)} = 6.50$, $P = 0.01$; $g = 1.0$; fatigue: $F_{(1,56)} = 4.80$, $P = 0.03$; $g = -0.8$; serenity: $F_{(1,56)} = 7.13$, $P = 0.01$; $g = 0.8$; shyness: $F_{(1,56)} = 10.24$, $P < 0.001$; $g = -1.0$; fear: $F_{(1,56)} = 9.25$, $P < 0.001$; $g = -0.5$). The pattern of *post hoc* effects was the same as that observed for hyperactivity-impulsivity symptoms on the ASRS and depression and anxiety scores (P values < 0.05).

Regarding quality of life assessed with the AAQoL questionnaire (Table 2), there was a main effect of health status for all variables, indicating worse quality of life in the ADHD patients (life productivity: $F_{(1,56)} = 30.45$, $P < 0.001$; psychological health: $F_{(1,56)} = 16.50$, $P < 0.001$; life outlook: $F_{(1,56)} = 21.20$, $P < 0.001$; relationships: $F_{(1,56)} = 24.64$, $P < 0.001$; total quality of life: $F_{(1,56)} = 35.17$, $P < 0.001$). There were also interactions between session and intervention for all domains (life productivity: $F_{(1,56)} = 19.06$, $P < 0.001$; $g = 1.3$; psychological health: $F_{(1,56)} = 8.67$, $P < 0.001$; $g = 0.9$; life outlook: $F_{(1,56)} = 14.73$, $P < 0.001$; $g = 1.0$; relationships: $F_{(1,56)} = 8.76$, $P < 0.001$; $g = 0.9$; total quality of life $F_{(1,56)} = 28.13$, $P < 0.001$; $g = 1.5$). These effects followed the same general pattern described above, that is, no significant difference between conditions at baseline,

Table 2: Mean (standard deviation) scores on the Adult ADHD Self-Report Scale (ASRS), Beck Depression Inventory (BDI), State-Trait Anxiety Inventory (STAI-T), Positive and Negative Affect Schedule—expanded form (PANAS-X), and Adult ADHD Quality of Life Questionnaire (AAQoL) per group (control and patients with attention deficit hyperactivity disorder (ADHD) submitted to mindful awareness practices (MAP) or to no intervention) at baseline and after the intervention period (endpoint) and significant effects.

Measure	Meditation Control ($N = 8$)		No intervention Control ($N = 9$)		Meditation ADHD ($N = 21$)		No intervention ADHD ($N = 22$)		Significant effects
	Baseline	Endpoint	Baseline	Endpoint	Baseline	Endpoint	Baseline	Endpoint	
ASRS									
Inattention	15.5 (3.3)	11.9 (3.4)	10.0 (2.8)	11.1 (5.1)	29.4 (3.9)	21.9 (5.1)	27.4 (5.9)	26.2 (4.9)	H; S × I
Hyperactivity-impulsivity	14.6 (4.1)	11.3 (3.5)	10.8 (4.4)	11.9 (3.2)	21.9 (7.1)	17.9 (5.6)	23.1 (6.9)	21.9 (6.5)	H; S × I
Depression (BDI)	10.0 (8.2)	4.6 (2.7)	4.0 (3.0)	4.1 (2.0)	14.0 (7.9)	10.6 (9.5)	12.4 (7.7)	12.6 (8.2)	H; S × I
Anxiety (STAI-T)	42.9 (6.2)	37.1 (3.3)	35.4 (3.9)	34.9 (8.5)	53.7 (11.7)	45.5 (11.3)	52.2 (11.2)	51.6 (10.2)	H; S × I
PANAS-X									
Negative affect	2.1 (1.1)	1.4 (0.2)	1.5 (0.4)	1.5 (0.4)	2.2 (0.8)	1.8 (0.7)	2.3 (0.7)	2.4 (0.8)	H; S × I
Positive affect	2.5 (0.8)	3.2 (0.9)	3.0 (0.5)	3.0 (0.5)	2.3 (0.6)	2.6 (0.7)	2.7 (0.8)	2.4 (0.7)	H; S × I
Fear	2.0 (1.0)	1.3 (0.2)	1.4 (0.2)	1.7 (0.6)	1.9 (0.7)	1.6 (0.7)	2.0 (0.6)	2.0 (0.6)	S × I
Hostility	1.9 (0.8)	2.6 (3.8)	1.4 (0.4)	1.4 (0.2)	2.1 (0.9)	1.7 (0.7)	2.1 (0.8)	2.1 (0.7)	
Guilt	2.0 (0.9)	2.6 (3.8)	1.5 (0.4)	1.7 (0.7)	2.0 (0.9)	1.5 (0.5)	2.0 (0.9)	2.2 (1.0)	
Sadness	2.0 (0.7)	1.3 (0.3)	1.4 (0.4)	1.6 (0.8)	2.2 (1.1)	1.8 (1.1)	2.1 (1.0)	2.4 (2.1)	H; S × I
Joviality	2.7 (0.9)	3.3 (1.1)	3.0 (0.6)	2.7 (0.5)	2.2 (0.6)	2.5 (0.9)	2.5 (0.8)	2.2 (0.7)	H; S × I
Self-assurance	2.1 (0.6)	2.7 (0.9)	3.3 (1.2)	3.2 (1.2)	2.0 (0.5)	2.7 (1.0)	2.5 (0.9)	2.4 (0.7)	H; S × I
Attentiveness	3.1 (0.8)	3.3 (0.7)	3.3 (0.7)	3.4 (0.5)	2.2 (0.7)	2.8 (0.7)	2.5 (0.9)	2.4 (0.8)	H; S × I
Shyness	2.2 (1.0)	1.4 (0.4)	1.9 (0.6)	1.7 (0.4)	2.0 (0.8)	1.3 (0.4)	2.1 (0.8)	2.0 (0.8)	S × I
Fatigue	2.6 (1.3)	2.0 (0.5)	2.1 (0.8)	2.0 (0.7)	2.9 (0.7)	2.3 (1.0)	2.5 (0.7)	2.6 (0.9)	H; S × I
Serenity	2.7 (0.6)	3.2 (0.6)	2.9 (0.6)	3.0 (0.7)	2.2 (0.6)	2.7 (0.7)	2.4 (0.7)	2.3 (0.5)	H; S × I
Surprise	1.6 (0.7)	1.6 (0.7)	1.7 (0.8)	1.5 (0.5)	1.5 (0.6)	1.7 (0.8)	1.9 (0.9)	1.7 (0.6)	
AAQoL									
Life productivity	64.5 (15.5)	77.8 (10.2)	63.4 (21.2)	61.3 (19.6)	34.4 (13.2)	57.1 (10.4)	38.4 (20.4)	43.3 (17.0)	H; S × I
Psychological health	60.9 (16.4)	65.3 (13.1)	64.4 (17.2)	58.3 (17.9)	39.5 (15.1)	57.7 (17.5)	39.4 (19.1)	42.2 (16.2)	H; S × I
Life outlook	56.3 (12.2)	76.4 (13.0)	66.0 (9.7)	67.5 (10.2)	48.2 (16.1)	60.4 (16.4)	45.9 (16.9)	43.2 (15.5)	H; S × I
Relationships	63.1 (20.2)	71.3 (14.3)	70.0 (16.4)	65.6 (18.1)	43.1 (15.9)	60.7 (13.2)	43.4 (18.9)	44.1 (15.0)	H; S × I
Total quality of life	61.2 (12.5)	72.7 (9.3)	66.0 (14.3)	63.2 (12.5)	41.3 (11.8)	59.0 (12.1)	41.8 (14.1)	43.2 (11.9)	H; S × I

H: effect of health status (ADHD versus controls); S: effect of session (baseline versus endpoint) or practice effect; I: effect of intervention (MAP versus no intervention); ×: interaction of factors (P values < 0.05). See text for details on the statistical analysis.

and improvement after MAP at endpoint compared with baseline and with participants who did undergo intervention (P values < 0.001); additionally, there was no significant difference in performance between sessions in participants who did not participate in MAP.

3.4. Effects of MAP on Attentional Performance Measures (Table 3). We employed the same GLMs and factors that were used to evaluate affective measures. The pattern of effects on attention performance differed from the pattern of effects on affective ratings. On the ANT, there were no effects of health status alone and no interaction between this factor and others. Regarding the effects of session (practice effects), we obtained various indications that the task was sensitive to practice effects because performance was better at the endpoint than at baseline for the variables executive control/conflict ($F_{(1,56)} = 12.80$; $P < 0.001$), hit RT ($F_{(1,56)} = 11.57$; $P < 0.001$), accuracy ($F_{(1,56)} = 31.33$; $P < 0.001$), omission errors ($F_{(1,56)} = 50.55$; $P < 0.001$), hit RT SE ($F_{(1,56)} = 7.29$; $P = 0.01$), and hit SE block change ($F_{(1,56)} = 4.90$; $P = 0.03$).

However, there were also positive effects of the MAP intervention irrespective of health status (see Figure 2 for the effect sizes of the intervention). The intervention interacted with session for the hit RT block change measure ($F_{(1,56)} = 8.16$; $P = 0.01$; $g = -0.9$). The pattern of *post hoc* contrasts was the same as that observed for most of the affective measures: there were no significant differences between conditions at baseline, but at endpoint the MAP intervention improved scores compared with baseline and with the scores of the participants who did not participate in the intervention (P values < 0.05), which were not statistically different at both sessions.

Table 3: Mean (standard deviation) scores on the Attentional Network Task (ANT) and the Conners Continuous Performance Test (CPT II) per group (control and patients with attention deficit hyperactivity disorder (ADHD) submitted to mindful awareness practices (MAP) or to no intervention) at baseline and after the intervention period (endpoint) and significant effects.

Measure	Meditation Control ($N = 8$)		No intervention Control ($N = 9$)		Meditation ADHD ($N = 21$)		No intervention ADHD ($N = 22$)		Significant effects
	Baseline	Endpoint	Baseline	Endpoint	Baseline	Endpoint	Baseline	Endpoint	
ANT									
Alerting	33.6 (22.2)	43.8 (28.8)	33.4 (21.4)	35.8 (27.0)	32.0 (29.0)	39.3 (19.7)	37.4 (28.8)	46.0 (27.1)	
Orientation	29.3 (11.6)	30.1 (13.8)	16.8 (14.4)	26.4 (22.7)	29.8 (30.5)	32.1 (21.2)	32.2 (41.0)	26.6 (23.8)	
Executive control/conflict	114.8 (38.9)	88.1 (38.0)	198.2 (68.2)	114.3 (55.2)	184.6 (98.5)	140.1 (77.2)	150.7 (64.9)	107.5 (69.9)	S
Hit RT (ms)	535.1 (75.5)	488.8 (46.8)	612.2 (114.6)	597.1 (142.1)	577.4 (123.0)	537.4 (90.2)	546.4 (101.8)	511.9 (89.8)	S
Accuracy (number)	274.9 (9.6)	284.0 (4.3)	274.8 (8.1)	278.1 (9.0)	272.0 (11.4)	278.5 (9.3)	273.4 (9.9)	277.0 (9.1)	S
Omissions (number)	5.4 (3.3)	3.0 (3.0)	5.3 (3.4)	3.8 (3.1)	7.2 (4.5)	4.4 (3.5)	7.0 (3.4)	4.6 (3.3)	S
Hit RT SE	16.1 (6.2)	13.2 (7.7)	18.6 (4.9)	15.9 (17.3)	16.4 (14.0)	11.3 (7.4)	20.2 (11.3)	11.9 (6.6)	S
Variability of SE	1.3 (1.0)	1.4 (1.6)	1.9 (1.1)	2.1 (1.5)	2.1 (1.6)	1.6 (1.6)	2.3 (1.8)	1.6 (1.1)	
Hit RT block change	−17.8 (17.4)	−26.1 (13.4)	−18.5 (25.1)	−10.1 (31.1)	−5.5 (22.9)	−19.7 (16.0)	−12.4 (22.0)	−1.9 (15.6)	S × I
Hit SE block change	−0.18 (0.66)	−1.18 (1.50)	−1.01 (1.74)	−0.99 (2.12)	−0.18 (2.36)	−1.29 (1.54)	0.08 (1.60)	−0.93 (2.18)	S
CPT II									
Omission errors (number)	1.4 (2.0)	0.0 (0.0)	1.7 (2.7)	1.1 (1.3)	2.4 (4.3)	2.1 (3.2)	3.8 (7.6)	2.8 (5.7)	
Commission errors (number)	9.1 (4.0)	4.5 (3.6)	7.2 (4.4)	7.7 (4.4)	15.1 (7.8)	10.6 (8.4)	12.5 (9.8)	12.9 (9.7)	H; S × I
Hit RT (ms)	385.8 (76.0)	407.0 (55.0)	408.5 (68.5)	396.9 (64.3)	386.3 (75.0)	397.1 (69.3)	376.9 (115.6)	378.2 (67.8)	
Variability of SE	5.9 (1.5)	5.1 (2.3)	7.6 (1.9)	7.8 (4.7)	7.9 (3.6)	8.4 (8.4)	9.7 (8.8)	9.8 (12.5)	
Hit RT SE	5.2 (1.6)	5.0 (1.6)	5.5 (1.4)	5.4 (2.0)	6.0 (2.2)	5.8 (3.0)	6.5 (2.6)	6.2 (3.7)	
Detectability (d')	0.9 (1.3)	1.3 (0.4)	1.1 (0.4)	1.0 (0.3)	0.7 (0.4)	0.9 (0.5)	0.9 (0.7)	0.8 (0.6)	H; S × I
Hit RT block change	−0.014 (0.035)	−0.013 (0.028)	−0.003 (0.021)	−0.003 (0.017)	0.001 (0.034)	−0.004 (0.025)	−0.011 (0.030)	−0.003 (0.027)	
Hit SE block change	−0.030 (0.059)	0.033 (0.058)	0.021 (0.065)	0.004 (0.081)	0.001 (0.063)	0.016 (0.060)	0.002 (0.103)	0.001 (0.066)	
Hit RT ISI change	0.058 (0.014)	0.061 (0.011)	0.046 (0.039)	0.052 (0.040)	0.046 (0.043)	0.050 (0.043)	0.066 (0.030)	0.058 (0.035)	
Hit SE ISI change	−0.015 (0.120)	0.019 (0.077)	−0.019 (0.100)	−0.006 (0.112)	−0.030 (0.099)	−0.017 (0.133)	0.002 (0.104)	0.027 (0.117)	
Response style (β)	0.6 (0.8)	0.7 (0.6)	0.9 (0.8)	1.7 (1.5)	1.1 (2.4)	0.7 (0.6)	1.0 (1.1)	0.5 (0.4)	
Perseverations	0.0 (0.0)	0.0 (0.0)	0.4 (0.7)	0.4 (0.7)	0.7 (1.5)	2.4 (5.9)	1.8 (3.6)	1.7 (3.4)	

Hit: correct responses; RT: reaction time; SE: standard error of the mean; ISI: interstimulus interval; H: effect of health status (ADHD versus controls); S: effect of session (baseline versus endpoint) or practice effect; I: effect of intervention (MAP versus no intervention); ×: interaction of factors (P values < 0.05). See text for details on the statistical analysis.

Regarding the CPT II (Table 3), a main effect of health status was found for commission errors ($F_{(1,56)} = 6.88$; $P = 0.01$) and detectability ($F_{(1,56)} = 4.06$; $P = 0.05$); the ADHD patients displayed worse scores, as expected. Furthermore, there was an interaction between session and intervention for both of these variables (commission errors $F_{(1,56)} = 8.74$; $P < 0.001$; $g = -0.9$; detectability $F_{(1,56)} = 13.24$; $P < 0.001$; $g = 1.1$), again with the same *post hoc* beneficial effects of MAP that were described for affective measures and hit RT block change on the ANT.

Changes in depression and anxiety scores did not correlate with performance changes in any of the attentional changes (P values > 0.15). Low correlations were found between ADHD symptoms and attentional measures: inattention ratings correlated with commission errors ($R = 0.38$; $P = 0.003$) and detectability ($R = -0.29$; $P = 0.02$), while hyperactivity-impulsivity ratings correlated with commission errors ($R = 0.35$; $P = 0.006$) and detectability ($R = -0.30$; $P = 0.02$).

4. Discussion

Overall, we found that the adults with ADHD had worse affective ratings, quality of life, and attentional performance compared with controls and that MAP improved measures in all of these parameters, in accordance with our hypothesis. However, these effects did not show significant differences between controls and patients, a finding that we did not expect given the larger number and greater intensity of negative symptoms in the patients. Most of the MAP-induced effects reached large effect sizes, which attests to the clinical importance of our findings.

First, we should address a possible difference between the individuals who were willing to participate in MAP and those who were not. We found only one difference at baseline between these groups of individuals, which did not interact with health status; therefore, we believe that our quasiexperimental design, though not ideal, did not negatively impact our main findings of the beneficial effects of the MAP. Among the 21 subjective measures evaluated at baseline, the ADHD patients and healthy controls who wanted to participate in the intervention (meditation ADHD and meditation control, resp.) rated themselves similarly to those who did not want to participate (no intervention ADHD and no intervention control, resp.). These measures were related to the scores of ASRS measures of inattention, hyperactivity-impulsivity, Beck Depression, STAI anxiety, PANAS-X measures of negative affect, positive affect, fear, hostility, guilt, sadness, joviality, self-assurance, shyness, fatigue, serenity, and surprise, as well as the quality of life measures, that is, life productivity, psychological health, life outlook, relationships, and total quality of life, except that the meditation ADHD and meditation control (intervention groups) reported being less attentive compared with the no intervention ADHD and no intervention control groups in the PANAS-X attentiveness score. However, there was no objective indication of worse attentiveness among these individuals on any of the 22 objective attentional measures on the ANT and CPT II measures. Hence, we believe that this sole effect does not reflect an actual difference in the profile of the participants who did and did not undertake MAP.

Regarding subjective ratings of mood, the ADHD patients reported more ADHD symptoms, depression, and anxiety, as well as more negative and less positive affect compared with healthy controls, as expected [24, 25]. MAP improved these symptoms in the ADHD patients, in accordance with the results of Mitchell et al. [43] and Zylowska et al. [15], and in the healthy controls, as reported by Astin [9], Jha et al. [10], and van den Hurk et al. [11]. Both the participants with ADHD and the healthy control participants found the intervention rewarding, as determined by their high satisfaction ratings, and both groups were motivated by MAP based on both their attendance of the weekly sessions and the frequency and extent of their home practices. In comparison, the mood ratings of the participants who did not participate in the MAP program did not change between sessions. This indicates that the affective state was stable during the period during which the program took place. Furthermore, the experience of having completed the questionnaires previously did not alter the participants' subjective ratings, so test-retest reliability seems to have been adequate for these measures.

Regarding the assessment of quality of life with the AAQol, which focuses on ADHD problems, we also showed that the ADHD patients had worse ratings than the controls did, as is commonly found [20], corroborating our hypothesis. Additionally, the interaction between session and intervention mirrored the above-mentioned beneficial MAP-induced effect on mood; the patients and controls reported greater life productivity and psychological health, a better outlook on life, and improved relationship issues after the intervention, and all effects sizes were large. This finding also confirms findings that nonclinical populations experience improved quality of life after mindfulness training [7, 8].

Concerning performance on attentional tasks, like others, we observed that the ADHD patients showed impairment on the CPT II measures commission errors, an indication of impulsivity [38–40], and detectability, or the ability to distinguish relevant from irrelevant information [30], which is related to the concept of executive control [26]. The classic ANT measures were not impaired in the ADHD patients at baseline. This finding supports those of Lundervold et al. [25] but differs from those of Lampe et al. [36], who showed executive deficits, which we found using the CPT II. Hence, it seems ideal to use both of these tasks to evaluate executive attentional deficits in ADHD.

Concerning the attentional effects of MAP, the CPT II measures that were impaired in ADHD patients at baseline compared with controls (i.e., commission errors and detectability) were improved by the intervention. Nonetheless, these effects were not specific to ADHD patients and were also observed in the controls (interaction of intervention and session). These results indicate better MAP-induced regulation of behavior and/or self-control of impulsive tendencies [66] with the consequential potential for improving attention and emotion [6, 27]. These attentional changes, though, are most likely not wholly secondary to improvements in mood and ADHD symptoms, considering that correlations were not present or low. This confirms that MAP can alter brain functioning related to attentional performance [12, 13, 31, 32, 41, 45].

Despite repetition of the attentional tasks (baseline and endpoint), we did not find any measure on the CPT II that exhibited practice effects (main effect of session with no interaction with other factors), indicating that results were not contaminated by a lack of test-retest reliability. In contrast, various variables obtained from the ANT were susceptible to repetition, as Ishigami and Klein [67] found, including the executive/conflict measure, for which performance improved at endpoint compared with baseline. Various other measures derived from the ANT that are classical CPT II measures (see [25]) were also improved at endpoint (hit RT, hit RT SE, hit SE block change, omission errors, and accuracy) irrespective of health status. Hence, MAP's positive executive effects on the ANT in ADHD patients, as reported by Zylowska et al. [15], may have been caused by practice and not the intervention itself. Note that these authors only compared performance between baseline and after MAP in ADHD patients and did not include a nonintervention control group. In contrast and in agreement with our results, Mitchell et al. [43], who controlled for practice effects, found that the same MAP protocol that was used here and by Zylowska et al. [15] had no beneficial effect on the classic ANT measures. Mitchell et al. [43] also failed to find MAP-induced effects on the CPT II, in contrast with our findings; this difference may be related to a lack of power, as their sample of ADHD patients was smaller.

Despite these practice effects, we did show objective beneficial changes resulting from MAP on a variable that was not evaluated in the latter studies. The measure hit RT block change, which was derived from the ANT data, improved after the MAP intervention, and this can be attributed to increases in the ability to sustain attention or vigilance [31, 32], an ability that is impaired in adults with ADHD [68] and seems to improve after mindfulness practices [5]. However, this effect is not commonly found when the CPT II is used [38]. Interestingly, this effect was not shown for the analogous measure obtained from the CPT data, or for the alerting variable of the ANT, a concept that is highly similar to sustained attention/vigilance (see [43]). Hence, it seems to be useful to calculate CPT measures using the ANT results, as proposed by Lundervold et al. [25], because doing so increases the likelihood of detecting susceptibility to practice effects and changes in attentional performance.

There are indications that mindfulness practices can improve executive attention in inexperienced meditators, especially after short-term programs (see [5]), but we did not find such improvements using the ANT. However, we did show a MAP-induced improvement in the CPT II variables detectability and commission errors, in contrast with some studies that used this task (see [5]). These measures are related to the concept of executive attention because they involve discriminating relevant from irrelevant visual signals, as well as inhibitory processes [26]. According to Fernandez-Duque et al. [26], this type of executive functioning relates to better metacognitive monitoring, which involves control processes such as conflict resolution and emotional regulation. This fits nicely with the improvement in affect found here.

Thus, a series of our findings indicated that the ANT and CPT are complementary in the present setting and should be used together when evaluating MAP and/or ADHD attentional effects. The measures were differently sensitive to practice effects; CPT measures derived from ANT data indicated MAP-induced improvement in sustained attention that the CPT did not, and the variables on the CPT that indicate executive functioning were positively affected by MAP, while those variables on the ANT were not. One possible reason for this is that these tasks have different characteristics. One main difference is that, in the ANT paradigm [33], the participant must respond to all trials; therefore, impulsivity, which is one of the main symptoms of ADHD [17–19], cannot be shown. In other words, commission errors and detectability cannot be determined in this task, and these variables are susceptible to ADHD and were sensitive to improvement with MAP. Another aspect of the ANT is that it involves a fixed time interval of 400 ms between the cues and the target. This increases the predictability of the need to respond, which is unlike the CPT, in which interstimulus intervals vary. This is important because it has been shown that adults with ADHD have deficits related to the estimation of time intervals [69], which may contribute to the usefulness of the CPT for detecting their attentional problems [37], as we found here. On the other hand, this lack of variability in the interstimulus intervals of the ANT may have enabled MAP-induced sustained attention improvement to be detected.

One possible hypothesis for the comparable improvement in mood, quality of life, and attentional performance between the ADHD patients and healthy controls after MAP is that our control group was small. With a larger sample, differences might have become apparent. Additionally, these similar results between groups may have resulted from the use of a treatment program that was developed specifically for adults with ADHD (see details in Zylowska et al. [15] and Zylowska [59]). Thus, the intervention used in our study may have led to specific improvement in aspects that are impaired in this clinical condition. It is therefore possible that other mindfulness programs may lead to different attentional performance improvements in healthy adults, as found by Tang et al. [70]. This is especially true considering that the effects found here for the control group indicated that attention has room for improvement by MAP, even in healthy individuals.

There were limitations to our study apart from the small number of control participants. Like Zylowska et al.'s [59] study, our study was not a randomized trial, as would have been ideal, because we were not able to recruit a sufficiently large sample of subjects who fit the eligibility criteria and were willing to practice meditation. Likewise, in our study, the experimenter was not blind to the treatment, as seems to have occurred in Zylowska et al.'s work. However, we believe that this did not compromise our data because the ADHD patients and controls who agreed to participate in the intervention and those who did not did not differ in terms of demographic variables or IQ or on any subjective measure except inattention.

It can also not be excluded that the awareness of participants that they would be submitted to the intervention biased the observed effects. However, we would expect this to influence only subjective measures and not the attentional ones, which were also improved, suggesting that our data do not reflect pure expectation effects. The possibility that patients with different ADHD subtypes would have reacted differently to the MAP intervention cannot be excluded, especially because people with different subtypes seem to perform differently on the ANT [71] and CPT II [72]. It must be considered, however, that new guidelines do not propose ADHD subtypes as separate clinical representations because they are not developmentally stable (see [20]). Age and gender specific effects must also be investigated, as should the impact of MAP on nonmedicated and medicated patients. Unfortunately, our sample was not large enough to conduct the latter types of analyses. Finally, our indirect measures of MAP-induced improvement in brain functioning in the form of better attentional performance should incentivize future investigations into the cognitive systems that are at play in this phenomenon.

4.1. Conclusions. Mindfulness awareness practices improved affective symptoms, quality of life, and attentional performance (sustained attention and executive control) in adult ADHD patients and controls. Hence, this intervention can be considered a useful complementary treatment for adults with ADHD that also has the potential to enhance attention, mood, and quality of life in nonclinical populations.

Conflict of Interests

The authors declare no conflict of interests with respect to the authorship and/or publication of this paper.

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Review Article

Measuring a Journey without Goal: Meditation, Spirituality, and Physiology

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The secular practice of meditation is associated with a range of physiological and cognitive effects, including lower blood pressure, lower cortisol, cortical thickening, and activation of areas of the brain associated with attention and emotion regulation. However, in the context of spiritual practice, these benefits are secondary gains, as the primary aim is spiritual transformation. Despite obvious difficulties in trying to measure a *journey without goal*, spiritual aspects involved in the practice of meditation should also be addressed by experimental study. This review starts by considering meditation in the form of the relaxation response (a counterpart to the stress response), before contrasting mindfulness research that emphasizes the role of attention and alertness in meditation. This contrast demonstrates how reference to traditional spiritual texts (in this case Buddhist) can be used to guide research questions involving meditation. Further considerations are detailed, along with the proposal that research should triangulate spiritual textual sources, first person accounts (i.e., neurophenomenology), and physiological/cognitive measures in order to aid our understanding of meditation, not only in the secular context of health benefits, but also in the context of spiritual practice.

1. Introduction

Mind-body therapies have become popular in a number of Western countries, with some estimates reporting that almost 20% of the US adult population have practiced a form of mind-body therapy in the past twelve months [1]. Mindfulness meditation practices are one such type of mind-body practices. Successful outcome studies from mindfulness based interventions, such as mindfulness based stress reduction (MBSR) and mindfulness based cognitive therapy (MBCT) [2, 3], have led to research inquiries regarding the cognitive processes that underlie the physical and mental health benefits of mindfulness practices. Studies to date have included both behavioral and physiological data focusing on key cognitive aspects of mindfulness practice, such as attention, memory, and emotion regulation, and have included secular and spiritual forms of mindfulness/meditation [4–13]. Yet, the Eastern/Buddhist traditions that mindfulness practices have typically been drawn from have a spiritual objective that goes beyond the alleviation of acute or chronic health problems (the usual focus of secular mindfulness practices). This raises questions around the purpose and goal of studying meditation and how traditional spiritual textual sources may help guide future investigations.

Buddhist mindfulness/meditation is practiced in the context of a moral and philosophical system that aims to solve existential angst and problems of egotism through acceptance of change and reduction of attachment via recognition of *nonself* [14]. Emerging from the practice of mindfulness is an appreciation that the duality we usually experience (mind/body being one such dualistic distinction) does not exist in an absolute sense, as all phenomena are interconnected and everything is impermanent and subject to change [14].

In many traditions the meditation practitioner embarks on a paradoxical journey where spiritual transformation takes place without a definable or measurable goal. Trungpa discusses this issue as a journey without goal, stating that

> *when we refer to a journey... On the one hand we are talking about nonbeing, no world, nonexistence; and on the other hand we are discussing*

> *the process of the path, how we could proceed along a path and exert ourselves... If we split hairs in that way, there is no truth anywhere, none whatsoever. Let it just be that way; let us have contradictions [15].*

Given the increased interest in investigating the benefits and processes involved in Buddhist and other Eastern traditions, it is timely to review and reflect on how measurement of this journey without goal can be achieved within an empirical framework.

2. The Relaxation Response

In the 1970s physiological research by Herbert Benson at Harvard Medical School led to the creation of a prominent and widespread meditation technique to elicit what he termed the relaxation response (RR), a counterpart to the stress response (SR). The technique itself is simple and straightforward, involving a few key steps that include sitting quietly and comfortably, closing the eyes, breathing through the nose with awareness of the breath for 10–20 minutes, and not judging the success of the practice [16]. Benson's research on the RR during the 1970s showed a pattern of physiological change that seemed to act in opposition to physical reactions seen in response to stress. These physiological changes included reduction in blood pressure, resting heart rate, and oxygen consumption [17]. For example, a study of office workers with normal blood pressure showed that practice of the RR technique led to lower blood pressure compared to a control group [12].

Although Benson's research initially stemmed from investigations involving spiritual practitioners of Maharishi Mahesh Yogi's Transcendental Meditation, the RR technique was designed to be practiced by the individual in either a secular or spiritual context. The importance of Benson's approach needs to be considered with regard to the scientific and cultural context of these early studies. There would have been great skepticism about the utility of meditation, and so establishing positive effects with physiological measures and rebranding the practice as a relaxation response would have made the study of meditation more palatable, thus opening the door to future research. In fact, Benson's research over the ensuing decades continued to investigate physiological changes due to the RR and included related practices that were likely to elicit the RR (such as advanced practitioners of Buddhism [5, 18]). As technological advances increased, Benson was able to study other physiological effects, as well as biochemical and genomic activity changes [10, 19–24].

Regarding biochemical changes most research had concentrated on the release of cortisol, with research on Buddhist monks and Transcendental Meditation practitioners showing reduced levels of cortisol (i.e., the release of cortisol is associated with stress) [25, 26]. Later it was suggested that nitric oxide (NO) could mediate the RR's physiological effects [24] given that it is a short-lived nitrogenous free radical known to mediate physiological processes, such as cardiovascular, immune, and nervous system function [27]. Indeed, research revealed that volumetric oxygen consumption (VO^2), which is considered to be a measure of RR elicitation, was negatively related to NO, where the decrease in VO^2 associated with the RR was accompanied by an acute increase in the presence of NO [20]. These researchers hypothesized that "NO changes play a role in the consistent pattern of blood pressure reduction that is seen during RR elicitation."

Research on genomic changes reported that the RR led to specific gene expression changes in both short and long term practitioners, suggesting that such changes may relate to long term physiological effects [21]. More specifically, Bhasin et al. report that RR practice "...enhanced expression of genes associated with energy metabolism, mitochondrial function, insulin secretion, and telemore [*sic*] maintenance, and reduced expression of genes linked to inflammatory response and stress related pathways..." [19]. This research provides the first evidence for what the authors argue is the RR evoking downstream health benefits through the improvement of mitochondrial energy production/utilization, which promotes mitochondrial resiliency through upregulation of ATPase and insulin function.

Other research from Benson's lab focused on meditation using MRI and fMRI. This research indicates that meditation activates neural structures involved in attention and the control of the automatic nervous system (e.g., dorsolateral prefrontal and parietal cortex, hippocampus/parahippocampus, temporal lobe, pregenual anterior cingulate cortex, striatum, and pre- and postcentral gyri) and that brain regions, including those associated with attention, were thicker in meditation participants than matched controls. This was most pronounced in older participants, raising the possibility that meditation might offset age-related cortical thinning. Hence, there is structural evidence for experience-dependent cortical plasticity associated with meditation practice [10, 23].

In considering these findings together, Dusek and Benson have provided a conceptual model, which integrates physiological and molecular level changes in relation to the RR and SR [28]. The aim of the model is to help guide mind-body research, specifically with health outcomes in mind. While the RR research of Benson and colleagues may appear to have only a secular/health interest this is not to say that the importance of faith and spirituality has not been considered. Not only did Benson's early research start out by investigating physiological effects of transcendental meditation, but also later work looked at other religious meditation practices. For example, Buddhist monks were studied in relation to specific and advanced meditation practices, including Tum-mo yoga, which involves producing an inner heat, where increases in finger/toe temperature of up to 8.3°C were observed, while another study reported that resting metabolism could be raised by 61% and lowered by 64% [5, 18]. These studies provide further evidence that meditation practices do lead to measurable physiological changes, where previously there had only been anecdotal accounts.

It could be argued that studying these physiological changes in meditators is similar to studying effects on free divers (many of whom use relaxation or yoga techniques to prepare themselves). In the case of studying free divers, understanding oxygen changes in the blood can help us understand how free divers achieve their goal by holding the breath for such a length of time that they are able to dive so deeply [29]. But do physiological changes in meditators reveal anything about the spiritual goal of meditators?

More direct consideration of spirituality and faith came from Benson's observation that around 25% of people practicing the RR "feel more spiritual" and these same people had "fewer medical symptoms than those who reported no increase in spirituality" [30]. More specifically, Benson detailed three ways in which a person's religious convictions/philosophy of life enhanced effects of the RR: (a) increased adherence and enjoyment of the routine amongst those with an appropriate philosophic/religious focus, (b) affirmative beliefs that led to *remembered wellness*, which would revive top down nerve cell firing patterns in the brain associated with wellness, and (c) faith in an eternal or life transcending force (being a soothing belief) got the fullest out of remembered wellness and disconnected unhealthy logic [30].

The concept of remembered wellness is a way to harness the potential of the placebo effect, and the description of how a person's spiritual beliefs can enhance the RR mirrors what Benson and Friedman describe as being the three components that bring about the placebo effect [4]. These three are "(a) positive beliefs and expectations on the part of the patient; (b) positive beliefs and expectations on the part of the physician or health care professional; and (c) a good relationship between the two parties." In the former case remembered wellness is a positive term for placebo, with the emphasis on faith rather than the physician.

Even with these considerations given to the role of spirituality, it can appear that positive physiological changes are the primary goal of the meditation practice, and this is often true for secular practice, especially in therapy. Yet for many practitioners of meditation these physiological effects are secondary gains, with the primary gain being spiritual transformation. However, without an operational definition of what spiritual transformation is, it is arguable whether it can be meaningfully measured. It might even be the case that the body in a state of near-perfect homeostasis equates with spiritual or existential satisfaction. Although the focus on health benefits in past and current research may be partly due to funding implications, where health research is more likely to be funded than spiritual research, it is too easy to dismiss the possibility of investigating the spiritual aspect in any greater depth.

Highlighting the importance of considering meditation practices alongside the spiritual traditions and textual sources that they are drawn from, Britton et al. point out that Buddhist texts describe a state of relaxed alertness (a balance between hyper- and hypoarousal), yet modern uses have placed emphasis "...on the relaxing effects of meditation without as much attention to the arousing or wake-promoting effects" [7]. However, there is now a growing body of work that has focused on cognitive aspects of alertness through considering the role of attention in mindfulness practices.

3. Mindfulness, Attention, and Wakefulness

Not all research has emphasized the relaxation aspect of meditation, with many studies investigating practices that fall under the umbrella term mindfulness. The term is common to Buddhist traditions, where it forms part of the eightfold noble path to *awakening*, and was adapted by Kabat-Zinn in his therapeutic program to mean "...paying attention in a particular way, on purpose, in the present moment, and nonjudgementally [*sic*]" [31]. Initially, his program was called stress reduction and relaxation but was changed to mindfulness based stress reduction (MBSR) in order to reflect the awakening aspect [32], and in both his definition and other researchers attempts to operationally define and model mindfulness, attention has been identified as having a key role [32–34].

Reflecting the above definition's emphasis on attention and present moment awareness/openness, Bishop et al. presented an operational definition of mindfulness with two key components: sustained attention and orientation towards present moment experiences [33]. There is further elaboration of the role of attention in Shapiro et al.'s discussion of the mechanisms of mindfulness. They discuss a cyclic process where attention, intention, and attitude are interwoven and occur simultaneously [34]. The inclusion of intention overlaps with Benson's emphasis on the potential to harness the placebo effect where outcomes of mindfulness practice have been shown to correlate with the original intentions of the practitioner (e.g., those with the intention of self-regulation, or self-exploration, or self-liberation achieve their stated aim) [4, 35].

A variety of techniques and methods have been used to investigate the role of attention in mindfulness meditation practices [4, 6, 7, 9–11, 13, 23, 35–46]. This includes behavioral data that supports the hypothesis that mindfulness practice leads to efficiencies in the dorsal attention system involved in voluntary top-down attentional selection, as well as indicating that retreat practice develops and encourages the emergence of receptive attention (i.e., improved alerting), which corresponds to the ventral attention system [40].

While having more of a focus on the physiological rather than the cognitive, Benson's research also includes evidence for the role of attention, with findings indicating that there are changes to structures of the brain involved in attention, including increased cortical thickness with meditation experience [10]. This finding was most pronounced for older adults and suggests that meditation might offset cortical thinning. Similarly, a study of Zen meditators found that there was no correlation between age and grey matter volume, nor age and attentional performance [42]. This was despite significant negative correlations being found for the control group. It was noted that this effect was most prominent in the putamen, which is implicated in attention. The authors suggest that "...the regular practice of meditation may have neuroprotective effects and reduce the cognitive decline associated with normal aging" [42].

These attentional effects may also have implications for emotional processing and affective control, where research has shown that meditation reduces habitual responding [13], and Lutz et al. suggest that focused attention training, as often employed in some styles of meditation, may be related with a reduction in emotionally reactive behavior [11]. However, effects of meditation experience are not all linear. For example, in one study that showed decreased activation of the amygdala (associated with emotion) with meditation experience, there was also an inverted U-shape curve regarding experience and attention related activation (i.e., monitoring, engaging, and orienting) [6]. The group of meditators who had an average of 19,000 hours of practice showed greater activation than nonmeditators. However, when a group with an average of 44,000 hours practice was compared with the less experienced group of meditators, the more experienced group showed less activation.

Other research also indicates there are nonlinear changes in activation with increased meditation experience [6, 7, 47–49], with Britton et al. arguing that brain areas involved in tonic alertness (vigilant attention) are more active in meditators (early stages of training) than nonmeditators, but expert meditators show less activation "as meditative expertise becomes more proficient and effortless in later stages" [7]. One explanation for this finding is that brain areas that were not previously coactivated come to have increased connectivity [7, 49–52].

These findings regarding attention and alertness are quite significant, especially if we contrast the relaxation response and clinical applications that seek to increase sleep duration/depth, with Buddhist texts and aims of enlightened awakening. Britton et al. point out that Buddhist meditators view the need for less sleep as a sign of progress and that sleep research has established a positive correlation between attention and wakefulness [53]. Moreover, there is only weak evidence that mindfulness meditation and MBSR promote sleep [54, 55], leading Britton et al. to argue that the Buddhist term awakening "…is not a metaphor, but rather an iterative process of neuroplastic modifications and increased efficiency that supports a new level of perceptual sensitivity and insight" [7]. It is interesting that even when mindfulness meditation is placed in a secular context, reference to spiritual traditions, such as Buddhism, can act to illuminate the practice and guide research investigations. Other issues relating to attention-based aspects of meditation could also benefit from similar considerations of spiritual and contextual practice.

A further example is the classification of meditation. A common categorization is to divide meditation into focused attention (FA) and open monitoring (OM) [11, 56]. Generally, beginners will be introduced and establish a practice using FA techniques, where there is a particular object to focus attention on (e.g., the breath), whereas OM meditation does not require an object of focus, but an aware and nonreactive acknowledgment of moment to moment awareness. In the case of FA there is an effortful commitment to sustain attention that helps to still the active mind. Once a student has established this in their practice they are then better able to practice OM. Lutz et al. describe a development in practice where "the 'effortful' selection or 'grasping' of an object as primary focus is generally replaced by the 'effortless' sustaining of an awareness without explicit selection" [11]. Differences have been found between FA and OM practices; for example, OM practitioners have been shown to have superior responses to unexpected stimuli compared to FA practitioners, reflecting a more distributed attentional focus [46].

However, care needs to be taken in making sure this division of meditation styles is not taken out of context of actual practice. There are overlapping features to the two types of meditation, and often a practice will deliberately and systematically include both aspects. For example, in the Vajrayana tradition (associated with Tibetan Buddhism) many students engage in deity meditation. This involves visualization, mantra chanting, and OM. Typically, a practice will begin with the reciting of a text that describes the visualization that is to be focused on. This recitation arrives at a *completion* stage where the visualization is held as an object of focus, while a mantra is chanted. This involves sustained attention and fits the description of a FA meditation practice. However, the practice always moves on to a *dissolution* stage, where the visualization is dissolved, the mantra ceases, and the practitioner remains in a state of OM. A beginner may spend more time on the FA aspects compared to a more experienced practitioner, but both are practiced together to some degree. Hence, it is important to consider the context of the practice and to refer to traditional texts that might provide insights. Note that a somewhat similar division has been made by Tomasino et al. in their meta-analysis comparing Buddhist practices (defined similarly to FA) with Hinduist practices (defined similarly to OM), which showed anterior activations for the former and posterior activations for the latter [57].

Another complicating factor is that meditation practices, such as the one described above, potentially involve other important cognitive processes that have been neglected by researchers in comparison to the focus on attention. Buttle makes the point that meditations involving the simultaneous coordination of visual (imagery) and verbal (mantra/chanting) practices are likely to involve working memory systems and notes that Buddhist texts often refer to mindfulness in the context of memory (e.g., remembering to return to the object of focus when the mind has wandered), whereas the secular practice of mindfulness has focused on attention [8]. Even the type of imagery used in a meditation can yield differences, with deity meditation (visualizing ones body/mind as that of a deity), but not mandala meditation (mentally imagining the environment), nor rig-pa meditation (awareness without an object of focus), yielding improved performance on visual and spatial working memory tests [58]. Such findings support the view that instead of adhering to strict categories, such as FA and OM, meditation should be viewed on a spectrum, which allows for consideration of techniques that are self-transcending in the sense that they aim to change their own activity and experience [58–60].

Many practices are also designed to increase feelings of loving-kindness, compassion, and equanimity and are likely to involve affective processing. Understanding the spiritual aims behind the evolution of these practices can help guide research questions and may offer a way to assess spiritual aspects of the practice alongside material health benefits. Currently, the author's lab is investigating physiological changes in relation to emotional and moral content, in order to get an impression of how meditation practices may affect moral appraisal, with a view to considering the potential for societal benefit (as emphasized in Mahayana Buddhism), as well as individual benefit of the practices.

4. Meditation and the Spiritual Journey: Further Considerations

In considering the physiological study of meditation in the context of spirituality, it is important to reflect on the role given to meditation. Many religions use some form of contemplation. However, it is rare for meditation to be the only element of focus for the spiritual practitioner, as the practice is usually accompanied by both an ethical and philosophical system. This is true of Buddhist traditions from where these secular mindfulness programs have borrowed their techniques. Yet, in terms of historical practice, Sharf has argued that it is unclear how many Buddhists meditated (maybe less than supposed) and it was uncommon for people to write about their own meditational experience [61]. Regarding contemporary accounts, Bronkhorst highlights a number of Buddhist traditions where meditation seems to have a limited role [62]. Furthermore, some mindfulness researchers are starting to investigate negative experiences that arise from practicing meditation, with Britton, as quoted by Rocha, pointing out that while there is an abundance of positive results, "…no one has been asking if there are any potential difficulties or adverse effects, and whether there are some practices that may be better or worse-suited (for) some people over others [*sic*]" and this is despite historical accounts, from various traditions, providing negative descriptions of meditation experience [63]. In a qualitative study of experiences of committed meditators, Lomas et al. observed that around 25% of experiences were negative and could be classified into four main types of negative problem: that meditation (1) was difficult to learn and practice, (2) led to troubling thoughts/feelings that were hard to deal with, (3) exacerbated mental health issues, and (4) in a few cases was linked to psychotic episodes. However, these negatives were also seen as part of the journey, and as challenges they led to spiritual transformation [64].

Just as the investigation of the alert, attentional aspect of meditation has been prompted by the Buddhist concept of awakening, further textual understanding of spiritual traditions involving meditation may help in guiding research and offering new hypotheses and insights. This could include research on the ethical and philosophical aspects of these spiritual traditions. This may proffer additional refinements within secular and therapeutic techniques but would also help build understanding of benefits of meditation for those whose practice has spiritual transformation as the primary goal.

With regard to ethics, Monteiro et al. discuss traditional and contemporary mindfulness noting that "the often-fierce criticisms of MBIs (Mindfulness-based interventions) have focused on a single theme: the omission of immediately apparent ethics…" [65]. This is seen as a problem by some Buddhist's, where viewing mindfulness as bare attention with no ethical framework is seen to have the potential to lead to wrong mindfulness (e.g., someone could use the practice to calm and focus the mind in order to carry out a negative action, such as killing). Monteiro et al. point out that ethics are interpreted differently by various Buddhist traditions, so there is no absolute code of ethics and that even without explicit ethics the implicit ethics in MBSR may positively affect moral reasoning [65, 66]. However, there has been no empirical comparison of meditators who do and do not have an explicit code of ethics, and this would be worth investigating in future, especially as some meditation practices have loving-kindness and compassion as their focus (e.g., the practice of *metta* in Theravadin Buddhism and the practice of deity meditation in Vajrayana Buddhism).

Regarding philosophy, the Buddhist aim of practice is to recognize the compounded nature of all phenomena, so that the impermanence (of all things) in our lives (including our life) is accepted, leading to the cessation of suffering (*Dukkha*) [14]. Suffering in this sense is a state of unsatisfactoriness where we continually grasp at our sense of self, as if we are permanent and nonchanging, when experience will inevitably and painfully contradict that belief [14]. Buddhist traditions place somewhat different emphasis on the philosophy (*the view*); for example, some traditions focus on the idea of *nonself*, whereas others focus on all phenomena being empty of an inherent nature [67]. To complicate this further, a tradition may include a number of graded philosophies in order to move the practitioner towards the experience of how reality actually is (empty of inherent existence), with the aim of eventually realizing this without further need for the prop of a philosophical structure (eventuating in *enlightenment*) [67]. While such philosophies are debated within Buddhist scholastic centers, they are also used alongside meditation, where meditation provides a method for realizing the view. Caution is taken not to rush the introduction of the view and meditation, with teaching "emptiness to the untrained" being a violation of the Mahayana ethical system [68] (for a detailed account of these philosophies progressive stages in relation to meditation, see Rimpoche and Hookham [67]).

Buddhist texts have also described stages of meditation with terminology and interpretations differing between Pali and Sanskrit based traditions. Similarly, within traditions there are different types of classification; for example, there are the nine stages of placing the mind, which places emphasis on the calming aspect of meditation (*shamatha*), similar to FA, and the four stages of realization arising, which places emphasis on the insight and wisdom aspect (*vipashna*), similar to OM [69, 70]. With regard to the latter, these four stages can be further broken down with each stage having three substages [70]. The first stage (*one pointedness*) is where the meditator is learning to develop strong mental concentration; the second stage (*simplicity/no complication*) is where they are learning the true nature of phenomena; the third stage (*one taste*) is where there is experience of all phenomena having the same essence (empty of inherent existence); and the fourth stage (*no meditation*) is where there is realization of the experience and nothing remains to be done [69, 70]. While practitioners will typically progress through these stages gradually, Buddhist texts also recognize two other types of practitioner: one who at the first stage simultaneously achieves the other stages (rare but stable), and one who moves both forwards and backwards skipping stages (unstable) [70]. This indicates that while research often correlates meditation experience with hours/years of practice, it may not capture the individual variability of practitioners' progress.

Therefore, given that there are these existing classifications of meditation experience, it would be useful to submit them to experimental study with physiological measures. Moreover, as these practices involve a high degree of self-reflection on the part of the meditator, it would be beneficial to compare behavioral and physiological measures with first person accounts (see Buttle for an example of a self-reflective account [71]). Some work in cognitive- and neurophenomenology has already begun [58, 72–74]. This approach actively involves "...the participant in generating and describing specific and stable experiential or phenomenal categories" and can "...provide a way for experimenters to better control and identify the subjective aspects of attention and emotion regulatory processes" [11]. For example, Louchakova-Schwartz was able to contrast two types of Vajrayana meditation, where one (rigpa) is empty of cognitive contents, but not cognition, while the other (deity meditation) involved the visualization of complex and meaningful images [58].

It seems that there are many questions remaining to be explored in relation to both secular and spiritual/religious practices of meditation. Investigations informed by spiritual practices have already seen shifts in emphasis (e.g., from relaxation to wakefulness), and future research may well benefit from further consideration of spiritually and traditionally based textual sources. There is even further potential for investigating stages of meditation informed by textual scholarship, first-person descriptions, and cognitive/physiological measures. Ideally, such research would contribute to the building of a psychological theory as called for by Bronkhorst:

> *This psychological theory should not just be shorthand for neurological processes, nor do we want mere folk psychology (or worse: psychobabble). Understanding brain processes is not sufficient to understand psychological processes, least of all when major transformations like those referred to in the early Buddhist texts are concerned. We need a psychological theory that is yet scientific in the strictest sense [62].*

However, Bronkhorst also cautiously notes that "the neurological changes that correspond to this radical psychological transformation may well be relatively minor" [62]. This is a view that seems consistent with the Zen idea that the state that is sought is quite ordinary [75] and with the idea that there is a paradox of the journey without goal [15]. Moreover, it also fits with the inverted U-shape findings regarding attention and expertise, demonstrating that as meditators gain experience there is an increase in activation regarding attention, but in expert meditators no such increase is seen as meditation becomes effortless.

5. Conclusion

Secular meditation techniques have been based on spiritual practices, with research indicating that the spiritual sources of these techniques can also be useful in shaping research questions. Behavioral and physiological measures have given insight into the cognitive and physical effects of practice, further contributing to our understanding of mind-body interactions. However, there are a vast number of questions that remain to be answered, both in terms of secular and spiritual practices. One avenue that is worthy of further exploration is the triangulation of information drawn from textual sources, first-person accounts, and experimental measures. Measurement of spiritual transformation in this context may turn out to be its own journey without goal (even the Buddha refused to answer questions on whether the self and body were the same or different [76]). However, as technical tools for measuring behavioral and physiological changes become more sophisticated and more sensitive, we should seize opportunities that offer the potential to increase our empirical understanding, whether it is to improve secular therapies or to offer insights into spirituality and the cognition of religion.

Conflict of Interests

The author declares that there is no conflict of interests regarding the publication of this paper.

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Review Article

Mindful Emotion Regulation: Exploring the Neurocognitive Mechanisms behind Mindfulness

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The purpose of this paper is to review some of the psychological and neural mechanisms behind mindfulness practice in order to explore the unique factors that account for its positive impact on emotional regulation and health. After reviewing the mechanisms of mindfulness and its effects on clinical populations we will consider how the practice of mindfulness contributes to the regulation of emotions. We argue that mindfulness has achieved effective outcomes in the treatment of anxiety, depression, and other psychopathologies through the contribution of mindfulness to emotional regulation. We consider the unique factors that mindfulness meditation brings to the process of emotion regulation that may account for its effectiveness. We review experimental evidence that points towards the unique effects of mindfulness specifically operating over and above the regulatory effects of cognitive reappraisal mechanisms. A neuroanatomical circuit that leads to mindful emotion regulation is also suggested. This paper thereby aims to contribute to proposed models of mindfulness for research and theory building by proposing a specific model for the unique psychological and neural processes involved in mindful detachment that account for the effects of mindfulness over and above the effects accounted for by other well-established emotional regulation processes such as cognitive reappraisal.

1. Definition of Mindfulness

The practice of meditation has exploded in popularity around the world becoming one of the most widely used psychological techniques and disciplines [1]. In the last twenty years there has been a drastic increase in clinical interventions that take advantage of meditation skills, especially mindfulness meditation. According to Salmon et al. [2], more than 240 hospitals and international clinics offered mindfulness-based stress reduction (MBSR) and this number has increased since. MBSR was developed in clinics by Jon Kabat-Zinn at the University of Massachusetts Medical Center to facilitate adaptation to medical illness that provides systematic training in mindfulness as a self-regulation approach to stress reduction and emotion management [3]. Clinical applications of mindfulness have become widespread since the introduction of the mindfulness-based stress reduction (MBSR), a treatment program originally developed for the management of chronic pain [4–6]. MBSR has subsequently been applied to reduce the psychological morbidity in emotional and behavioral disorders and for the treatment of chronic mental illness [7], fibromyalgia [8], anxiety and panic attacks [9, 10], mood swings and stress in cancer patients [11], binge eating disorder [12], and multiple sclerosis [13].

Originally derived from Pali, the language of Buddhist psychology, the term "mindfulness" comes from the combination of two words, Sati which means "awareness" and Samprajanya, "clear comprehension," thus indicating a way of being aware and attending to what happens. Mindfulness is considered to originate from eastern introspective spiritual practices, mainly Buddhism. In the most general sense it means to "pay attention with patience and care to what happens" [14, 15] and can be cultivated through meditation. However, you can find forms of mindfulness and meditation in almost all of the world's religions, such as yogic meditation in the Hindu tradition, kabbalah meditation in Judaism, contemplative prayer in Christianity, and Sufi meditation in Islam [16].

Adopted in western societies amongst enthusiasts of transcendental and metaphysical practices, mindfulness increasingly attracted scientific research to become recognized as an effective psychological practice for stress, pain management, and mental health problems [17].

Models of psychopathology recognize that automatic behavior without conscious attention to behavior (mindlessness) is associated with intrusive and ruminative thoughts about past or future events, leading to distressed states of mind, passivity, and the repetition of habitual coping patterns [18]. According to Kabat-Zinn, mindfulness meditation addresses this state of mind by cultivating a state of mind that is "on purpose" and "attentive" to reduce "mind wandering" (see [19] for the negative effects of mind wandering).

Mindfulness has been defined as a "nonelaborative, nonjudgmental, present-centered awareness in which each thought, feeling, or sensation that arises in the attentional field is acknowledged and accepted as it is" [20]. Kabat-Zinn [21] proposed a list of attitudes and behaviors that help develop being mindful in everyday life:

(1) nonjudging: being an impartial witness to your own experiences without premature conclusions;

(2) patience: letting things unfold in their own time;

(3) beginner's mind: being receptive to new possibilities and not getting stuck in a rut of your own expertise;

(4) trust: developing a basic trust in yourself and your feelings;

(5) not striving: paying attention to how you are right now however that is;

(6) accepting: seeing things as they actually are in the present;

(7) letting go: letting go is a way of letting things be, of accepting things as they are.

Mindfulness-based stress reduction therapy is only one of many western adaptations of mindfulness practices applied in clinical settings. While mindfulness practice takes many forms, one common practice, especially in mindfulness-based therapies, is mindfulness of the breath. In a typical practice instruction, Kabat-Zinn suggests that participants sit comfortably with eyes closed and direct their attention to the physical sensations of breathing by simply noticing it, paying attention to it, and being aware of it. When thoughts, emotions, physical feelings, or external sounds occur, practitioners are instructed to accept them and allow the recognition of these stimuli to come and go without judging or getting involved. When attention has drifted off and is becoming caught up in thoughts or feelings it is advised that the practitioner notes this drift and gently brings attention back to breathing.

The defining psychological processes in mindfulness meditation are the unique attentional focus and attitudinal stance taken by the practitioner. The philosopher Husserl described the basic assumption of mindfulness as "paying attention to the experience as it presents itself without any interpretational filtering."

This first component of mindfulness requires awareness and controlled effort to maintain full conscious focus in the "present moment" without wandering into thoughts of the past or the future. Mindfulness meditation seeks to cultivate this skill by first building awareness or "sustained attention" [22, 23], namely, the ability to maintain attentional focus on one object for a sustained period of time. Mindfulness traditionally focuses attention on the breath without repressing the flow of thoughts, feelings, and sensations that may supervene on the attentional focus. With repeated practice meditators report a capacity to focus and sustain their attention whilst experiencing a decreased frequency of distractions or intrusions into their attentional field during both formal meditation and everyday life situations [24].

2. Evidence for Psychological Mechanisms in Mindfulness

A considerable number of studies have empirically documented better performance during attentional tasks in meditators compared to controls [25–28].

The next process, closely related to the maintenance of attention, involves attentional switching, redirecting attentional drift back to the breath. Mindfulness meditation requires that this switching and refocusing is conducted with an attitude that involves nonjudgment and openness to current experience [29], an accepting state of mind that has been referred to as "intimate detachment" ([30] quoted in [31]) or "decentering" [32]. The meditator therefore does not engage with the content of the thoughts and feelings but aims to experience these as raw and unprocessed. In other words the attentional strategy implies a direct experience of events in the mind and body without being captured by them [33]. This observational stance has also been referred to as a metacognitive skill characterized by a decentering from environmental and internal psychophysiological stimuli or processes to produce a reflective space in which new ways of perceiving and responding become possible, rather than enacting habitual automatic or ruminative patterns [14]. In their systematic review Chiesa et al. [29] noted that neuropsychological testing supported these attentional processes in mindfulness meditation, although supportive findings were not observed in all studies, which the authors attributed to inconsistent operationalization and methodological limitations across studies.

One of the consequences of attentional focus in mindfulness meditation is the increase in body awareness by practitioners attending to internal perceptions, developing their understanding of subtle sensations and perceptions of their body [34, 35], with studies based on self-administered questionnaires showing a significant increase in body awareness in practiced meditators (see [36]).

Various neuroimaging studies support the above psychological observations and provide insight into the neurological processes activated by mindfulness meditation. We will consider these studies in the next section.

3. Neuroimaging Evidence for Mindfulness Mechanisms

Neuroimaging techniques have allowed scholars to uncover the neural mechanisms behind attentional and body awareness processes. Hölzel and colleagues [34] argued that mindfulness is underpinned by several distinct but interconnected neural mechanisms as hypothesized by Kabat-Zinn [18]. The dorsal medial prefrontal cortex (dmPFC) and the anterior cingulate cortex (ACC) in both hemispheres are activated in mindfulness meditation. The cingulate cortex plays a primary role in the fusion of attention, motivation, and motor control [37]. The rostral (ACC) part is activated in tasks with an emotional overload, whereas the dorsal (dmPFC) part is triggered by cognitive control tasks [38]. It is reasonable to assume that when a mental event such as a thought or a memory interferes with the attentional focus, the ACC may contribute to the maintenance of attention, alerting neural systems to solve the conflict by a top-down regulation mechanism that prioritizes cognitive control [39, 40]. According to Hölzel and colleagues [34], the area that shows more pronounced activation in experienced meditators while they are focusing their attention is precisely the rostral ACC, emphasizing the importance of this regulatory structure during meditation. Tang and colleagues [41] showed that five days of integrative body-mind training are sufficient for its effective activation during a resting state.

In a further study by Grant et al. [42] using structural MRI methods, they showed that cortical thickness in the dorsal ACC of experienced meditators was greater than that of control subjects. Furthermore, Tang and colleagues [41] have shown that eleven hours of integrative body-mind training (another form of mindfulness practice) is sufficient to observe improved integrity and efficiency of white matter in the corona radiata. Corona radiata is an important white-matter tract connecting the ACC to other structures, so its communication efficiency plays a key role in modulating brain activity in ACC. Thus IBMT can be a way to improve self-regulation and to reduce various mental disorders [43].

Another line of experiments confirmed that mindfulness increases activity and structural properties of brain regions connected to body awareness. For example, Farb and colleagues [44] found a greater activation of the insula (a region involved in proprioception and viscerosomatic processing) in individuals trained in mindfulness-based stress reduction, as compared to the control group. In addition, it was discovered that the thickness of the insula is greater in experienced meditators as compared to controls [45] and that there is a greater concentration of gray matter in the right anterior insula [46].

Taken together, these studies provide evidence that mindfulness practice affects psychological and neural processes and systems that improve attentional capacity and body awareness and engage cognitive control processes.

4. Clinical Evidence for the Effects of Mindfulness

According to Bishop [3], randomized clinical trials confirmed the positive effect of meditation and provide encouraging results with patients showing a significant reduction in psychological morbidity associated with mental illness [47–49] and a decrease in stress level, resulting in increased emotional well-being.

Several psychological treatments of different schools have explicitly or implicitly incorporated mindfulness principles. Among these are

(1) dialectical behavior therapy (DBT) [50], an approach that develops emotion-regulation skills across a variety of mental disorders including borderline personality disorder by incorporating mindfulness exercises and attentiveness to emotions, thoughts, and feelings in addition to cognitive and behavioral treatment tasks [51];

(2) mindfulness-based cognitive therapy (MBCT) [52], which combines a mindfulness training program with cognitive restructuring tasks to reduce relapses in depression [53];

(3) acceptance and commitment therapy (ACT) [54], which helps patients modify their relationships with inner experience through taking an accepting observing position of thoughts, feelings, and sensations and take committed action in accordance with their own values, similar to a mindful attitude;

(4) intensive short-term dynamic psychotherapy (ISTDP) [55, 56], which guides the patient in a moment-by-moment focusing to develop the patient's capacity to observe and attend to emotional and bodily responses within the therapeutic and other relationships;

(5) relational and attachment focused psychoanalysis [57, 58], in which the therapist mindfully distances from his/her own responses in order to reflect on countertransference, guiding interpretations, and responses to the patient, thereby inviting the patient into a similar mindful stance toward themselves, the therapist, and others.

After a decade of observations and studies, therapeutic mindfulness approaches have shown positive effects in patients with anxiety disorders [59, 60], posttraumatic stress disorder [61], substance abuse [62, 63], eating disorders [12, 64], depression [53], and personality disorders [41].

Neuroimaging studies further support the therapeutic effects of applying mindfulness in the treatment of clinical populations. In patients with social anxiety disorder, Goldin and colleagues [65] found improvements in attentional skills indicated by increased activation in the zone modulated by attention in the parietal regions, with a concomitant decrease in negative emotions.

In further research Goldin and colleagues [65] found that a course of MBCT in patients with a history of suicidal depression supported stable neural functioning in relative left-frontal activation indicating the maintenance of their level of positive affective style compared to patients receiving treatment as usual who showed decreased activation and thus worsening positive affectivity.

Despite the evidence of the effectiveness of mindfulness in psychopathological disorders, the precise and unique neurocognitive mechanism by which these effects occur requires study and theoretical explication. To support the development of therapeutic methods it is necessary to distinguish the unique mechanisms contributed by mindfulness over and above common therapeutic factors. Clarity about unique factors will allow precise mindfulness techniques to be introduced into a variety of treatment programs and settings, therefore relying less on applying wholesale mindfulness treatment packages in order for patients to benefit from its unique factors. Whilst some therapeutic methods focus on mindfulness meditation as a specific practice within the treatment such as MBSR, MBCT, and DBT, other therapies include mindfulness attitudes and techniques as integrated within the therapeutic discourse such as ACT, ISTDP, and relational and attachment focused psychoanalysis. The delivery of mindfulness techniques may therefore vary but knowing what specific active factor mindfulness delivers would aid in further focusing the use of mindfulness in these treatments in order to assure efficiency and effectiveness in treatment delivery.

5. Models and Hypotheses about the Mechanisms of Mindfulness Meditation

Despite the amount of evidence on the psychological and neural effects of mindfulness, research is required on the specific neurocognitive mechanisms that underlie this meditative practice and what unique mechanisms may account for its specific therapeutic effects over and above the therapeutic factors that are common to psychological therapies generally [17].

To investigate the active factors in mindfulness meditation, it is necessary for research to be guided by theoretical models of mindfulness in order to refine understanding about unique and common therapeutic factors.

The evidence reviewed thus far points to mindfulness being characterized by an increased attention to both external (environmental) and internal (body awareness) stimuli. Mindfulness meditation promotes an adaptive observational stance toward inner experience and responses to stimuli characterized by a compassionate or calm stance where the aim is not to give in to, avoid, or control the experience or stimuli but to maintain observational exposure from a decentered position [20, 66, 67]. Mindfulness therefore aims to create psychological distance between the observing self and the emotion to enable emotional regulation that minimizes negative consequences [5]. But what are the processes that occur during the observing stance that support emotional regulation?

Shapiro and colleagues [14] proposed that mindfulness comprises three interacting processes of intention, attention, and attitude. The meditator is guided by an *intention* to self-regulate, to self-explore, and finally to self-liberate using an *attentive* moment-by-moment focus on the contents of consciousness with an *attitude* of compassionate open-heartedness. The authors assert that this is a developmental process through which a person increasingly develops an objective observing position of self and others through which metacognitive insights are obtained about "I am not my pain" and "my sense of self is ever-changing." This model implies the use of cognitive reappraisal as a key means to regulate emotional states, namely, that the practitioner is "reperceiving" or reappraising their relationship with their emotional experience or habitual responses and sense of self so that the person is no longer fused or identified with their emotion or state but reframes it as an impermanent mental phenomenon.

In the model proposed by Hölzel and colleagues [34] sustained attention and body awareness are proposed as processes by which the meditator identifies and is exposed to habitual reactions and previously avoided or suppressed internal and external experiences. Habitual responses are prevented by taking a nonreactive stance that is focused on experiencing thereby allowing for extinction of the habitual response. The passing of habitual responses brings to mind the transitory nature of experiencing perceptions, emotions, and cognitions and allows for a change in perspective of the self. Emotional regulation is thus achieved by a mindful exposure and response prevention requiring experiencing and cognitive reappraisal of aversive stimuli as transitory or even as positive or meaningful.

Both of these models outline both cognitive and experiential processes that enable emotional regulation through mindfulness meditation. Cognitive processes are involved in purposeful focusing of attention and reappraisals that allow for a new way of understanding the person's observing position and the transitory nature of external and internal experience. These may be referred to as top-down processes whereby the meditator engages executive attention and control in order to engage with experience. In addition to this the models refer to bottom-up experiential processes whereby the person remains conscious of raw unprocessed present-centered experiencing that prevents or interrupts habitual responses and is enabled by an attitude of nonjudgment, compassion, and open curiosity. In order to enable the experiential process, cognitive reappraisal may be required of self and the situation in order to take on the appropriate attitude that will allow experiencing.

These theoretical models of mindfulness allow us to begin to ask questions about the relative contribution of different mechanisms in producing the emotional regulatory effects of mindfulness meditation. It is proposed that the different facets of mindfulness meditation (intention, attention, attitude, body awareness, reappraisal, and changes in perspectives on self) employ both cognitive and experiential mechanisms that enable internal experience of self and the situation to be regulated. Whilst mindfulness meditation methods are unique (e.g., focusing on observing the breath) the question raised is whether the mechanisms of change are unique and if so, which mechanisms are specifically unique and effective in producing the mindfulness effects? Clarity about the mechanisms of change is relevant to the application of mindfulness techniques to other therapies.

Does mindfulness regulate our emotions primarily because it changes our way of thinking about self and the situation, namely, via cognitive reappraisal of an emotional situation as positive [34, 68], or because it produces an intimately detached or decentered accepting point of view that allows for raw experiencing (see, e.g., [20, 69])? Modinos and colleagues [70] in a study of neuroimaging have shown that the dispositional traits of mindfulness are positively correlated with the activation of the dorsomedial prefrontal cortex (dmPFC) when reappraisal was used. However other studies have shown opposite results, that is, a substantially lower activity in dmPFC during reappraisal in mindfulness meditators [71, 72]. One can ask then, if mindfulness is able to regulate our emotions, what are the mechanisms by which this happens? Does mindfulness produce emotion regulation through cognitive reappraisal alone or through other regulatory mechanisms as well? In other words, does mindfulness have an effect primarily using a cognitive mechanism or an experiential mechanism? We turn our attention now towards experimental evidence and the light this may shed on the mechanisms of mindfulness to produce emotion regulation.

In recent years, for its widespread application in everyone's life, the processes by which we regulate our emotions have caught the attention of many researchers. We daily regulate our emotions in order to channel them into adaptive actions. According to Gross, emotional regulation is nothing more than a set of processes through which we regulate our emotions [73]. The emotional regulation process either mitigates, enhances, or simply maintains stability of an emotion. People are able to adjust both negative and positive emotions by attenuating or increasing them.

6. Experimental Evidence of a Mindful Emotional Regulation: Exploring the Unique Psychological and Neural Processes Involved in Mindfulness

In the last two decades clinicians have shown that mindfulness training can improve emotional disorders [74] and negative mood [75] and reduce physiological responses such as skin conductance [76] and amygdala activity [67]. These findings point to the emotional regulatory function of mindfulness for which recent studies have provided direct experimental evidence.

Early investigations [76] into the effects of mindfulness meditation recorded galvanic skin response of a group of experienced meditators and of controls while viewing unpleasant video. Results showed that, beside a first rise in galvanic skin response similar in both groups, meditators were able to lower their arousal to a greater degree than controls. More recent investigations by Taylor and colleagues [77] similarly tested the skills of mindfulness meditators to reduce the emotional intensity they felt in response to an unpleasant image. The authors tested twelve long-time meditators and ten beginner meditators as they looked at pleasant, unpleasant, and neutral images, recording the task with fMRI. The results showed that both groups were able to experience reduced emotional reactions on a subjective and neural level using mindfulness whilst looking at the images. Yet Taylor and colleagues [77] further observed two different emotional regulation mechanisms that depend on the degree of experience of the meditator. In experienced meditators the medial prefrontal and posterior cingulate cortices were deactivated and did not influence brain regions involved in emotional reactivity during emotional processing. However, for beginner meditators, mindfulness induced a downregulation of the left amygdala during emotional processing. Brefczynski-Lewis and colleagues' [78] study with sound stimuli similarly found a negative correlation between the length of meditation hours and activation of the right amygdala while listening to unpleasant stimuli. These studies therefore suggest that practiced mindfulness skills lead to emotional regulation through accepting emotional states and enhancing present-moment awareness, whilst beginner mindfulness skills appear to rely on higher cortical brain regions to control low-level affective cerebral systems. The mechanism of self-regulation utilized during mindfulness therefore depends on the degree to which the meditator has practiced mindfulness.

In examinations of individuals with higher dispositional mindfulness Modinos and colleagues [70] showed that greater dorsomedial prefrontal cortex (dmPFC) activation occurred during a task of reappraising negative stimuli compared to activation during a task of merely attending to the negative stimuli. This dmPFC activation was inversely correlated with the amygdala response to negative scenes thus offering brain image evidence for the role of cognitive control strategies during mindfulness in regulating emotional arousal in people with higher dispositional mindfulness.

Therefore research suggests that beginner mindfulness skills as well as high dispositional mindfulness traits are more likely to involve top-down emotional regulation mechanisms based on cognitive control mechanisms, whilst experienced meditators are more likely to use bottom-up regulation mechanisms that rely on the perceptual system rather than cognitive system. Mindfulness is a skill and the emotional regulatory mechanism it deploys therefore appears to depend on the degree of meditation practice rather than purely on the application of the mindfulness method.

Cognitive reappraisal has been suggested as a core cognitive control skill whereby mindfulness practice may regulate emotions [34]. However such skill is not unique to mindfulness meditation and is a core feature taught to patients in numerous psychological therapies. To explore the emotional regulatory mechanism unique and therefore specific to mindfulness, recent experimental investigations have examined the relative contribution of cognitive reappraisal mechanisms versus the mindful state of intimate detachment in achieving emotional regulation during mindfulness meditation.

Opialla and colleagues [79] recently directly compared novice subjects using mindfulness versus subjects using only cognitive reappraisal whilst viewing negative emotional pictures. The researchers observed the medial prefrontal cortex activated in both groups indicating that similar top-down neural mechanisms for emotional regulation occur in the mindfulness process as in the cognitive reappraisal process.

However, Opialla and colleagues [79] further observed that the mindfulness group showed selective insula activation, a region shown to be involved in the regulation of the experience of emotions [80–82], whereas the caudate was selectively active in the cognitive reappraisal group, which is a region usually associated with cognitive control. These results therefore suggest that even in a group of novice mindfulness meditators, emotion-focused or experiential mechanisms of emotional regulation operate which are not present in subjects who purely employ cognitive reappraisal and for whom cognitive control mechanisms are more active.

Research is therefore pointing more towards mindfulness practice contributing a unique bottom-up experiential process in regulating emotions that employs different pathways to that utilized by cognitive reappraisal. Grecucci and colleagues [69] further explored the differential contribution of cognitive reappraisal and mindful detachment when accounting for the frequency of practice. They compared emotional experience and behavior in response to socially unpleasant stimuli in both practiced meditators and beginner meditators. Both groups' responses were measured when they used alternately cognitive reappraisal to cope with an experimental situation of social unfairness and when they used intimate detachment (the unique mindfulness experiential strategy) when dealing with a similar social unfairness. Whilst both groups were able to regulate their emotionally driven behaviors, experienced meditators were more able to regulate themselves than beginners when using the experiential "intimate detachment" strategy, whilst neither group outperformed the other in emotion regulation when using a cognitive reappraisal strategy. The evidence suggests that greater practice in mindfulness therefore does not necessarily enhance a person's capacity to self-regulate using cognitive reappraisal but does enhance the use of intimate detachment as a means of self-regulation.

These findings substantiate the growing evidence that mindfulness meditation enables emotional and physiological regulation. Furthermore the findings suggest that one of the unique components of mindfulness practice is to enable emotional regulation through the practice of intimate detachment that relies on bottom-up neural activations and pathways. The effectiveness of intimate detachment is also sensitive to the practice effect with more practiced meditators being more able to regulate their emotions and responses. Yet what specific mechanism may be proposed that could account for the neural and psychological process of intimate detachment?

In line with the above cited and other recent evidence [81, 83–85], we outline a neural circuit comprising the prefrontal cortex (PFC), the anterior cingulate cortex (ACC), the amygdala (A), and the insula (I) that are involved in the unique processes of mindful emotion regulation. This circuit includes "top-down" control regions such as the PFC and the ACC and more "bottom-up" emotional regions such as the I and the A.

These two neural networks (PFC-ACC and A-I) interact via connective neural structures such as the corona radiata. Focused, sustained, intimately detached attention on emotional states (activation of PFC and ACC) leads to increased awareness and knowledge of emotions (I and A activation). The mindfulness practitioner's effort to stop the generation of thought and to pay attention to internal perceptions and emotions is reflected in PFC and ACC activation. Ruminative thoughts triggered by unpleasant emotions further reinforce those negative emotions leading to a maintenance or escalation of negative emotions. Breaking this cycle by redirecting intimately detached attention to emotions stops this vicious cycle. We propose that activation of PFC impulse control and ACC stimulus discrimination and attentional focus are some of the neuropsychological processes that enable intimate detachment. Yet, with increased frequency of mindfulness practice there is greater activation of the ACC [34, 41, 42] and less utilisation of PFC functions, which signifies a greater reliance on perceptual stimulus discrimination rather than active cognitive control strategies. The PFC and ACC regions are activated in the service of attuning to emotions through greater regulatory connectivity with the A-I regions. Whilst the PFC region can contribute to emotional regulation via cognitive reappraisal, this is not unique to mindfulness. Instead, it is the increasing activation of the ACC functions of stimulus discrimination, attention to emotional stimuli, and resolution of stimulus conflict that are more involved in the unique process of intimate detachment that enables emotional regulation. This particular utilisation of the PFC-ACC regions and its connectivity with the I-A regions is also enhanced by practice.

This broad neurological model for the effects and mechanism of intimate detachment in mindfulness offers a structure for further research and model building. It may guide future research enquiry about more detailed neuropsychological processes (such as different attentional processes) that are required in order to enable the state of intimate detachment. For example, are certain attentional skills (attentional focusing versus shifting skills) more or less important in developing the capacity for intimate detachment? What are the specific psychological components characterised by greater ACC activation in practiced meditators? How can this enhance our understanding of how patients could achieve the experiential emotional regulatory state of intimate detachment or decentering?

7. Conclusions

Mindfulness meditation has become a widespread, accessible, and effective method for improving mental and physical well-being. In this paper we reviewed the psychological and neural mechanisms believed to be at the heart of this method. Current evidence for the components of mindfulness meditation refers to attentional processes, body awareness, and cognitive regulatory processes such as cognitive reappraisal. Clinical effectiveness across a range of psychological disorders, stress, and pain conditions has been evidenced but without specific understanding of how mindfulness meditation enables such clinical recovery. More recently models of mindfulness meditation have been put forward in order to support research enquiry into the specific and unique components that characterize it. Such models allow for more rigorous examination and operationalization of the method to guide research. Increasingly investigators are focusing on the impact mindfulness has on emotional regulation which accounts for the effects on mental health. Two component processes that have attracted examination are emotional regulation through the process of cognitive appraisal and through the process of intimate detachment, the latter being the more experiential aspect of mindfulness meditation. Whilst cognitive reappraisal plays a significant role in mindfulness, we have highlighted evidence that shows that it is the stance of intimate distancing that is unique to mindfulness in enabling emotional regulation and that it is this unique method that is especially enhanced in experienced meditators. Based on the evidence we have proposed a neural circuit whereby the stance of intimate detachment operates. This model may enable researchers to focus future investigations on neuropsychological processes that contribute to developing the state and skill of intimate detachment. Further refinement of our understanding of how intimate detachment is achieved may also aid the application of this unique aspect of mindfulness methods within various psychological therapies.

Conflict of Interests

The authors declare that there is no conflict of interests regarding the publication of this paper.

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Clinical Study

Qigong as a Traditional Vegetative Biofeedback Therapy: Long-Term Conditioning of Physiological Mind-Body Effects

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A contemporary understanding of Chinese Medicine (CM) regards CM diagnosis as a functional vegetative state that may be treated by vegetative reflex therapies such as acupuncture. Within this context, traditional mind-body exercises such as *Qigong* can be understood as an attempt to enhance physiological proprioception, by combining a special state of "awareness" with posture, movement, and breath control. We have formerly trained young auditing flutists in "White Ball" *Qigong* to minimize anxiety-induced cold hands and lower anxiety-induced heart rate. Functional changes occurred 2–5 min after training and were observed over the whole training program, allowing the children to control their symptoms. In our current work, we report that warm fingers and calm hearts could be induced by the children even without *Qigong* exercises. Thus, these positive changes once induced and "conditioned" vegetatively were stable after weeks of training. This may show the mechanism by which *Qigong* acts as a therapeutic measure in disease: positive vegetative pathways may be activated instead of dysfunctional functional patterns. The positive vegetative patterns then may be available in critical stressful situations. *Qigong* exercise programs may therefore be understood as an ancient vegetative biofeedback exercise inducing positive vegetative functions which are added to the individual reactive repertoire.

1. Introduction

The contemporary understanding of the diagnosis in Traditional Chinese Medicine (TCM) considers TCM as a traditional model of vegetative system biology with the purpose of a systemic therapeutic approach [1–8]. Within this concept, *Qigong* is understood as a traditional vegetative biofeedback therapy consisting of concentrative motion and postures combined with breathing exercises. Actually the "*qi* activation" is achieved by breath control and a special mental state of "awareness" [9, 10], thereby improving and strengthening the overall state of vegetative regulation (homeostasis) [1, 11–15].

Several studies on *Qigong*-related effects concerning physiological processes and variables have been published elsewhere. Actually some of these studies point to significant changes on parameters such as the blood pressure, heart rate and variability, decrease of plasma triglycerides, total cholesterol and low density lipoprotein (LDL) cholesterol, increase of HDL cholesterol, skin temperature, and improvement in lung functions such as the increment in forced expiratory volume and the reduction in the number of exacerbations, between others [16–22].

One of the prime benefits of *Qigong* seems to be stress reduction, and one of the main concepts of this practice is to use the mind to guide activation and deactivation patterns by imagination. Excessive stress may have a negative impact on the health state of a person and may be associated with an increase of anxiety, psychological disorders, and functional impairments of organs within the body [11]. It was shown that *Qigong* training may reduce emotional exhaustion and depersonalisation and even improves anxiety and reinforce attention and effectiveness in high school students [23–34].

Although in some European countries *Qigong* is considered and supported by the health systems as a preventive measure, training programs for children are not widely spread. As this is possibly due to a lack of data, we were interested in a further understanding of the modes of action of *Qigong*. We chose the so-called "White Ball" exercise system, as it takes 5 min to do it and can be integrated at work or at school [9, 10].

In its traditional understanding, TCM holds that "*qi*," a functional power in the body, may be seen in functional physical signs. These are related to measurable physiological processes and aspects such as the increase of the peripheral microcirculation, thus the increase of the skin temperature and the changes on acupoints electrical potential and resistance and even on the surrounding biomagnetic field [24, 35–37]. Objective detection methods to evaluate the physical effects of *Qigong* therefore are an important prerequisite for the development of clinical study designs. Some authors have reported significant changes in the intensity and frequency of the infrared radiation emitted from the hands of *Qigong* practitioners, as well as detection of dynamic changes of temperature by thermography [24, 38, 39]. Qin et al. (1997) suggested that infrared thermography could be used to measure the dynamic changes of temperature in the hands and arms during *Qigong* practice [39].

We had previously refined this method and shown that young flutists, suffering from cold hands and elevated heart rate before auditions, would show elevation of hands temperature and reduction of anxiety-induced heart rate after the *Qigong* exercises and along the training program. We were now interested whether this effect was only to be seen while training was going on or whether *Qigong* exercises can result in stable changes of the functional vegetative repertoire, which we could even call a remodelling of vegetative functions and pathways. In this sense, stable changes of vegetative functional reactions would explain long-term effects of *Qigong* by the remodelling of vegetative functional patterns. It would also explain some of the positive long-term emotional changes, as emotionality and body experience are understood as interrelated [5, 40].

2. Materials and Methods

2.1. Sampling and Study Design. A group of seven healthy Caucasian volunteer children, aged between 10 and 12 years, six females and one male, students of flute from a local music academy, and without any previous experience in *Qigong*, were examined for *Qigong*-related effects against performance-related anxiety in well-controlled conditions [25]. In addition to the physiological measurements of that study, we could examine the effects of the exercises by thermography of the hands prior to and after a seven-week *Qigong* training program. Control experiments were conducted with the same individuals, so each one performed two consecutive measurements, the baseline or control and the *Qigong* exercise. In these two assays, the adopted physical posture was the same; however, the intention, mind focus, or the achievement of a "special mental state of awareness" was completely different.

2.2. Infrared Thermography. Experiments were performed at a mean room temperature of 20°C measured with a type K thermocouple connected to a Labfacility digital thermometer, model 2000L. An Infrared camera from FLIR, model A325 (sensibility < 0.07°C; precision ±2%), was used and supported by a tripod, placed 2 metres away from the target. Capture and image analysis were carried out with the program ThermaCAM Researcher Pro 2.9 from FLIR Systems, and the recording frequency was one photo every ten seconds.

2.3. Qigong Posture and Training. The *Qigong* exercise selected for this study was the "White Ball" standing exercise according to the Heidelberg Model of TCM as described in detail elsewhere [10]. In brief, the exercise chosen from this system includes a nondynamic basic *Qigong* posture, similar to the *Wu Chi* posture in the *Zhan Zhuang* system [41–43], minimizing the effects of physical movement. In the exercise, the imagination of holding the ball in front of the abdomen (so-called lower *Dantian*) is used to induce a sensation traditionally referred to as "*qi*" sensation, similar to "deqi" sensation observed in acupuncture. Children were instructed to do the exercise daily for seven weeks. They had accompanied training for 30 minutes with an experienced *Qigong* practitioner twice a week.

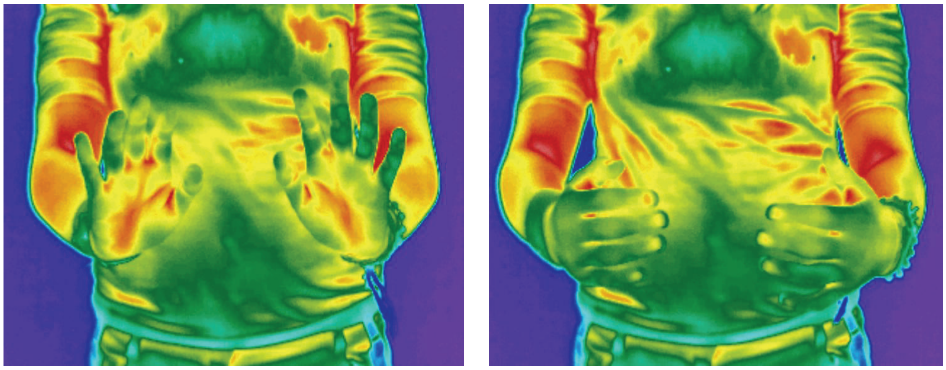
2.4. Statistical Analysis. The following variables were considered in the thermography analysis: final temperature on the tip of the middle finger (FT TMF); activation time (AT: time to increase 1°C on the tip of the middle finger); final temperature on *Láogōng*, Pc8 (FT Pc8); heating rate (HeatR—$^{\circ}Cs^{-1}$).

Pearson correlation analysis and principal components analysis (PCA) were performed to detect structure in the relationships between variables. Eigenvalues were observed and two factors were enough to explain almost all the variabilities. Results are shown as figures and tables. Pearson correlation analysis and PCA were performed with Statistica for Windows release 6.0.

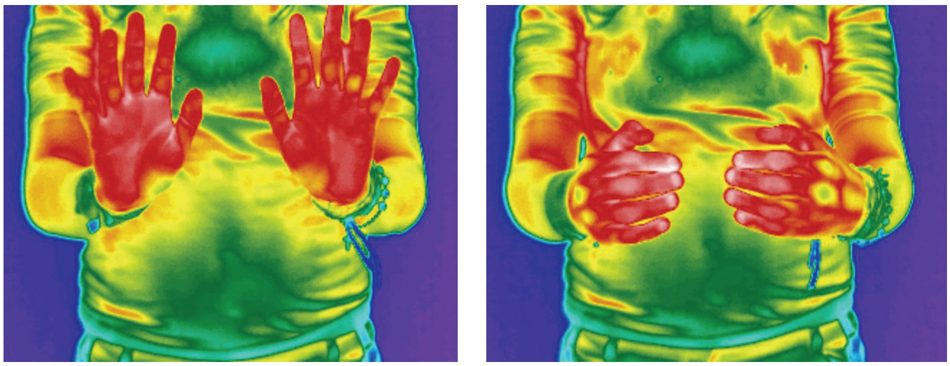
3. Results and Discussion

In brief, thermography indicated changes of local microcirculation during the exercises as shown in Figure 1.

Statistically significant changes in temperature measured by thermography occurred during the exercises and at the beginning and at the endpoint of the observation interval. Highly significant differences ($P < 0.01$) were obtained when comparing the first and second assays with the respective baselines. Moreover, when comparing the first with



(a)



(b)

Figure 1: Thermograms of the *Qigong* exercise ((a) before; (b) after).

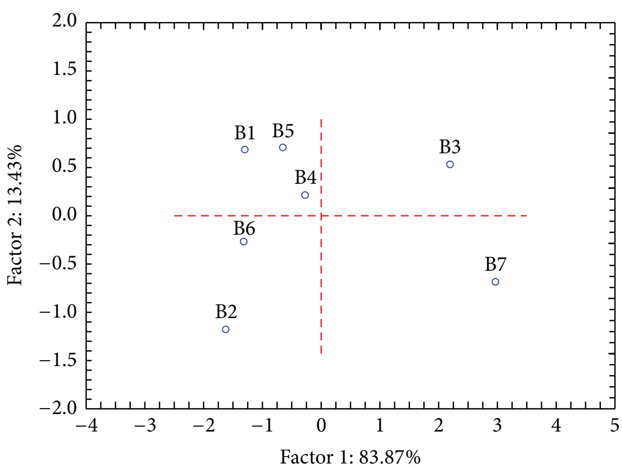


Figure 2: Principal components analysis (PCA) concerning the variables FT TMF, AT, FT Pc8, and HeatR at the beginning of the *Qigong* program.

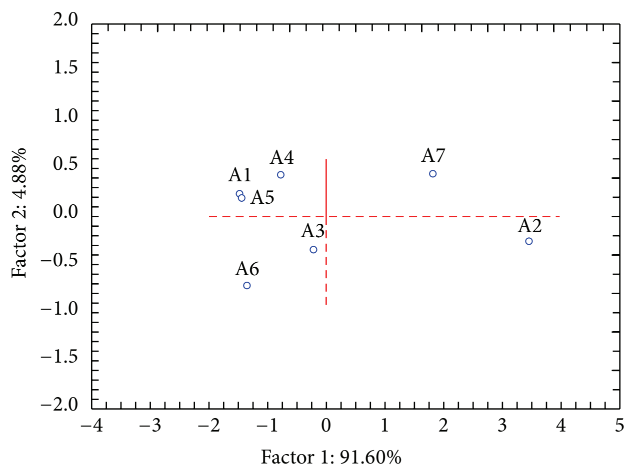


Figure 3: Principal components analysis (PCA) concerning the variables FT TMF, AT, FT Pc8, and HeatR at end of the *Qigong* program.

the second assays no statistically significant differences were obtained ($P = 0.364$). This could be an indicator that this group of children quickly developed the capacity of vegetative activation through *Qigong* practice being able to minimize anxiety-induced cold hands in a short period of time and on demand as a part of the child reactive repertoire. Furthermore, there was an improvement on the performance of almost every child along the *Qigong* program, with a tendency to a homogeneous response on the measured vegetative effects, as can be seen when comparing the PCA results shown in Figures 2 and 3. On the mentioned figures, dots are plotted according to the PCA scores related to the variables (Figure 4) and represent each child, before (b) and after (a) the *Qigong* program. Moreover, dots plotted on

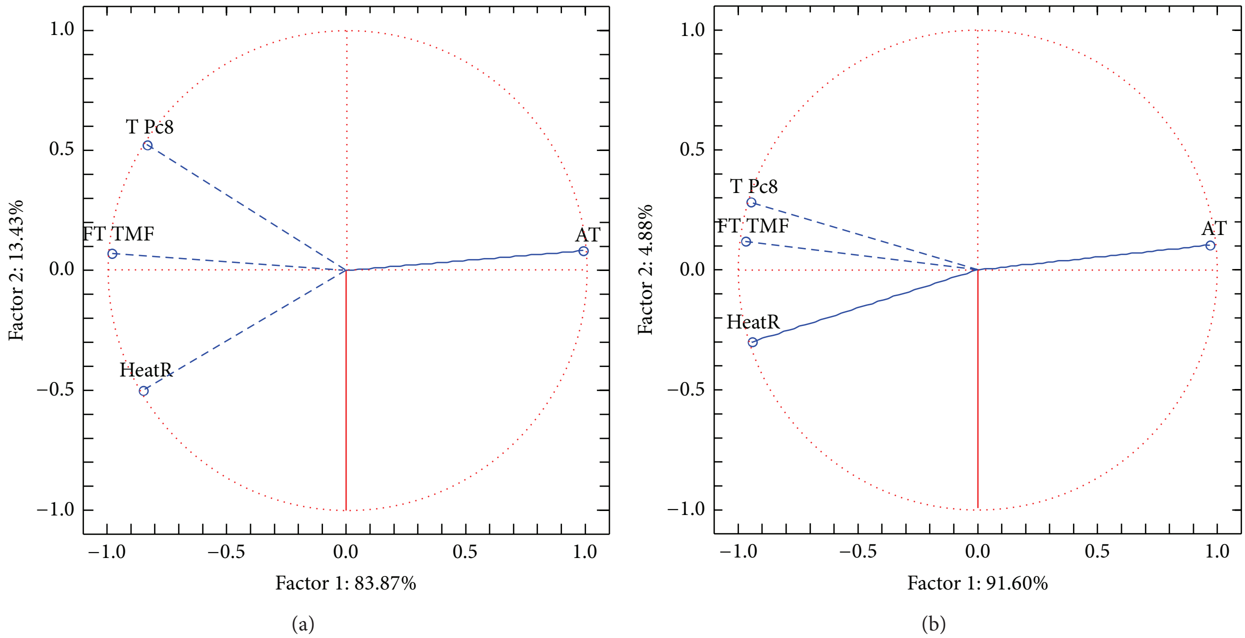


FIGURE 4: PCA variables projection on the graphical plane: (a) before and (b) after the *Qigong* program.

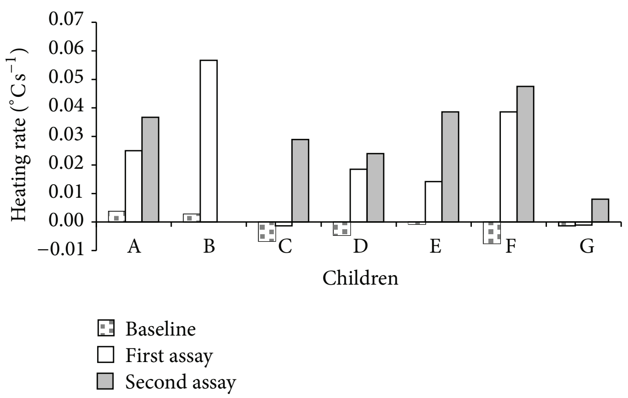


FIGURE 5: Heating rate for each child (A to G) in the baseline assay and at the beginning and end of the *Qigong* training program.

Figure 3 are close to each other, thus indicating a group tendency that reflects the vegetative conditioning of positive physiological effects within the program.

As can be seen in Figure 5, with exception of child B, there was a general noticeable increase of the heating rate at the end of the *Qigong* training program. This means that children developed the ability to quickly activate and increase the hands microcirculation, thus increasing the hands temperature in a shorter period of time.

The time until physiological activation was less than 2 minutes in all examined cases. The results indicate that, like in other *Qigong* exercises, the system of the "White Ball" can change the temperature of the skin as shown by thermography. Unlike other "*qi*" exercise cycles in TCM, the "White Ball" system is only a short exercise of approximately 5 minutes. The short duration nature of this *Qigong* exercise can be confirmed by the activation time of less than 2 minutes in all tested individuals.

TABLE 1: Correlation between the heating rate (HeatR) and the heart rate (HR) and final temperature on the tip of the middle finger (FT TMF) at the beginning and ending of the *Qigong* training program.

Variable	HR	FT TMF
HeatR beginning	$r = -0.423$ $P = 0.345$	$r = 0.764$ $P = 0.045$
HeatR ending	$r = -0.625$ $P = 0.133$	$r = 0.878$ $P = 0.009$

Heart rate results point to a significant decrease of this variable along the *Qigong* program, thus indicating a higher level of relaxation and a lower level of anxiety. Actually the mean heart rate at the beginning of the program was 102.9 beats per minute, with a standard deviation of 20.5 beats per minute and at the end these values were 92.0 and 17.2, respectively.

As can be seen in Table 1, the heating rate correlates negatively with the heart rate, meaning that the heart rate tends to decrease as the faster hands temperature gets higher. Oppositely, the final temperature on the tip of the middle finger (FT TMF) correlates positively with the heating rate, thus indicating that the faster the heating rate, the higher the FT TMF. In both cases, the correlation coefficient r is higher for the results of the second assay, pointing to an improvement of the *Qigong* group.

4. Conclusions

Our findings show that children quickly learned this *Qigong* system with obvious development of individual vegetative skills and the reduction of anxiety-induced effects. These effects were stable after weeks of training, allowing for playing the flute with warm fingers and reduction of the anxiety-reduced elevation of the heart rate even without prior application of *Qigong* exercises. It seems that these positive vegetative changes in the behavioural pattern appear to be naturally available on demand in critical stressful situations as a part of the child reactive behavioural repertoire. We consider this to be an effect by conditioning a vegetative new pattern. Therefore, our data suggest that, by the exercise, a change in the functional vegetative pattern is first elicited. This may be then engrammed and conditioned to be elicited by another stimulus, in this case the context of flute and audition. Having to audit then elicits a functional pattern that is free from anxiety-induced manifestations of the vegetative system.

Overcoming the dysfunctional and disturbing effects of individual challenges in life may be considered to be a necessity for the prevention of a number of constellations like blackouts in examinations, failure in professional presentations, panic attacks, and states of anxiety and burn-out. Our data suggest that *Qigong*, if correctly understood and practised, may be a useful tool in this context.

Our data may also be helpful in the demystification of Chinese Medicine. Thermography allows visualizing the effects of the microcirculation on the hands temperature during *Qigong* practice. Actually, TCM holds that the "mind" guides the "*qi*" which guides the "*xue*" (blood).

The Heidelberg model of TCM sees strong analogies of the effects of "*xue*" as described by the classical scriptures with the clinical effects of microcirculation in Western medicine. Therefore, "*qi*," translated by this model as a vegetative functional capacity, guides and steers the microcirculation. In other words, this old phrase from classical scriptures can be demystified as "the mind" (imagination and awareness) can guide and therefore activate vegetative capacities, which in return lead to changes in microcirculation.

We believe that such demystifying approaches to the corpus medicus of Chinese Medicine may be helpful to objectify its vegetative mechanisms underlying *Qigong* therapy and acupuncture. These exercises should be further explored and demystified as an ancient form of vegetative biofeedback therapy with long clinical experience.

The "White Ball" system is a simple, short duration *Qigong* exercise, easy to learn, that does not require much space, with positive effects on anxiety and stress management. It could be a powerful tool in the management of these disorders even when used in a classroom, at work, or elsewhere. As the conditioning effect may be more pronounced in the developing nervous system, these helpful patterns may be especially worthwhile and effective in children. Therefore, the supposed mechanisms of conditioning positive vegetative behavioural patterns suggest the application of these exercises especially at a young age.

Conflict of Interests

The authors declare that there is no conflict of interests regarding the publication of this paper.

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Review Article

Neurophysiological Effects of Meditation Based on Evoked and Event Related Potential Recordings

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Evoked potentials (EPs) are a relatively noninvasive method to assess the integrity of sensory pathways. As the neural generators for most of the components are relatively well worked out, EPs have been used to understand the changes occurring during meditation. Event-related potentials (ERPs) yield useful information about the response to tasks, usually assessing attention. A brief review of the literature yielded eleven studies on EPs and seventeen on ERPs from 1978 to 2014. The EP studies covered short, mid, and long latency EPs, using both auditory and visual modalities. ERP studies reported the effects of meditation on tasks such as the auditory oddball paradigm, the attentional blink task, mismatched negativity, and affective picture viewing among others. Both EP and ERPs were recorded in several meditations detailed in the review. Maximum changes occurred in mid latency (auditory) EPs suggesting that maximum changes occur in the corresponding neural generators in the thalamus, thalamic radiations, and primary auditory cortical areas. ERP studies showed meditation can increase attention and enhance efficiency of brain resource allocation with greater emotional control.

1. Introduction

Meditation has been described as a training in awareness which over long periods of time produces definite changes in perception, attention, and cognition. The neurophysiological correlates of meditation have been determined by electrophysiological recordings (from the 1960s to the present time) and more recently by neuroimaging studies (from the 1980s till the present time). Among electrophysiological variables sensory evoked potentials (EPs) provide a relatively noninvasive way of studying changes in specific sensory pathways during meditation [1]. It is believed that meditation alters cortical functioning and corticofugal controls which may significantly modify the processing of information at brainstem and thalamic levels [2–4]. Hence short, mid, and long latency EPs would be expected to help map changes from the brainstem up to the association or secondary cortical areas [5]. The present review was undertaken to determine which modalities and latencies of EPs were recorded in meditation and the conclusions derived.

EPs are evoked spontaneously with repetitive sensory stimulation and can provide information about brain resource allocation and the speed of stimulus processing, whereas event-related potentials (ERPs) are not spontaneous but elicited with cognitive task processing [6–8]. Hence ERPs can provide additional information regarding the discriminative ability of the brain and neurocognitive processing related to shifting attention. The present review also discusses studies which evaluated the effect of meditation on different modalities of ERPs.

2. Methods

2.1. Search Strategy for Meditation and Evoked Potential Studies. The database searched was PubMed using the search words "Meditation, Evoked Potentials." Fifty-eight citations were obtained from PubMed. To be included in this review articles had to be written in English (8 articles were excluded as they were written in other languages). Articles were excluded from the review if (i) they reported event-related potentials (ERPs) rather than EPs (19 articles were excluded for this reason) and (ii) they did not deal directly with the subject of meditation (5 articles were excluded for this reason), (iii) the articles were not experimental studies but were review articles or descriptive (5 articles were excluded for this reason), and (iv) the study recorded variables other than EPs such as EEG, MRI, and spectroscopy studies (10 articles were excluded for this reason). Eleven articles reported evoked potential changes in different meditations and are reviewed here for their study design, method of meditation, and conclusions derived.

2.2. Search Strategy for Meditation and Event-Related Potential Studies. The databases searched were PubMed using the search words "Meditation, Event-Related Potentials." Sixty citations were obtained from PubMed. To be included in this review articles had to be written in English (8 articles were excluded as they were written in other languages). Articles were excluded from the review if (i) they reported evoked potentials (EPs) rather than event-related potentials (ERPs) (15 articles were excluded for this reason) and (ii) they did not deal directly with the subject of meditation (3 articles were excluded for this reason), (iii) the articles were not experimental studies but were review articles or descriptive (5 articles were excluded for this reason), and (iv) the study recorded variables other than ERPs such as EEG, MRI, and spectroscopy studies (11 articles were excluded for this reason). Details of one study were not available. Seventeen articles reported event-related potential changes in different meditations and are reviewed here for their study design, method of meditation, and conclusions derived.

2.3. Method of Review. The whole papers were obtained and the details related to (i) stimulus modality for EPs or nature of the ERP, (ii) sweep width or latency of the EPs, (iii) type of meditation, (iv) study design, and (v) changes (if any) in EP or ERP components and the corresponding changes in the neural generators were noted.

3. Results

3.1. Details of the Evoked Potential Studies. Out of the eleven studies 10 used auditory stimuli while one used visual stimuli. With regard to sweep width out of the nine studies two reported short latency EPs, four mid latency EPs, two long latency EPs, and one long latency visual evoked potential (LLVEP) and there were also two combinations of (i) short latency and mid latency auditory EPs and (ii) short, mid, and long latency auditory EPs. Details about the components of EPs are given in Table 1.

The meditation techniques studied were all eyes closed practices; two were transcendental meditation (TM), two Qigong, five meditations on the Sanskrit syllable "OM," one a moving meditation called cyclic meditation, and one Sahaja yoga meditation. Apart from the moving meditation the other eight techniques directed the thoughts in a fixed pattern for all practitioners towards either a single syllable or phrase or a set of thoughts. In the moving meditation as well, the sequence of thoughts was fixed and played on a CD [9].

Hence in all the studies the meditation techniques involved directing the attention in a specific way in all practitioners. The next point considered was the study design which included the controls used.

The range of experience in meditation was from naïve to twenty years. The sample size varied widely in the nine studies with a range between five and sixty practitioners and group average ± S.D. was 27.8 ± 18.4.

3.2. Details of the Event-Related Potential Studies. Out of the seventeen studies four used auditory oddball paradigm, three used the attentional blink task, two used mismatched negativity, two used affective picture viewing, one used global-to-local target task, one used the Stroop task, one used visual A-X continuous performance task, one used row/column speller, one used anticipatory and pain evoked ERPs, and one used discrimination of the imagery of the hand movement.

The meditation techniques used were Vipassana meditation in six studies, Sahaja yoga meditation, open monitoring meditation, Sudarshan Kriya yoga meditation, musical meditation, meditative mindfulness, cyclic meditation, mindfulness based cognitive therapy one each in seven studies, and two mixed traditions and 2 did not specify the meditation techniques used. All meditation techniques were performed with eyed closed.

3.3. Observations Common to Both EP and ERP Research in Meditation. In meditation research it is often difficult to find an appropriate control group which does not practice meditation but is otherwise comparable to the meditation group in other ways. This is because meditators often have other changes in their lifestyle such as abstaining from caffeine, nicotine, and other stimulating substances, different hours of rising and sleeping, and other differences. For this reason in some studies the meditators themselves are assessed under identical conditions on another day as a control, which may be described as the self-as-control [10].

This design was followed in four of the EP studies which are presented in Table 2 [5, 11–13]. There were two single group studies [1, 14]. These were the earliest studies on evoked potentials and meditation. The absence of a comparison or control state or group is an obvious disadvantage, as the effect of time during a session can be expected to influence the evoked potential components and the meditation effect would not be separated from this. In five other papers [15–19] the approach taken was to have separate groups of participants. In only one trial [17] the participants were randomized as three groups. The advantage of the separate groups design over the self-as-control is that nonmeditators would not get inadvertently into meditation which is a disadvantage of the self-as-control design, where experienced meditators may get into the meditative state automatically, even during a control session.

Out of the seventeen ERP studies, 12 studies had a two-group design, four studies had a self-as-control design, and one had mixed design in which the study was conducted in two phases, phase 1 was a cross sectional study and phase 2 was a longitudinal study. This is described in Table 3. The disadvantages and advantages are comparable to those described above for EP studies. With ERP studies there is an additional point; since the participants are given a task

Table 1: Neural generators of evoked potential components.

S. number		Name of the components	Latencies (msec)	Neural generators
		Wave I	1.9	Auditory portion of the eighth cranial nerve
		Wave II	3.6	Near or at the cochlear nucleus. A portion from the eighth nerve fibers around the cochlear nucleus
1	Short latency auditory evoked potential	Wave III	4.2	The lower pons through the superior olive and trapezoid body
		Wave IV	5.2	The upper pons or lower midbrain, in the lateral lemniscus and the inferior colliculus; a contralateral brainstem generator for wave V is suggested
		Wave V	5.8	
		Na	14–19	Medial geniculate body
		Pa	25–32	Superior temporal gyrus
2	Mid latency auditory evoked potential	Nb	35–65	Dorso-posterior-medial part of Heschl's gyrus that is the primary auditory cortex
		N1	40–60 ms	Secondary auditory cortex in the lateral Heschl's gyrus
		P1	80–115 ms	Bilateral parts of the auditory superior cortex
	Long latency auditory evoked potential	N2	140–180 ms	Mesencephalic-reticular activating system (RAS)
		P2	220–280 ms	Anterior cingulate cortex

it is usual to record before and after meditation, not during meditation, as doing the task would interfere with meditation.

3.4. Results of EPs

3.4.1. Auditory Evoked Potentials. Discussing the short latency or brainstem auditory evoked potentials first, there were three studies. In the earliest study [14] the peak latency of wave V which corresponds to the inferior colliculus varied with the intensity of the stimuli and hence could not be considered as an effect of the transcendental meditation (TM) practiced. In the second study which reported short latency auditory evoked potentials in Qigong meditators [15] there was a significant increase in the peak amplitudes of waves I to V of short latency auditory evoked potentials. An increase in amplitude is suggestive of recruitment of increased neurons in the underlying neural generators [20]. This suggested that Qigong meditation activates areas in the brainstem. There was no change in short latency auditory evoked potentials in patients with epilepsy who practiced Sahaja yoga possibly because they were novices to meditation [17]. In the other study which reported changes in short latency auditory evoked potentials the peak latency of wave V increased during random thinking, focusing and meditative focusing, but not during meditation [11]. An increase in peak latency signifies delayed transmission through the respective neural generators [5], in this case located in the brain stem. Hence it would appear as if random thinking, focusing, and meditative focusing all delay auditory information transmission at the brainstem level but this does not happen during meditation on "OM."

The mid latency auditory evoked potentials correspond to neural generators in the thalamus, primary auditory cortex, and Haschl's gyrus [2–4]. With Qigong meditation the amplitudes of Na and Pa components decreased during meditation [15]. The Pa wave peak amplitude also decreased during meditation on "OM" in sixty practitioners [12] but there was an increase in peak amplitude of Na wave during meditation on "OM" in a separate study [18]. The Na wave is believed to be due to activity at the mesencephalic and diencephalic level [21] and the Pa wave corresponds to activity at the superior temporal gyrus [22]. A third component of the mid latency auditory evoked potentials is the Nb wave. This wave appears relatively localized in the dorso-posterior-medial area of Heschl's gyrus, that is, the primary auditory cortex [23]. The Nb wave peak amplitude increased and peak latencies of Pa and Nb waves decreased after the moving meditation called cyclic meditation (CM), which incorporates movement [5]. The peak latency of Nb wave reduced during meditation on "OM" as well [19]. Hence the moving meditation altered the auditory pathway at the level of superior temporal gyrus and Heschl's gyrus with a delay in auditory transmission despite an increase in number of neurons recruited. During meditation on "OM" the delay in auditory transmission was found only in the dorso-posterior-medial area of Heschl's gyrus.

Long latency auditory evoked potentials showed no significant change in an early study on transcendental meditation practitioners [1]. The P2 component showed a decrease in peak amplitude during Qigong meditation and a decrease in peak latency during meditation on "OM." The P2 wave partly reflects auditory output of the mesencephalic activation system [24, 25]. From MEG and EEG data based on depth electrodes in patients, the neural generators for the P2 component were localized in the planum temporale as well as the auditory association complex (Brodmann area 22) [26–29]. Also it is speculated that the P2 component may receive contributions from cortical areas in the depth of the Sylvian fissure. Hence this area, which is associated with complex auditory functions, changes during both Qigong and OM meditations.

3.4.2. Summary of Changes in Auditory Evoked Potentials. Out of the four studies which evaluated short latency auditory

Table 2: Details of the evoked potential studies.

S. number	Reference	Modality auditory/visual/somatosensory and latency	Type of meditation	Meditation experience, duration	Components altered and brain area	Sample and design
1	Electroencephalogr Clin Neurophysiol. 1978, 45 (5): 671–673 [1]	Auditory Long latency	Transcendental meditation	18 months to 6 years	No significant change	Single group
2	Intern J Neuroscience. 1980, 10 (2-3): 165–170 [14]	Auditory Short latency	Transcendental meditation	6 to 9 years	Wave V latency increased in moderate intensity stimuli and wave V latency decreased in high intensity stimuli	Single group
3	Am J Chin Med. 1990, 18 (3-4): 95–103 [15]	Auditory Short latency, middle latency, and long latency	Qigong meditation which involves the initial "concentrating," a subsequent "circulating," and finally the "dispersion" of Qi	1 to 20 years	There was a significant increase in amplitude in wave I-V of BAER, Na and Pa wave of MLR decreased, and P2 wave of LLAER also decreased during meditation	3 groups: BAER, MLAER, and LLAER
4	Am J Chin Med. 1993, 21 (3-4): 243–249 [16]	Visual Cortical evoked potentials	Qigong meditation in which the practitioner concentrates on the "Dantian"	2.3 years for the experienced group, 1.9 months for the learning group	Peak-to-peak amplitude of N80-P115-N150 and N150-P200-N280 increased in the experienced group	3 groups: practitioner group learning group, and control group
5	Int J Neurosci. 1994; 76 (1-2): 87–93 [18]	Auditory Middle latency evoked potentials	"OM" meditation in which the participants meditated with effortless absorption in the single-thought state of the object of meditation, that is, "OM."	10 years	Experienced meditators had significant increase in peak amplitude of Na wave during meditation and significant reduction in Na wave peak amplitude during control session	Two-group study (experienced meditators and nonexperienced)
6	Indian J Med Res. 1993; 98: 237–9 [19]	Auditory Middle latency evoked potentials	"OM" meditation in which the participants meditated with effortless absorption in the single-thought state of the object of meditation, that is, "OM."	5–20 years	Experienced meditators had a significant reduction in the peak latency of the Nb wave	Two-group study (experienced meditators and nonexperienced)
7	Appl Psychophysiol Biofeedback. 2000, 25 (1): 1–12 [17]	Auditory BAEP MLAEP	Sahaja yoga in which the participants make certain mental assertions by placing the hand on different parts of the body.	Not experienced $N = 10$ (Sahaja yoga group), $N = 10$ (mimicking exercise group), and $N = 12$ (control group)	Significant increase in Na-Pa amplitude of MLR following meditation practice	Randomized controlled study
8	Clin EEG Neurosci. 2009, 40 (3): 190–195 [5]	Auditory Mid latency	Cyclic meditation in which a series of *asanas* (postures interspersed with relaxation techniques) are practiced with awareness.	6–48 months	After cyclic meditation there was a significant increase in the peak latency of the Pa wave and of the Nb wave; peak amplitude of the Nb wave also increased	Self as control design

Table 2: Continued.

S. number	Reference	Modality auditory/visual/somatosensory and latency	Type of meditation	Meditation experience, duration	Components altered and brain area	Sample and design
9	Int J Yoga. 2010 3 (2): 37–41 [11]	Auditory Brainstem auditory-evoked potentials (BAEPs)	"OM" meditation in which the participants meditated with effortless absorption in the single-thought state of the object of meditation, that is, "OM."	6 months	Wave V peak latency significantly increased in cancalata, ekagrata, and dharana, but no change occurred during the dhyana session	Self as control
10	Clin EEG Neurosci. 2012, 43 (2): 154–60 [12]	Auditory Mid latency	"OM" meditation participants were instructed to keep their eyes closed and dwell on thoughts of OM, without any effort, particularly on the subtle (rather than physical) attributes and connotations of the syllable.	6–60 months	Significant increase in the peak latencies of Na and Pa waves during meditation and the peak amplitude of Pa wave was significantly decreased during meditation	Self as control design
11	Clin EEG Neurosci. 2014, pii: 1550059414544737 [13]	Auditory Long Latency	"OM" meditation in which participants were instructed to keep their eyes closed and dwell on thoughts of OM, without any effort, particularly on the subtle (rather than physical) attributes and connotations of the syllable.	6–60 months	Decrease in the peak latency of the P2 wave during and after meditation	Self as control design

Table 3: Details of event related studies.

S. number	Citation	Participants	Nature of the ERP task	Design	Intervention	Findings
1	Neuroscience. 2014, 281C: 195–201 [31]	Healthy experienced meditators and nonmeditators	Affective picture viewing	Two-group study	No intervention was given but this study compared between long-term experienced Sahaja yoga meditators and nonmeditators	Mid latency (140–400 ms) ERPs were attenuated for both positive and negative pictures and a stronger ERP negativity in the time window 200–300 ms was found in meditators regardless of picture valence. We assume that long-term meditation practice enhances frontal top-down control over fast automatic salience detection, based on amygdala functions.
2	Int J Psychophysiol. 2013, 90 (2): 207–214 [32]	Healthy experienced meditators aged 20–61 years	Auditory oddball task with two tones (standard and target)	One group was assessed in two separate conditions (self as control)	Vipassana meditation and random thinking	The Vipassana experts showed greater P3b amplitudes to the target tone after meditation than they did both before meditation and after the no-meditation session. These results suggest that expert Vipassana meditators showed increased attentional engagement after meditation.
3	Soc Cogn Affect Neurosci. 2013, 8 (1): 100–111 [34]	Healthy Vipassana meditators Exp. = 2.5–40 years	Three-stimulus auditory oddball task	One group was assessed in two separate conditions (self as control)	Vipassana meditation and instructed mind wandering	Meditation compared to control condition had decreased evoked delta (2–4 Hz) power to distracter stimuli concomitantly with a greater event-related reduction of late (500–900 ms) alpha-1 (8–10 Hz) activity, which indexed altered dynamics of attentional engagement to distracters. Additionally, standard stimuli were associated with increased early event-related alpha phase synchrony (intertrial coherence) and evoked theta (4–8 Hz) phase synchrony, suggesting enhanced processing of the habituated standard background stimuli. Finally, during meditation, there was a greater differential early-evoked gamma power to the different stimulus classes. Correlation analysis indicated that this effect stemmed from a meditation state-related increase in early distracter-evoked gamma power and phase synchrony specific to longer-term expert practitioners. The findings suggest that Vipassana meditation evokes a brain state of enhanced perceptual clarity and decreased automated reactivity.
4	Front Hum Neurosci. 2012, 6: 133 [38]	Healthy meditators and nonmeditators	Global-to-local target task	Study conducted in two phases Phase 1: cross sectional study Phase 2: longitudinal study	Open monitoring meditation	Meditators showed an enhanced processing of target level information. In contrast with control group, which showed a local target selection effect only in the P1 and a global target selection effect in the P3 component, meditators showed effects of local information processing in the P1, N2, and P3 and of global processing for the N1, N2, and P3. Thus, meditators seem to display enhanced depth of processing. In the longitudinal experiment, meditation modulates attention already after a 4-day meditation retreat. Together, these results suggest that practicing meditation enhances the speed with which attention can be allocated and relocated, thus increasing the depth of information processing and reducing response latency
5	Soc Cogn Affect Neurosci. 2013, 8 (1): 85–92 [45]	Healthy meditators and nonmeditators	Stroop task	Two-group study	Comparison between meditators and nonmeditators, meditators are from various traditions	Meditators showed greater executive control (i.e., fewer errors), a higher error related negativity (ERN), and more emotional acceptance than controls.
6	BMC Psychiatry. 2012, 12: 15 [44]	Patients with bipolar disorder and normal healthy participants	A visual A-X continuous performance task	Two-group study	Mindfulness based cognitive therapy (MBCT)	MBCT in bipolar disorder improved attentional readiness and attenuated activation of nonrelevant information processing during attentional processes
7	J Neural Eng. 2011, 8 (2): 025019 [42]	Healthy individuals	Row/column speller task	Two-group study	Meditative Mindfulness Induction (MMI) and non-MMI control group	MMI subjects were significantly more accurate than control subjects and they produced significantly larger P300 amplitudes than control subjects at Cz and PO7
8	Neurosci Res. 2011, 71 (1): 44–48 [46]	Healthy meditators and nonmeditators	Emotional load of stimuli (IAPS pictures)	Two-group study	No intervention was given but this study compared with experienced meditators and nonmeditators	The result showed different emotional processing in meditation practitioners: at high levels of processing meditators are less affected by stimuli with adverse emotional load, while processing of positive stimuli remains unaltered
9	Pain. 2010, 150 (3): 428–438 [47]	Healthy meditators and nonmeditators	Anticipatory and pain-evoked ERPs	Two-group study	No intervention was given but this study compared with experienced meditators and nonmeditators; meditators were from different traditions	Meditation reduces the anticipation and negative appraisal of pain

Table 3: Continued.

S. number	Citation	Participants	Nature of the ERP task	Design	Intervention	Findings
10	J Neurosci. 2009, 29 (42): 13418–13427 [37]	Healthy meditators and nonmeditators	Attention blink task and attention auditory task	Two-group study	Vipassana and loving kindness meditation	Three months of intensive meditation training reduced variability in attentional processing of target tones and reduced reaction time variability. Those individuals with greatest increase in neural response consistency had largest decrease in behavioral response variability. Reduced variability in neural processing was observed regardless of whether the deviant tone was attended or unattended. *n* significantly affect attention and brain function.
11	Conf Proc IEEE Eng Med Biol Soc. 2008, 2008: 662–665. [48]	Meditators and nonmeditators	Discrimination of the imaginative hand movement and the idle state	Two-group study	Type of meditation not specified	The meditation practice can improve the classification accuracy of EEG patterns. The average classification accuracy was 88.73% in the meditation group, while it was 70.28% in the control group. An accuracy as high as 98.0% was achieved in the meditation group.
12	Int J Psychophysiol. 2009, 72 (1): 51–60. [33]	Healthy experienced meditators	Auditory oddball task with two tones (standard and target)	One group was assessed in two separate conditions (self as control)	Vipassana meditation and random thinking	During meditation N1 amplitude from the distracter was reduced frontally; P2 amplitudes from both the distracter and oddball stimuli were somewhat reduced; P3a amplitude from the distracter was reduced. The meditation-induced reduction in P3a amplitude had a positive correlation with the quality and experience of meditation
13	J Cogn Neurosci. 2009, 21 (8): 1536–1549. [36]	Healthy meditators and nonmeditators	The attentional blink task	Two-group study	Vipassana Meditation	Theta phase locking in conscious target perception and suggest that after mental training the cognitive system is more rapidly available to process new target information. Mental training was not associated with changes in the amplitude of T2-induced responses or oscillatory activity before task onset
14	Neuroreport. 2007, 18 (16): 1709–1712. [39]	Healthy meditators and nonmeditators	The mismatch negativity (MMN) paradigm	Two-group study	Sudarshan kriya yoga meditation	Meditators were found to have larger MMN amplitudes than nonmeditators. The meditators also exhibited significantly increased MMN amplitudes immediately after meditation suggesting transient state changes owing to meditation.
15	PLoS Biol. 2007, 5 (6): e138. [35]	Healthy meditators and nonmeditators	The attentional blink task	Two-group study	Vipassana	Three months of intensive mental training resulted in a smaller attentional blink and reduced brain-resource allocation to the first target, as reflected by a smaller T1-elicited P3b, a brain-potential index of resource allocation. Those individuals that showed the largest decrease in brain-resource allocation to T1 generally showed the greatest reduction in attentional blink size. These observations provide novel support for the view that the ability to accurately identify T2 depends upon the efficient deployment of resources to T1. The results also demonstrate that mental training can result in increased control over the distribution of limited brain resources.
16	Int J Neurosci. 2006, 116 (12): 1419–1430. [43]	Healthy individuals	Auditory oddball task with two tones (standard and target)	One group was assessed in two separate conditions (self as control)	Cyclic meditation	There was reduction in the peak latencies of P300 after cyclic meditation at Fz, Cz, and Pz compared to the "pre" values. The P300 peak amplitudes after CM were higher at Fz, Cz, and Pz sites compared to the "pre" values.
17	Chin Med Sci J. 1999, 4 (2): 75–79. [40]	Healthy meditators and nonmeditators	The auditory mismatch negativity (MMN) and P300	Two-group study	Musical meditation	MMN amplitudes in the trained children were larger than those in the control group. In addition, the MMN amplitudes were identical in attend and ignore conditions for both groups.

evoked potentials changes occurred in brainstem evoked potentials only in Qigong [15], not in transcendental meditation [14], in Sahaja yoga [17], or in "OM" meditation [11]. With respect to mid latency auditory evoked potentials assessed in four meditations changes were seen in all four meditations [5, 12, 15, 17–19], that is, Qigong, Sahaja yoga, meditation on "OM," and cyclic meditation. This suggests that meditation modifies neural generators at the level of specific thalamic nuclei, thalamic radiation, and primary sensory cortices irrespective of the meditation techniques. Long latency AEPs changed in two out of the three meditations in which they were recorded. Hence there were changes during Qigong and "OM" meditation but not during TM.

3.4.3. Visual Evoked Potentials. Visual evoked potentials were recorded in a single study on Qigong meditators [16]. There was a significant increase in peak-to-peak amplitude of N80-P115-N150 and N150-P200-N280 waves during Qigong meditation. The authors suggest that N80-P115-N150-P200 recorded may have corresponded to N70-P100-N130-P170 reported by Vaughan in 1996 [30]. The first positive component is believed to be generated within thalamocortical radiations; the subsequent negative component is generated in lamina IV cb. The next positive component reflects inhibitory activity within this lamina and the later positive component reflects extra striate cortex activity. This suggests that Qigong meditation increases the activity in the visual pathway from thalamocortical radiations up to the extra striate cortex with all the relay centers in between being included.

3.5. Results of ERPs. Healthy experienced Sahaja yoga meditators and nonmeditators were assessed in a two-group study using an affective picture viewing task [31]. In this comparison between long-term Sahaja yoga meditators and nonmeditators, mid latency ERPs were attenuated for both positive and negative pictures and a stronger ERP negativity between 200 and 300 ms was found in meditators regardless of picture valence.

There were two separate studies on healthy experienced Vipassana practitioners using an auditory oddball task [32, 33]. In both the studies the groups were assessed in two separate conditions ("the self as control" design), that is, Vipassana meditation and random thinking. In one of the studies Vipassana practitioners showed greater P3b amplitudes to the target tone after meditation than they did both before meditation and after the nonmeditation session [32]. The other study reported changes in multiple components in response to the standard and target stimuli; the meditation-induced reduction in P3a amplitude had a positive correlation with the quality and experience of meditation [33].

In another study healthy Vipassana meditators were given a three-stimulus auditory oddball task [34]. The group was assessed in two separate conditions, that is, Vipassana meditation and instructed mind wandering. Meditation compared to the control condition had decreased evoked delta power to distracter stimuli concomitantly with a greater event-related reduction of late (500–900 ms) alpha-1 (8–10 Hz) activity, suggestive of a modification of attentional engagement to distracters. Additionally, standard stimuli were associated with increased early event-related alpha phase synchrony (intertrial coherence) and evoked theta phase synchrony. Finally, during meditation, there was a greater differential early-evoked gamma power to the different stimuli. Correlation analysis indicated that this effect from a meditation state-related increase in early distracter-evoked gamma power and phase synchrony was specific to longer-term expert practitioners.

Two separate studies compared healthy Vipassana meditators and nonmeditators using the attentional blink task [35, 36]. In one study three months of intensive mental training resulted in a smaller attentional blink and reduced brain-resource allocation to the first target, as reflected by a smaller T1-elicited P3b, a brain-potential index of resource allocation [35]. This efficiency in brain resource allocation might explain the findings of the other study which reported changes, especially in theta phase locking in conscious target perception [36].

Healthy practitioners of Vipassana and loving kindness meditation and nonmeditators were assessed in an attention blink task and an attention auditory task [37]. Hence this two-group study compared practitioners of Vipassana and loving kindness meditation with nonmeditators. Three months of intensive meditation training reduced variability in attentional processing of target tones and reduced reaction time variability. Those individuals with greatest increase in neural response consistency had largest decrease in behavioral response variability. Reduced variability in neural processing was observed regardless of whether the deviant tone was attended to or unattended. Meditation can significantly affect attention and brain function.

Performance in a Global-to-Local target task was compared between healthy open monitoring meditators and nonmeditators [38]. The study was conducted in two phases. Phase 1 was a cross sectional study. Phase 2 was a longitudinal study. Open monitoring meditation practitioners showed an enhanced processing of target level information, in contrast to the control group, which showed a local target selection effect only in the P1 and a global target selection effect in the P3 component; meditators showed effects of local information processing in the two other components (other than P3) and of global processing for two other components. Thus, meditators seem to display enhanced depth of processing. In the longitudinal experiment, meditation modulated attention after a 4-day meditation retreat.

Two studies reported the effect of meditation on mismatch negativity (MMN) [39, 40] Healthy practitioners of Sudarshan Kriya yoga and nonmeditators were compared using the mismatch negativity (MMN) paradigm [39]. In this two-group, comparative study Sudarshan Kriya yoga meditators were found to have larger MMN amplitudes than nonmeditators. Meditators also exhibited significantly increased MMN amplitudes immediately after meditation suggesting transient state changes owing to meditation. The MMN is related to neuropsychological functioning, particularly to executive functions [41]. Another study on healthy comparing children with training in musical meditation and nonmeditators using auditory mismatch negativity (MMN) and P300 [40] reported similar results.

Apart from the mismatch negativity (MMN) paradigm P300 can also be a useful indicator for neuropsychological functioning such as brain resource allocation for attentional processing. Two separate studies on two different types of meditation supported the findings mention in the above paragraph [42, 43]. Healthy practitioners of meditative mindfulness and a control group were assessed using a row/column speller task [42]. In this two-group study, the meditative mindfulness induction (MMI) and non-MMI control group were compared. MMI subjects were significantly more accurate than control subjects and they produced significantly larger P300 amplitudes than control subjects at the vertex and parietooccipital region. In a separate study, practitioners of a moving meditation called cyclic meditation were assessed on two separate days, practicing cyclic meditation or an equal duration of supine rest for comparison [43]. On both days they were given an auditory oddball task with two tones (standard and target). There was a reduction in the peak latency of P300 after cyclic meditation at the frontal region, vertex, and parietal region. Also the P300 peak amplitudes after CM were higher at the same sites.

In addition to the studies on healthy participants the effect of meditation was evaluated on patients with bipolar disorder which is characterized by a number of attentional abnormalities. Patients with bipolar disorder and normal healthy participants were assessed with a visual A-X continuous performance task [44]. In this two-group study, mindfulness based cognitive therapy in bipolar disorder improved attentional readiness and attenuated activation of nonrelevant information processing during attentional processes.

Four separate studies compared meditators and nonmeditators using different tasks for ERPs [45–48]. In one of the studies healthy meditators of various traditions and nonmeditators performed the Stroop task [45]. Meditators showed greater executive control (i.e., fewer errors), a higher error related negativity, and emotional acceptance than controls. Another study used emotionally loaded stimuli (i.e., the International Affective Picture System) [46]. The result showed different emotional processing in meditation practitioners. At high levels of processing meditators are less affected by stimuli with an adverse emotional load, while processing of positive stimuli remains unaltered. In another study healthy meditators from different traditions and nonmeditators were assessed using anticipatory and pain-evoked ERPs [47]. Meditation was found to reduce the anticipation and negative appraisal of pain. Practitioners of imaginative meditators and nonmeditators were assessed during hand movement(s) and the idle thinking state [48]. Imagining moving the hand is associated with event-related desynchronization of the beta EEG. This occurred more often and predictably in meditators compared to controls.

3.5.1. Summary of Event-Related Potential Studies. The results of the study on Sahaja yoga practitioners showed meditation can enhance frontal top-down control over fast automatic salience detection, based on amygdala functions following long-term meditation [31]. Studies on Vipassana meditators showed increased attentional engagement after meditation, enhanced perceptual clarity, decreased automated reactivity, increased efficiency in distribution of limited brain resources, and switching attention [32–37]. Similar findings were reported in studies done on open monitoring meditation, Sudarshan Kriya yoga, musical meditation, and meditative mindfulness and cyclic meditation [38–43]. Meditators were also reported to have greater emotional acceptance, were less affected by stimuli with an adverse emotional load, and reduced the anticipation and negative appraisal of pain [45–47]. Hence meditation can induce a mental state which is characterized by efficient brain resource allocation with greater emotional control.

4. Limitations of EP and ERP Studies Reviewed

One of the main limitations of the studies reviewed is in the study design. Out of the 11 EP studies there was just one [17] which randomized the participants to the three experimental conditions. The other multiple-group studies [16, 18–21] did not use randomization. Three other early studies [1, 14, 15] had a single group which is an obvious disadvantage. The remaining 4 studies assessed the meditators as their own control on a separate day or days. In one out of four studies the assignment to meditation or the control intervention was random [5], whereas in the other 3 studies [11–13] the sequence was fixed and hence the effect of one intervention on another could not be ruled out. Also a disadvantage of the self-as-control design is that meditators with long experience in meditation may get into a meditative state even during the nonmeditation control sessions. Apart from the disadvantages in study design another disadvantage especially in the early studies [1, 14–16] was small sample sizes (range between 5 and 15). This is not seen in more recent studies [12, 13] ($n = 60$ and $n = 48$, resp.). On the whole evoked potentials offer poor spatial and temporal resolution compared to fMRI and MEG. Also the localization of changes is restricted to the sensory pathway activated by the specific stimulus. Despite these limitations evoked potentials continue to be useful to studies on practices like meditation as they are far less distracting and do not involve a drastic change in posture as is required for fMRI.

In the ERP studies reviewed the number of multiple-group studies (12 studies) was higher than the EP studies reviewed in the present study. However the evidence of the ERP studies is also with similar limitations as none of the ERP studies used randomization as a method of allocating the participants to different groups.

5. Limitations of the Present Study

The present study has several limitations: (i) the present study did not review studies on meditation and EEG, (ii) the studies on meditation and EPs were not homogenous, (iii) the studies reviewed in the present study were not categorized according to the Jadad scale, and (iv) the studies included in the present study were searched from only one database, that is, PubMed.

6. Directions for Future Research Suggested by This Study

The present study has shown that EPs are useful in localizing changes in meditation to areas such as the brainstem, thalamus, thalamocortical radiations, primary sensory cortices, and association cortical areas and ERPs can provide useful information about neurocognitive processing of attention and brain resource allocation. Most of the studies are limited by small sample sizes, lack of proper controls, no objective way of assessing the quality of meditation, and a wide range of variation in the practitioners sampled. This can be corrected in future studies. Also studies can be specifically designed to verify whether the findings of EP studies which suggest that changes occur in the thalamus, thalamocortical connections, and primary relays and enhancement in attention and increased efficiency of brain resource allocation as suggested by ERP studies are indeed correct. To verify these results more rigorous studies with a better design, larger sample size and studies of EPs and ERPs in combination with neuroimaging during meditation are recommended.

Conflict of Interests

The authors declare that there is no conflict of interests regarding the publication of this paper.

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Research Article

Creating Well-Being: Increased Creativity and proNGF Decrease following Quadrato Motor Training

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Mind-body practices (MBP) are known to induce electrophysiological and morphological changes, whereas reports related to changes of neurotrophins are surprisingly scarce. Consequently, in the current paper, we focused on the Quadrato motor training (QMT), a newly developed whole-body movement-based MBP, which has been reported to enhance creativity. Here we report the effects of 4 weeks of daily QMT on creativity and proNGF level in two interrelated studies. In Study A, we examined the effects of QMT compared with a walking training (WT) in healthy adults, utilizing the alternate uses task. In contrast with the WT, QMT resulted in increased creativity. In addition, the change in creativity negatively correlated with the change in proNGF levels. In Study B, we examined QMT effects on creativity and additional metacognitive functions in children, using a nonintervention group as control. Similar to Study A, following QMT, we found a negative correlation of proNGF with creativity, as well as working memory updating and planning ability. Together, the current results point to the relationship between increased creativity and decreased proNGF following MBP. Thus, the current research emphasizes the importance of widening the scope of examination of "*MBP in motion*" in relation to metacognition and well-being.

1. Introduction

Creativity is considered important both for personal well-being and social growth [1]. It is an important function through which we can cope with significant challenges in our environments in novel and appropriate ways [2]. The lexeme in the English word creativity comes from the Latin term creō, meaning "to create, make." Thus, creativity means bringing into being, as it involves generation of novelty and transformation of existent information [1]. In its wider meaning, creativity can be understood as the ability to adapt cognitive processing strategies to face new and unexpected conditions and is thus closely related to efficient problem-solving and coping with stress, resulting in increased well-being [3–6]. Research examining the effects of mindful training on creative performance has been relatively scarce and mainly focused on sitting meditations. While some studies found evidence for a strong positive impact of meditation practice on creativity [7], others found only a weak association or no effect at all [8, 9]. Research examining the effect of whole-body movement-based mind-body practices (MBP) on creativity is lacking, and the current report is intended to start filling this gap. To this aim we examined the Quadrato motor training (QMT), a whole-body movement practice, which has been recently found to increase creativity and emotional well-being [10, 11]. In addition, a single session of QMT was found to improve spatial cognition and reflectivity [12] in contrast to two different control groups controlling separately for cognitive and motor load.

In addition to the QMT-induced effects on creativity and well-being, QMT has been found to increase alpha (8–13 Hz) synchronization [10, 12]. Since decreased alpha synchronization [13], in parallel to increased proNGF levels, was found in different health-related disorders, such as Alzheimer's disease [14], in the current paper we expanded our examination from electrophysiological to physiological effects of QMT by analyzing the effects of 4 weeks of daily QMT on creativity and proNGF level in healthy adults and children.

Neurotrophins (NTs) are central players of many aspects of the developing and adult nervous system, including neuronal differentiation, synaptogenesis, and synaptic plasticity. Nerve growth factor (NGF) was the first neurotrophin to be described [15]. It is involved in the regulation of naturally occurring neuronal death, synaptic connectivity, fiber guidance, and dendritic morphology of neuronal populations in the peripheral (sympathetic) and central nervous system (for a review see [16]). Early observations by Aloe and coworkers have revealed that NGF is actively synthesized by the submandibular salivary gland in mice, overproduced following aggressive behaviour and released in the bloodstream under stressful conditions [17]. Its relevance in the limbic areas involved in mood, cognition, and circadian activities as well as in the neuroendocrine system suggested that it might regulate the individual responses to stress by modulating the activity in networks that determine how plastic changes influence mood and behaviour [18, 19].

NGF is produced by neurons as a precursor, *proNGF*, and released in the synaptic space, where it undergoes cleavage and maturation. Finally, the mature form is internalized by the postsynaptic membrane through binding to the high affinity TrKA (tropomyosin-related kinases) receptor (for a review see [20]). In addition, proNGF is believed to contribute to neuronal plasticity and neural connection shaping of the adult brain, a function that is likely mediated by the complementary ability of proNGF to promote apoptosis during development (for a review see [21]). Consistent with this, proNGF gained large attention when it became clear that not only it is the most prevalent form in the human brain, but also it significantly increases in the brains of Alzheimer's patients and of individuals with several degrees of cognitive impairment [14, 22]. Thus, from the psychoneuroimmunological point of view, motor-mental practices could be important means to contribute to the proper activation of neurotrophic pathways aimed at facilitating coping with stressful conditions and at increasing creativity and well-being.

Although a large literature is available on the correlation between training, environmental enrichment, and increased brain-derived neurotrophic factor (BDNF) levels and their neuroprotective effects in both humans (see [23] and the references therein and [24]) and animal models [25–27], very few reports have explored the relationship with proNGF. Likewise no studies that investigate the connection between proNGF level and creativity are available to date, and no research that we are aware of examined whether whole-body cognitive training practices influence the relationship between the two. Consequently, the aim of the present study was to examine the effects of QMT on three main parameters: creativity, salivary proNGF, and the correlation between them. To this end we conducted two interrelated studies, examining the effects of 4 weeks of daily QMT on creativity and proNGF in healthy adults and children. In addition, we examined the relationship between change in proNGF level and creativity. In the developmental study we extended behavioral testing to further high-level and metacognitive functions to obtain a more comprehensive view on the type of cognition affected by the QMT.

2. Materials and Methods

2.1. Study A

2.1.1. Participants and Design. A total of 40 female university students (mean age ± SD: 30 ± 5.5 years) were enrolled in the study, none of whom had practiced QMT before. All were healthy with no medical history that might affect their performance. The study was conducted at the Sapienza University and was approved by the CNR Research Ethics and Bioethics Advisory Committee. Upon arrival, the participants signed a written informed consent. Subsequently, saliva samples were collected and a cognitive task tapping creativity was performed. All data were collected both before and after 4 weeks of daily practice. Participants were randomly allocated to one of the two groups: (1) Quadrato motor training (QMT, 3 choices and whole-body response) and (2) walking training (WT, 1 choice and whole-body response). Although originally the initial group sizes were identical ($n = 20$), the final number of participants finishing the 4-week training varied between the groups (QMT, $n = 13$; WT, $n = 6$). The QMT has been described in detail elsewhere [10]. Here, we describe it briefly.

2.1.2. Training Groups

Quadrato Motor Training (QMT). The QMT requires standing at one corner of a 0.5 m × 0.5 m square and making movements in response to verbal instructions given by an audio tape recording. There are 3 optional directions of movement. The instructions direct participants to keep the eyes focused straight ahead and hands loose at the side of the body. They are also told to immediately continue with the next instruction and not to stop in the case of mistakes. At each corner, there are three possible directions to move in. The training thus consists of 12 possible movements. The daily training consisted of a sequence of 69 commands lasting 7 minutes. Two important variables that were addressed in motor learning studies are limb velocity and the decision regarding the responding limb [28, 29]. In order to control these parameters, we used a movement sequence paced at a rate of an average of 0.5 Hz (similar to a slow walking rate) and instructed the participants to begin all movements with the leg closest to the center of the square.

Walking Training (SMT). The participants belonging to the WT group were instructed to make successive steps (one step following the auditory stimulus) using the same QMT pace, duration, and auditory cue, but their movement was free in space (not within a square). This group also practiced with the same recordings of auditory stimuli as the QMT group.

However, while the QMT group was told that each number represented a different corner of the square, the WT group was told to simply walk beginning at a certain location and to continue in response to the instructions. That is, regardless of the number specified on the tape, they always made a step. This reduced the uncertainty regarding the direction of the movement, compared to the QMT group. The WT group thus provided a control performing a task with similar motor demands, but with reduced cognitive demands.

2.1.3. Cognitive Examination: The Alternate Uses (AU) Task. The AU task is an established psychometric creativity test which provides measures for both fluency and flexibility [30, 31]. This task has been previously used to study changes in ideational flexibility following whole-body training [32, 33]. In this task, the participant is required to name as many different ways as possible in which a given item might be used within a 1-minute time frame. For example, a shoe can be used to walk with or can serve as a drum. Two basic measures were computed from the AU task: *ideational fluency*, defined as the total number of ideas generated, and *ideational flexibility*, defined as the tendency to generate a heterogeneous pool of responses or to use a variety of categories and themes when producing ideas [34]. Flexibility conveys information that is not conveyed by fluency [34, 35]. Here, the *ideational fluency* score was defined as the mean number of uses given by the participant for the three items. On the basis of all the uses made by the participants, 10 independent categories were defined across all the items. These included broad categories of usage such as "a weapon" or "a costume." The *ideational flexibility* score was defined as the mean number of different categories employed by the participant across all three words presented [36]. Hence, in order to calculate the flexibility score, all responses for a given item were first divided into the different independent categories. For additional details see [10, 12].

2.1.4. proNGF Examination

Saliva Sample Preparation. Unstimulated whole saliva samples were collected by passive drool and stored at -80°. Prior to electrophoresis, samples were subjected to vortex for 30 seconds and then centrifuged at maximum speed for 15 minutes. Saliva supernatants were transferred to fresh tubes, protease inhibitor cocktail (Roche) was added, and total protein concentration was determined. In order to measure the level of salivary NGF, we utilized western blotting and not ELISA assays, since this last technique does not allow discriminating between precursor and mature NGF [37]. Samples were examined in triplicate to take into consideration potential variability due to saliva flow rate, before the training and following 4 weeks of daily QMT practice.

Western Blot Analysis. 50 μg of total proteins were resolved by SDS-PAGE on 4–15% precast gradient gels, transferred onto 0.2 μm PVDF membranes by Trans-Blot Turbo Blotting System (BIO-RAD), and hybridized with anti NGF (Santa Cruz Biotechnology, sc-548, 1 : 1000), followed by anti-rabbit secondary antibody (Jackson ImmunoResearch, 111-035-003, 1 : 20000). The bands corresponding to proNGF were quantified with Image Lab software and normalized to the most intense band visible on the membrane in the protein loading control.

2.1.5. Statistical Analysis. To answer the first question, that is, what are the effects of whole-body training on functional and molecular aspects of cognition, we submitted fluency and flexibility scores of creativity as well as NGF level to a Group (QMT versus WT) × Training (pre versus post) mixed-model analysis of variance (ANOVA). Since baseline differences were observed in flexibility score, we also analyzed the data with the regressor variable method, that is entering the post-treatment measure as the dependent and the baseline measure as the covariate in a univariate ANOVA model. To answer the question whether intervention-induced changes in proNGF level represent a correlate of changes in creativity, the strength of the correlation between pre-post Δ values of proNGF level and of indices of fluency and flexibility was estimated by means of bivariate correlation analysis (Pearson's r).

2.2. Study B

2.2.1. Participants and Design. A total of twenty healthy children participated in this study (mean age ± SD: 10, 4 ± 0.4 yrs), none of whom practiced QMT before. A similar design applied as in Study A, except that in this study; the control group consisted of subjects that did not undergo any form of intervention. Among the contacted children, 12 children volunteered and were divided into two groups: one performed the QMT ($n = 5$) and the other one represented the no training control ($n = 7$). Both groups were retested after the end of the intervention period. The study took place in two schools. A written informed consent was signed by all parents before entering the study. The study was approved by the CNR Research Ethics and Bioethics Advisory Committee. Following a month, 12 healthy children finished the training (QMT, $n = 5$), control group (C, $n = 7$).

Cognitive tests were administered by a trained experimenter in the morning, within the same week in the same order and not preceded by physical education lessons to avoid acute exercise effects on cognitive function [38]. Cognitive tests were administered following the saliva sampling. Since the number of children was small, instead of counterbalancing, we have decided a fixed testing sequence for all children, with the saliva samples collection first.

2.2.2. Cognitive Examination. Cognitive testing comprised tests of creative thinking and of executive function, lasting about 20–25 min and 30–35 min, respectively. Creative thinking: (1) Torrance Test of Creative Thinking (TTCT); executive function: (2) random number generation (RNG) task and (3) planning and attention subtasks of the Cognitive Assessment System (CAS).

Torrance Test of Creative Thinking. The Italian version of the Torrance Test of Creative Thinking (TTCT), Figural Form A [39], was group-administered at school. The TTCT Figural

Form A is designed for individuals in kindergarten through graduate school and beyond. It consists of three timed pencil and paper picture construction and completion activities lasting 10 minutes each, with one-minute break between tasks for a total working time of about 30 minutes. According to testing guidelines, the administrator invited the examinees to enjoy these activities and created a playful problem-solving atmosphere to minimize threatening feelings linked to a performance-oriented climate.

Activity I: Picture Construction Task. Children had to construct a picture using a darkened curve shape (jellybean or teardrop) provided on the page as a stimulus which must be integrated in the picture construction.

Activity II: Picture Completion. Children had to use 10 incomplete figures to make a figure or object drawings to the incomplete figures, avoiding usual and obvious completions.

Activity III: Parallel Lines. Children had to use 30 pairs of straight lines drawn on three pages to make an original picture out of each pair of lines, overcoming the tendency to perceive the same stimuli in the same way.

Data Coding and Scoring. Scoring of the TTCT was performed by a trained investigator based on three subscales of norm-referenced measures: fluency, flexibility, and originality. Fluency was scored by the number of figural images produced by the examinees; it reflects the ability to generate a large amount of relevant ideas. Flexibility was scored by the variety of categories of relevant responses. Originality was scored by the number of statistically infrequent responses on the basis of normative data; it reflects the ability to produce uncommon or unique ideas. According to the TTCT manual, raw scores were converted into standard scores to have comparable ranges for fluidity, flexibility, and originality.

Random Number Generation Task. This is a test that taps executive cognitive function and is feasible also with children [40]. The participants were tested individually. They were told that the RNG is a game involving numbers and were instructed to verbally generate a random sequence of numbers between 1 and 10 to each beat of a 70-beat sequence with an interbeat interval of 1.5 seconds. Randomness was explained by means of an age-appropriate instruction including a "hide-and-seek" type game [40]. Prior to data collection by tape recording, participants performed a familiarization trial of 70 numbers and could ask questions concerning the test. Both the omission of a number generation in correspondence of one tone and the production of numbers lower than 1 (0) or higher than 10 (11, 12, etc.) were considered errors and discarded. If errors exceeded a predefined maximum threshold of five, the entire block was repeated. The randomness of the sequence of numbers was measured by means of 18 different indices described by Towse and Neil [41]. Among those, five indices were selected as they reflect two components of executive function: inhibition of mental routines (turning point index (TPI), adjacency score (Adj), and runs score (Runs)) and working memory updating (redundancy score (Red), and mean repetition gap (MeanRG)).

The TPI is a ratio between the real frequency of turning points between ascending and descending series of numbers (i.e., the response change between the digits "2" and "5" in a hypothetical sequence "9, 7, 2, 5, 6, and 8") generated by the participant and their theoretical frequency in random responses. Turning points in random responses are assumed to be $2/3 * (n - 2)$, where n is the number of digits to be generated. A TPI lower than the optimal value of 100 indicates that participants produced more or fewer turning points than theoretically expected. The Adj measures the relative frequency of pairs of adjacent ascending or descending numbers (i.e., 7-8 or 4-3) as compared to the total number of response pairs produced by the participant. It ranges between 0% and 100% and reflects the habitual tendency to count forward or backward. The Runs score is an index of variability of the number of digits in successive ascending or descending runs. Counting from 1 to 9 and from 9 to 1 along the whole sequence of generated numbers leads to the highest Run value, whereas alternating ascending and descending pairs of digits as "4, 7, 9, and 2" will lead to lowest scores or even to null if this alternation is produced throughout the sequence.

The Red index reflects the unbalance of response alternative frequencies in a sequence that derives from a more frequent usage of given numbers than expected based on the theoretical frequency of each digit in random responses. In the present experiment, a perfect equality of response alternative frequencies corresponds to the generation of each number from 1 to 10 seven times each and would lead to a Red score of 0% (no redundancy), whereas repeating the same digit along the whole sequence would lead to a Red score of 100% (complete redundancy). The MeanRG is the mean number of responses given until each digit reoccurs calculated for all digits throughout the whole sequence (i.e., in the sequence "2, 8, 4, 6, 2, 9, 7, and 8"; the digits "2" and "8" reoccur with a mean gap equal to 4). If the participant regularly varies all possible digits throughout the sequence, then the MeanRG is high, whereas repeating one or more items much more frequently than theoretically expected leads to a low MeanRG value.

TPI, Adj, and Runs were merged into an average index of inhibition and Red and MeanRG into an average index of memory updating. High levels of TPI, but low levels of A comb and Runs correspond to a high inhibition ability, as well as high levels of Mean RG, but low levels of Red correspond to a high ability to update working memory. Thus before averaging, all indices were standardized and Adj, Runs, and Red were reversed.

Cognitive Assessment System. To assess children's cognitive performance, the Cognitive Assessment System (CAS) [42] (Italian version 2005) was used. The CAS consists of 12 subtests that assess 4 aspects of cognition: Planning, Attention, Simultaneous, and Successive processes (PASS theory) [43]. For the present study, because of school time constraints, participants only performed the Planning and Attention tasks which are the test performances most strongly relying on executive functions. Also, we did not collect test-retest reliability data, since acceptable to good reliability data are available for children of the age 5–10 years considered in this study [42].

Planning Subtasks. Planning is a cognitive process by which the individual determines, selects, and uses a strategy to efficiently solve a problem. The Planning scale is composed of three subtests. The first subtest, Matching Numbers, contains 4 items, each with 8 rows of numbers and 6 numbers per row, with numbers increasing in digit length every four rows. The child must locate and underline the two numbers in each row that are the same. The second subtest, Planned Codes, contains two items, each within a matrix of 7 rows and 8 columns of letters with empty boxes. A caption is presented that shows correspondence between letters and codes presented as a legend at the top of the page (i.e., A to OX and B to XX). The child's task is to fill in the empty boxes under each letter with the corresponding codes discovering their internal organization to solve the task. The last subtest, Planned Connections, contains 8 items. The first six require the child to join a series of numbers that are randomly distributed in space in a sequential order, with an increasing length of numbers to be connected. The last two items require the child to alternately connect numbers and letters serially (i.e., 1-A-2-B, etc.). The items are designed so that a child cannot complete a sequence by crossing one line over the other. To evaluate performance on the first two subtests, the raw score is the ratio of the accuracy and time to completion. For the third subtest, the raw score is the sum of the times required to complete each item. All these scores are then converted to an age-based standard score and summed to obtain a total scale value.

Attention Subtasks. The Attention scale is composed of three subtests that require the child to use focal attention to detect target stimuli and avoid distractions. The first subtest, Expressive Attention, is a Stroop-like test composed of three items that measures attention selectivity and interference control under time pressure. The first and the second items are without interference condition, while the third is with interference. There are two age-specific sets of items. For example, in the version for children 8 years and older, the noninterference conditions are reading color words (Blue, Yellow, Green, and Red), all written in dark ink and naming the colors of a series of rectangles (printed in blue, yellow, green, and red). In the interference condition, the words Blue, Yellow, Green, and Red are printed in a different color ink than the colors of the words' name and the child is instructed to name the color ink the word is printed in, rather than to read the word. Only this last item is used as the measure of attention. The second subtest, Number Detection, measures selectiveness and capacity to resist distraction under time pressure. It is comprised of pages of numbers where the child must underline the correct numbers among a large quantity of distracters in different formats. For example, the child must find a particular stimulus (the numbers 1, 2, and 3 printed in an open font) on a page containing many distracters (the same numbers printed in a different font style). The raw score is the ratio of the accuracy and the time to completion summed across the items. The third subtest, Receptive Attention, is a two-page subtest that measures the ability to focus and then shift attention between different stimulus dimensions under time pressure. On the first page, children of 8 years and older must identify and underline pairs of target letters that are physically identical (e.g., TT but not Tt), whereas on the second, pairs of letters that have the same name (e.g., Aa not Ba) are targets to be underlined. For all subtests, the raw score is the ratio of the accuracy and time to completion summed across items/pages. The raw score for each subtest is converted to an age-based standard score and summed to obtain a total scale value.

2.2.3. Molecular Examination. For salivary sample preparation and western blotting analysis see Study A.

2.2.4. Statistical Analysis. To answer the question regarding the effects of the QMT on cognitive performance and on neurobiological markers of brain health, a general linear model of multivariate analysis of variance (MANOVA) and subsequent ANOVAs were applied to the pre-post Δ values of fluency, flexibility, and originality dimensions of creative thinking, average indices of inhibition and working memory updating, and total scores of planning and attention, as well as on proNGF level. In the present nonequivalent control group design, baseline cognitive differences could not be excluded between groups, since participants were not individually randomized to the intervention or control condition. Thus, in addition to the change score method (Δ values), data were analysed with the regressor variable method, that is entering the post-treatment measure as the dependent and the baseline measure as the covariate. These methods were considered more appropriate to tap differential intervention effects than using a mixed model with group as between-participants factor and measurement time (pre- versus post-intervention) as repeated measures factor.

To answer the question of whether and to what extent intervention-induced changes in proNGF level represent a correlate of changes in cognitive efficiency, the strength of the correlation between pre-post Δ values of proNGF level and all above listed cognitive performance indices was estimated by means of bivariate correlation analysis (Pearson's r). In order to avoid that preexisting baseline differences among children could prevent from detecting correlations between intervention-related cognitive improvements and their potential neurobiological markers, bivariate correlations were also computed between post-intervention measures of proNGF level and all indices of cognitive efficiency. In order to control for multiple comparisons, we chose $P < 0.007$.

3. Results

3.1. Study A

3.1.1. Cognitive Results. The first 2-way ANOVA designed to answer the question concerning the whole-body training-induced effects on fluency revealed a main effect for training

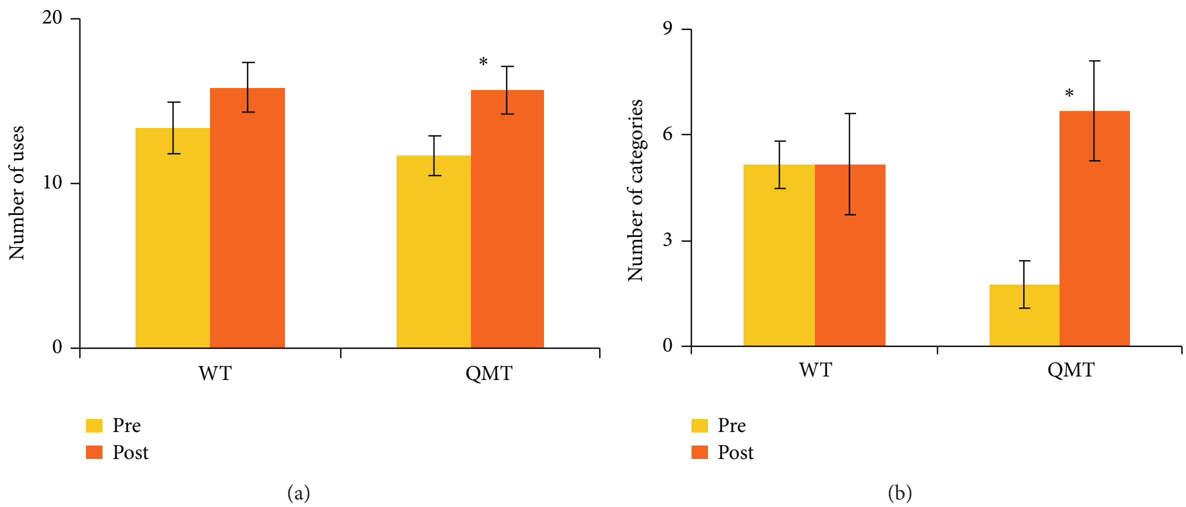

FIGURE 1: Change in creativity as a function of group and training for (a) ideational fluency and (b) ideational flexibility. Data are expressed as mean ± SEM; $^{*}P < 0.05$.

($F(1, 17) = 27.95$, MSE = .35, and $P < 0.01$), with post-training being generally higher compared to pre-training (Figure 1(a)). Although the Group × Training interaction was not significant ($F(2, 15) < 1$), fluency significantly increased only in the QMT group ($t(12) = -7.21$, $P < 0.001$) (Figure 1(a)). The second ANOVA which was conducted for flexibility yielded a significant Group × Training interaction ($F(1, 17) = 6.69$, MSE = .82, and $P < 0.05$). Post-hoc analysis (t-tests) showed that for the QMT group, flexibility significantly increased ($t(12) = -5.14$, $P < 0.001$) in contrast to WT group which showed no change following training (Figure 1(b)).

The results of the univariate ANOVA performed on post-intervention fluency values with pre-intervention fluency values as covariates yield a significant effect only for the pre-intervention score entered as covariate ($F(1, 17) = 56.71$, $P < 0.001$), with post-training being generally higher compared to pre-training in both intervention groups (Figure 1(a)). Instead, the results of the ANOVA performed on post-intervention flexibility values with pre-intervention flexibility values as covariates yield a significant effect for group ($F(1, 16) = 6.72$, MSE = 1.6, and $P < 0.05$) and not only for the pre-intervention score entered as covariate ($F(1, 16) = 9.75$, $P < 0.01$).

3.1.2. Molecular Results. The third ANOVA which was performed on NGF values revealed no main effect for Training or Group × Training interaction. The results of the western blot analysis are shown in Figure 2. Figures 2(a) and 2(c) show representative gels for a typical QMT and control participant, respectively; Figures 2(b) and 2(d) show the quantification for all the QMT and control participants, respectively. It can be easily observed that following daily QMT practice for a duration of a month there was a trend of proNGF level decrease for the majority of participants (77% of the participants). This trend of proNGF decrease was further observed in 67% of the WT group.

3.1.3. Correlation between Cognitive and Molecular Results. We then investigated whether the increased ideational flexibility was correlated with the observed changes in proNGF level by means of a Pearson's correlation. Change in ideational flexibility was calculated by subtracting the number of independent categories before training from the number of categories after training. In order to calculate change in proNGF we calculated the percentage by subtracting post- from pre-training proNGF. As can be seen in Figure 3, change in ideational flexibility was significantly and negatively correlated with change in proNGF ($r = -0.43$, $P < 0.05$, $n = 19$).

Taken together the results of Study A show that similar to the effects of one QMT session [10], 4 weeks of daily QMT practice induce increased ideational flexibility in adults. On the other hand, contrary to one session of QMT, 4 weeks of daily QMT practice may further enhance ideational fluency. However, a differential effect of QMT as compared to simple WT emerged only for flexibility. In addition, training-induced changes in ideational flexibility are negatively correlated with decrease of proNGF. A limitation of this study is that we used only one measure of cognitive function, whereas in exercise and cognition research it is recommended to use multiple measures of the target high-level cognition to assess the construct more broadly and understand the task specificity of the effects [44]. Furthermore, limiting the assessment of QMT effects to the adult population does not allow appreciating the educational potential at developmental age, where exercise is expected to have wider ranging effects of larger size [45]. To overcome these limitations and in order to better dissect the link between molecular and cognitive changes, we introduced the design of Study B, in which we examined the effects of QMT (compared to a control group performing no training) in children, and used a set of cognitive tasks, validated for children, that target not only creativity, but also another relevant metacognitive function (i.e., planning) and further components of higher-level cognition (i.e., working memory updating and executive

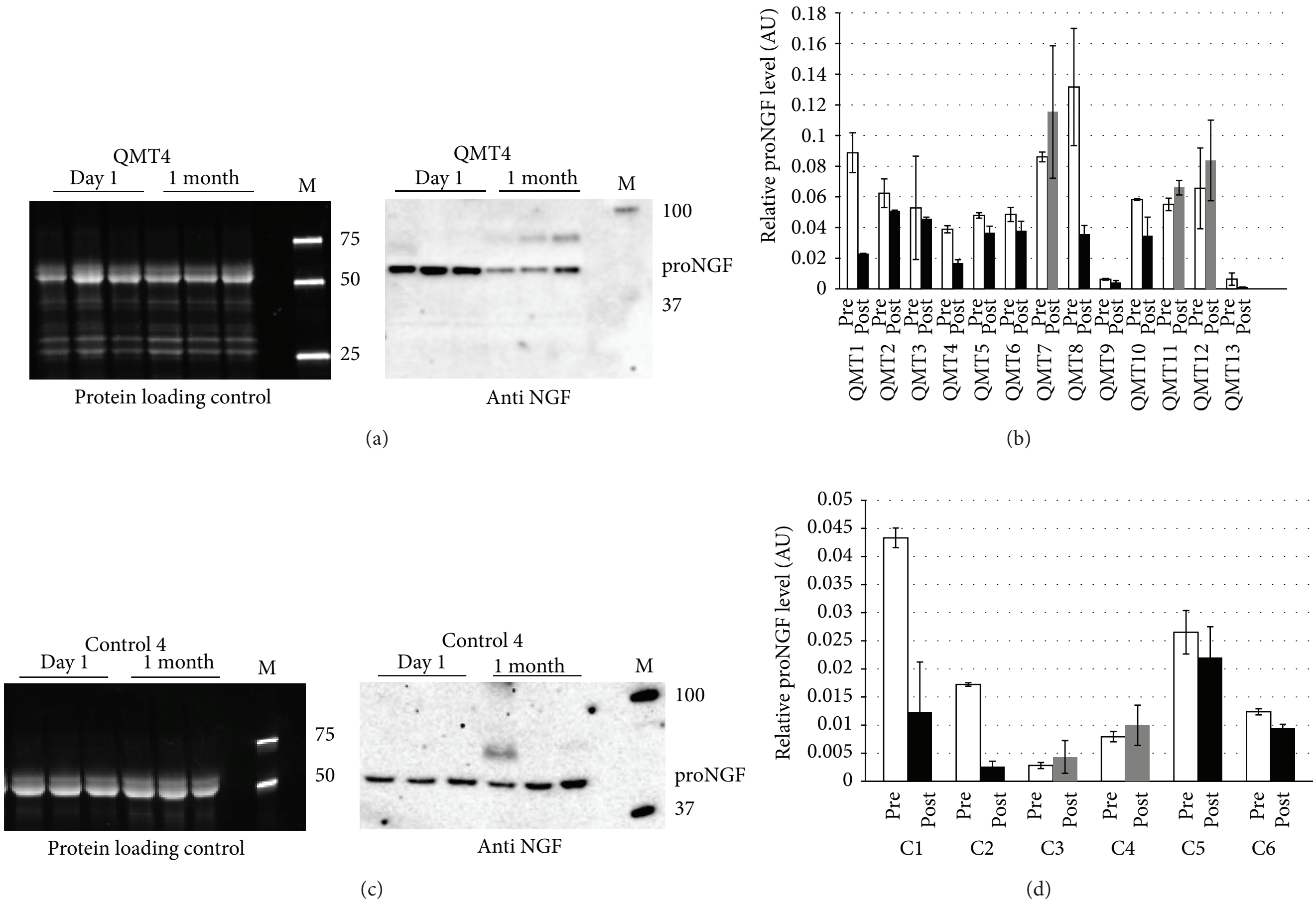

Figure 2: Western blot analysis of proNGF level in healthy adults. (a) Representative gel and blot for a typical QMT participant (QMT4). Left panel: picture of the gel after electrophoresis, showing total salivary proteins. Right panel: immunoblot showing proNGF. M: molecular size marker (values in kD). (b) Histograms represent relative proNGF level for all the QMT participants: each histogram indicates the average of the 3 proNGF values normalized to the most intense band present in the corresponding lane of the protein loading control. Data are expressed as mean ± SD. White (pre), relative proNGF level before starting the training; black (post), relative proNGF level after 1 month of training: the value is lower than before the training; grey (post), relative proNGF level after 1 month of training: the value is higher than before the training. (c) As in (a), but for a typical control participant (Control 4). (d) As in (b), but for all the control participants.

attention) that contribute to, but do not overlap with, creative thinking and planning.

3.2. Study B

3.2.1. Cognitive Results. The effect for group of the MANOVA performed on pre-post Δ values of cognitive performance and concentration of neurobiological markers as a function of group approached significance ($P = .063$). Subsequent ANOVAs did not show any significant difference ($.313 \geq P \geq .960$) for all dependent variables except for Attention ($F(1, 10) = 10.99$, $P = .008$, and $\eta_p^2 = .52$), where the pre-post Δ values were significantly higher in the experimental than in the control group (8.0 versus 1.6). However, the results of the ANOVAs performed on post-intervention values with pre-intervention values as covariates did not yield any significant effect for group ($.349 \geq P \geq .926$) for all dependent variables. The ANOVA performed on post-intervention scores of Attention also was nonsignificant ($P = .711$), while the effect of pre-intervention score entered as covariate was significant ($F(1, 9) = 8.42$, $P = .018$, and $\eta_p^2 = .48$), thus indicating that baseline differences between groups were responsible of the significant group effect found in the analysis.

3.2.2. Molecular Results. The results are shown in Figure 4. Figures 4(a) and 4(c) show representative gels for a typical QMT and control participant, respectively; Figures 4(b) and 4(d) show the quantification for all the QMT and control participants, respectively.

3.2.3. Correlation between Cognitive and Molecular Results. Results of the bivariate correlation analyses run on pre-post Δ values did not yield any significant association between

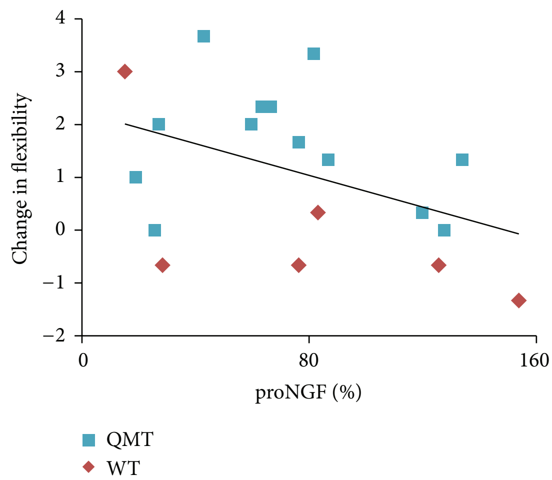

Figure 3: Significant correlation between change in ideational flexibility and proNGF level ($n = 19$). Change in ideational flexibility, calculated by the subtraction of pre- from post-training, was negatively correlated with the change in NGF level, calculated as percentage ($r = -0.43$, $P < 0.05$, and $n = 19$).

change scores of proNGF concentration and change scores of cognitive performance neither for the intervention group ($.93 \geq P \geq .14$) nor for the control group ($.89 \geq P \geq .23$). Similarly, all correlations computed on pre-intervention values were nonsignificant for both the experimental ($.73 \geq P \geq .25$) and the control groups ($.99 \geq P \geq .07$). Instead, the analysis performed on pos-tintervention values showed very high and significant negative correlations between proNGF level and cognitive performance indices only for the intervention group for (1) planning sum score ($r = -.95$, $P = .005$); (2) working memory updating average index ($r = -.96$, $P = .004$); and (3) flexibility and originality dimensions of creative thinking ($r = -.96$, $P = .004$; $r = -.95$, $P = .005$, resp.). See Figures 5(a)–5(d). No significant correlation was found for fluency ($P = 0.017$), inhibition ($P = .28$), and attention ($P = .13$) for QMT. In addition, no significant correlations between NGF level and cognitive performance indices emerged at post-test for the control group ($.37 \geq P \geq .17$).

4. Discussion

4.1. Cognitive Effect of QMT. In exercise and cognition research in the last decades, scientists have progressively focused on the effects of physical activity on higher-level cognition, with major interest in how the quantitative parameters of exercise and their physical fitness outcomes moderate or mediate physical exercise effects on cognitive functioning [44]. Recently, it has been proposed to shift the focus toward the qualitative exercise characteristics to reap largest cognitive benefits from gross-motor cognitive training tasks that are both physically effortful and cognitively engaging [46]. This new approach bridges the areas of whole-body mental training [10, 12, 47] and exercise and cognition research [46, 48], with their intersection point being represented by a shared neuroscience perspective. The main aim of the current report was to study whole-body MBP-induced creativity enhancement, neurotrophic change, and the relation between them. To this end, we examined the effects of 4 weeks of daily Quadrato motor training (QMT) on creativity compared to a walking training in healthy adults (Study A). We found that, similar to the effects of a session of QMT [10], 4 weeks of daily QMT significantly increased ideational flexibility in healthy adults. A similar trend of improved creativity was observed in children, associated with the specific improvement of planning ability that shares with creativity metacognitive characteristics and of working memory, a core executive function involved in both creative thinking and planning (Study B).

4.2. Neurotrophic Effect of QMT. Neurotrophins, such as NGF, are central players in the functions of nervous system. They are involved in neuronal shaping and plasticity, as well as synaptic connectivity in the sympathetic and central nervous systems. Among neurotrophins, BDNF has been widely analyzed in correlation with physical training of various natures, mainly acute and moderate aerobic exercises. Several reports have highlighted variations in BDNF levels, following training, both in animal models [26, 27] and in humans [23, 24, 49]. In addition, it was reported that environmental enrichment aimed at stimulating cognition and learning, along with exercise, is a mean of increasing BDNF levels [27, 50]. These and many other reports point to a role for BDNF in mediating the beneficial effects of physical and mental practices on the individual's brain health and general well-being. To the best of our knowledge, analogous studies on NGF/proNGF in healthy humans have not been conducted. With the aim of filling this gap and examining the effects of MBP on proNGF, we have measured levels of salivary proNGF before and after 4 weeks of daily QMT in adults and children. The choice of analyzing proNGF is due to the fact that the mature form NGF is almost never detectable outside the cells, with the precursor being the prevalent form present in the extracellular space [21]. In both age groups we observed a trend of decreased proNGF following QMT. This trend may have significant theoretical and practical implications, as evidence of increased proNGF levels in Alzheimer's patients and in individuals with several degrees of cognitive impairment highlights the association of this factor with brain health [14, 22, 51]. A more recent research reported both increased proNGF and decreased BDNF levels in postmortem brain samples of subjects with several tauopathies (non-Alzheimer's disease dementias) as compared to age matched controls [52]. Interestingly, we may have also suggested an inverse relationship between proNGF and BDNF. More specifically, in a parallel longitudinal study with healthy participants, we have shown increased amounts of proBDNF following 3 months of daily QMT practice [53]. These results appear symmetrical to the ones conducted on the dementia patients, supporting previous claims for the inverse directionality of change in BDNF and proNGF following training [54]. As widely reported in the literature, NGF plays a pivotal role as a factor that helps regulate

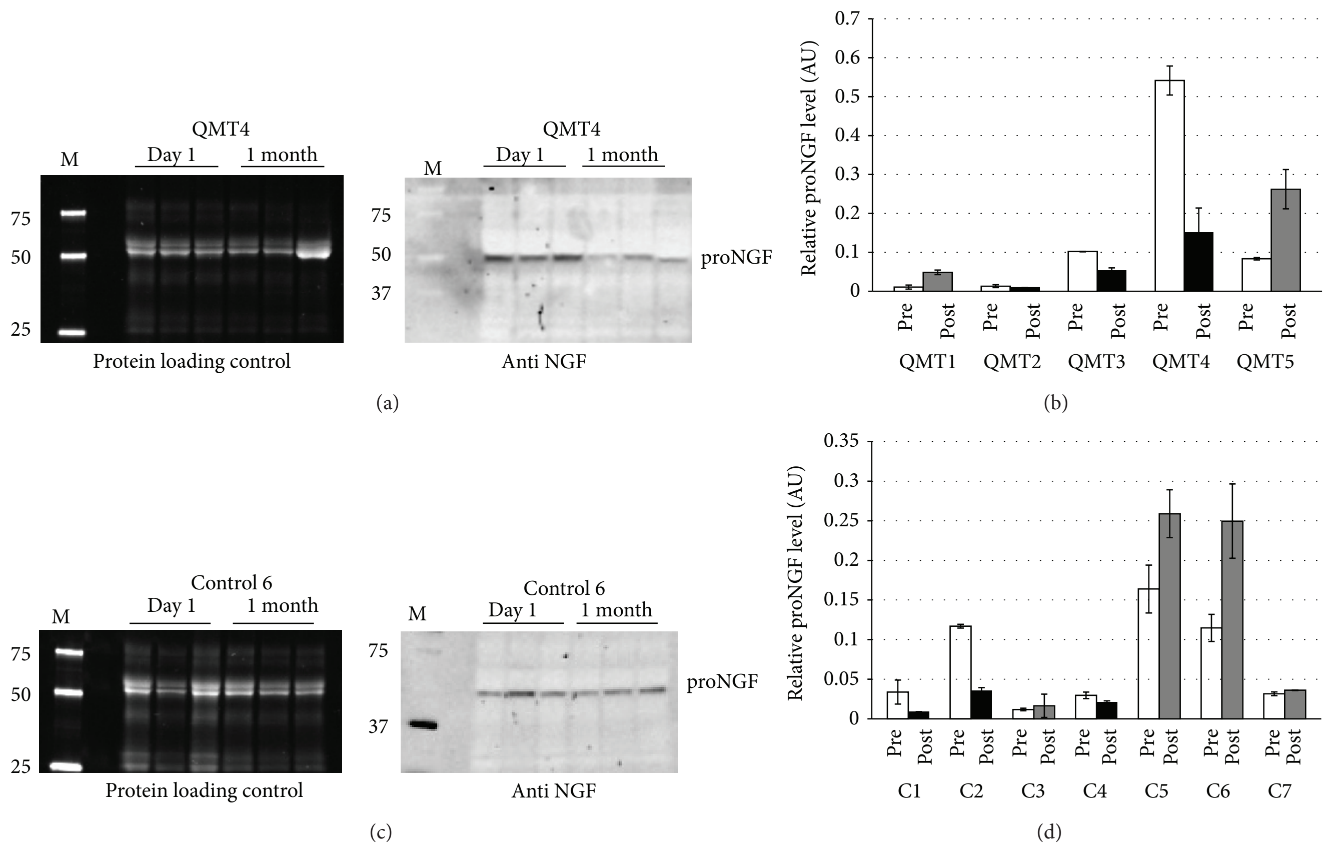

Figure 4: Western blot analysis of proNGF level in healthy children. (a) Representative gel and blot for a typical QMT participant (QMT 4). Left panel: picture of the gel after electrophoresis, showing total salivary proteins. Right panel: immunoblot showing proNGF. M: molecular size marker (values in kD). (b) Histograms represent relative proNGF level for all the QMT participants: each histogram indicates the average of the 3 proNGF values normalized to the most intense band present in the corresponding lane of the protein loading control. Data are expressed as mean ± SD. White (pre), relative proNGF level before starting the training; black (post), relative proNGF level after 1 month of training: the value is lower than before the training; grey (post), relative proNGF level after 1 month of training: the value is higher than before the training. (c) As in (a), but for a typical control participant (control 6). (d) As in (b), but for all the control participants.

individual's responses to stress ([19], see [55] for a review). Taken together these concepts lead us to speculate that a first phase of stress reduction (i.e., decrease of proNGF and increased emotional well-being) could be prodromal to the subsequent increase of BDNF which, in turn, could correlate with increased neuroplasticity, considering the structural changes shown by MRI of brains of sitting or movement meditation [53, 56, 57].

From the molecular point of view the decrease may be explained in several ways: (i) less proNGF mRNA and/or protein is produced, (ii) less protein is secreted from the cells, (iii) processing and/or degradation of the precursor is enforced outside the cells, and (iv) binding of the molecule to its receptor and therefore its internalization are enhanced. At this stage it is not possible to distinguish among all this options and further work is needed to elucidate this point (i.e., by utilizing salivary cells to look for proNGF mRNA and/or protein levels).

4.3. Correlation between Change in ProNGF and Creativity. In adults, a negative correlation was found between change in flexibility and proNGF (Figure 3). The results of the corresponding analysis performed on children's data are consistent with the findings of the adult study: a negative correlation between proNGF and behavioral indices of cognitive functioning, related to the whole-body cognitive training intervention, was in fact observed (Figure 5). Together, these are novel results, since NGF/proNGF concentration has been largely neglected in exercise and cognition research aimed at identifying neurobiological markers of acute [58] and chronic [59] exercise effects on brain health and cognitive efficiency.

Nevertheless, in contrast to adults, in the case of children there was a significant negative correlation not between pre-post Δ values of proNGF and cognitive performances, but only between post-test values in the group that underwent the QMT. This finding may suggest that at developmental age, children's cognitive performance did not consistently vary as a function of exercise-induced changes in neurotrophic factors. Several factors may have influenced children's baseline cognitive performance and its changes over time, impeding to see a strict relationship between intervention-related changes in cognitive efficiency and their potential neurobiological marker. However, whatever the size of the neurobiological and functional effect of QMT, the whole-body cognitive

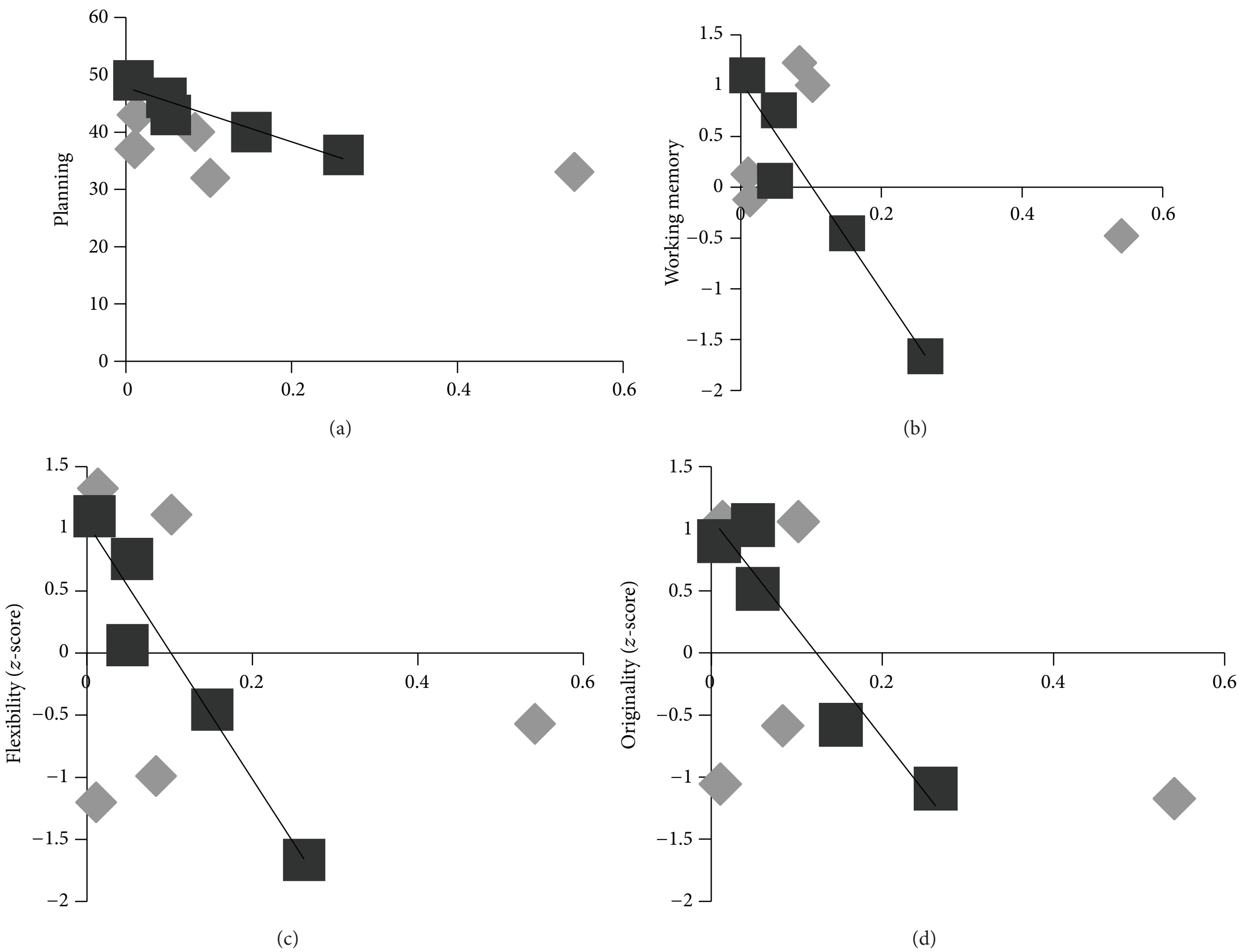

Figure 5: Significant correlations between proNGF level and cognitive performance following 4 weeks of daily QMT ($n = 5$) for (a) planning ($r = -.95$, $P = .005$); (b) working memory updating average index ($r = -.96$, $P = .004$); and (c) flexibility and (d) originality dimensions of creative thinking, for pre (gray) and post (black) QMT. Regression line is shown for post-QMT.

training seems to "align" several types of cognitive performance to the concentration of a specific neurobiological marker. After this mindfulness training, there seems to be a prioritization of the neurobiological factor which seems to assume a major role as correlate of cognitive and metacognitive efficiency.

The extension of the present study to children, even though preliminary in nature with a small sample size, adds to the adult study because of the broader set of cognitive performances tested and the selectivity of the intervention-related association between cognitive performances and neurobiological factors. The correlational results suggest that a reduced proNGF level is a biological marker of the potential of whole-body cognitive training to enhance specific components of higher-level cognition. While in the last decades, the attention of exercise and cognition researchers [44] and neurodevelopmentalists [60] has focused on interventions aiding executive function, recently it has been proposed to go beyond this view and consider quality physical activity as enrichment aiding the development of metacognition [48]. Metacognition reflects the acquisition and use of declarative, procedural, and strategy knowledge to successfully deal with problem solving tasks. Tomporowski and colleagues [48] propose that quality physical activity interventions that are cognitively challenging would alter children's metacognitive processes through changes in executive function efficiency.

Interestingly, the present results are consistent with this novel view: significant correlations with the neurobiological marker after the QMT were found for a foundational executive function as well as for metacognitive functions such as planning and creativity that rely on, but neither overlap with, nor critically depend on, single executive functions [61, 62]. Instead, no significant correlation emerged between proNGF and executive attention performance or inhibition. These diverging results are not surprising, since inhibition seems not to be linked to planning in young children [63]. Moreover, the absence of association between executive attention and proNGF level is in line with evidence that some types of mindfulness practices enhance other subcomponents of the attention networks [64]. Therefore, the QMT seems to be a specific type of mindfulness physical activity that has the potential to influence the development of metacognition and to enhance executive functions [10, 12].

An alternative interpretation of the presence of significantly high (negative) correlations between proNGF concentration and cognitive performances may be a learning effect due to the short time between cognitive measurements before and after the intervention. Interindividual differences in learning slopes of cognitive tasks during the preliminary training trials may have dampened, at pre-test, the potential interrelation between cognitive efficiency and its neurobiological marker that may exist prior to any change induced by the whole-body cognitive training intervention. However, this interpretation is less probable, since the significant alignment of neurobiological and cognitive-behavioral data at post-test occurred for the intervention group only. Furthermore, tests as the RNG, showing no significant correlation with proNGF concentration at pre-test and a very high correlation at post-test, are reported to be stable against learning effects [65]. To exclude any influence of differential learning effects of cognitive test performance on the relationship of interest, future studies are warranted with participants acting as their own controls with two successive measurement time points before the intervention and one after it. In addition, due to the low power of the correlation analysis ($n = 19$ in Study A, $n = 5$ in Study B) and the nonsignificant effect of training on proNGF level, probably requiring longer duration, this finding should be treated as suggestive and should be tested in the future, using larger groups and longer training periods.

4.4. Limitations. The current study is a preliminary attempt to examine empirically the question of the connection between MBP-induced effects on creativity and neurotrophic change. Its main limitations are the small and unbalanced sample size. In the future, a study on a larger sample that includes additional training regimes with a similar level of engagement may extend the current results. Future studies should expand the age group under examination and combine the examination of electrophysiological and physiological effects of QMT.

4.5. Conclusions, Implications, and Future Directions. In conclusion, the current research emphasizes the importance of examining the neurobiological correlates of mindful-physical activity practices. The present results support the usefulness of integrating physical and mental training across the lifespan [46, 66] and suggest that exposure to holistic forms of environmental enrichment as the QMT aids the development of executive function [45] and metacognition [48]. The results also further our understanding of the underlying biological mechanisms, confirming and extending the concept that brain growth factors are central to the benefits of exercise [59]. In comparison to other MBP, the QMT has the advantage of being a training of relatively short duration (possibly several minutes) and that can be practiced in limited spaces. These unique aspects render the QMT a technique warranted for scientific exploration, with the future aim of implementing this technique in various health promoting and educational setups.

Conflict of Interests

The authors have declared that no conflict of interests exists.

Acknowledgments

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Research Article

The Effects of Guided Imagery on Heart Rate Variability in Simulated Spaceflight Emergency Tasks Performers

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Objectives. The present study aimed to investigate the effects of guided imagery training on heart rate variability in individuals while performing spaceflight emergency tasks. *Materials and Methods*. Twenty-one student subjects were recruited for the experiment and randomly divided into two groups: imagery group ($n = 11$) and control group ($n = 10$). The imagery group received instructor-guided imagery (session 1) and self-guided imagery training (session 2) consecutively, while the control group only received conventional training. Electrocardiograms of the subjects were recorded during their performance of nine spaceflight emergency tasks after imagery training. *Results*. In both of the sessions, the root mean square of successive differences (RMSSD), the standard deviation of all normal NN (SDNN), the proportion of NN50 divided by the total number of NNs (PNN50), the very low frequency (VLF), the low frequency (LF), the high frequency (HF), and the total power (TP) in the imagery group were significantly higher than those in the control group. Moreover, LF/HF of the subjects after instructor-guided imagery training was lower than that after self-guided imagery training. *Conclusions*. Guided imagery was an effective regulator for HRV indices and could be a potential stress countermeasure in performing spaceflight tasks.

1. Introduction

Numerous studies and anecdotes showed that astronauts experienced many negative emotions in space, such as anxiety, stress, and depression, which would deteriorate even further under emergency situations and ultimately lead to unreliable or incorrect operations [1]. Some researchers and practitioners have realized that emotion management is an important scientific issue in long-term manned spaceflight missions and many psychology interventions were applied to ground training and in-orbit missions [1, 2]. However, there is limited research investigating the interventions of stress and associated symptoms in Chinese individuals when they perform tasks.

Autonomic cardiac control is crucial in health and social behavior. As a marker of cardiac autonomic nervous system function, heart rate variability (HRV) has been reported to indicate cardiac health, cardiac mortality and morbidity, and overall mortality risk [3]. Cardiac autonomic function through its sympathetic (SNS) and parasympathetic (PNS) branches modulates heart rate (HR). It is also proven to be correlated with physiological effects of depression, anxiety, anger, and stress [4].

As a mind-body relaxation technique, guided imagery has been widely used for decreasing patient's stress and anxiety and increasing an athlete's sport performance [4, 5]. Previous evidences support the effectiveness of guided imagery to relieve stress, anxiety, and depression [4, 6, 7]. Thus, it has been utilized as a treatment strategy in those individuals or patients who need mental and physical relaxation [8, 9]. The use of guided imagery has been reported to reduce self-reported measures of stress, anxiety, and fatigue as well as neuroendocrine measures of stress such as cortisol among nonpregnant subjects [9]. Most of imagery research focuses on sports training and clinical treatment [8, 10]; seldom is it applied to the domain of manned spaceflight [11]. Moreover, among many susceptible physiological biomarkers to evaluate and intervene in mental and physical state, heart rate variability (HRV) is an important clinical and investigational tool to reflect changes in cardiac autonomic regulation under extreme environments [12]. Therefore, guided imagery was applied as a tension countermeasure as well as HRV intervention for Chinese in centrifuge training [11].

HRV is the change in the time interval between heartbeats, from beat to beat. It is controlled by the autonomic nervous system including the sympathetic nervous system (SNS) and the parasympathetic nervous system (PNS). Generally, the SNS activity increases heart rate, and the PNS activity decreases heart rate. HRV is believed to be an indicator of the dynamic interaction and balance between the SNS and the PNS [13, 14]. Thus, HRV is the final result of rhythmic, integrated activity of autonomic neurons and provides a method to measure nervous system competence. Moreover, HRV reflects the capacity of the central autonomic network, including the prefrontal cortex, central nucleus of the amygdala, hypothalamus, and brainstem, to meet and adapt to environmental demands [15] and underpins individual's capacity to regulate their emotions [16] and may be critical to psychological flexibility [17, 18].

Given the high demand of operation pressure in manned spaceflight, the present study aimed to explore the impact of guided imagery training and self-guided imagery training on HRV of Chinese operators when performing spaceflight emergency tasks. This study revealed the enhancing effects of guided imagery on the indices of HRV and identified how instructor-guided imagery plays a more effective role in intervention than self-guided imagery.

2. Materials and Methods

2.1. Ethics Statement. The study was approved by the ethics commission of China Astronaut Research and Training Center. All subjects signed consent forms prior to participating in the experiment.

2.2. Study Design and Subjects. A between-subjects experiment was designed to explore the effects of guided imagery training on physiological variables. The presence of training is a between-subject factor which has two groups: one is imagery group, and the other is control group. For the imagery group, subjects received two kinds of imagery training: instructor-guided and self-guided imagery. On the contrary, subjects in the control group just used the corresponding time to sit still and review the operations. In addition to investigating whether training is effective, another purpose of this study is to investigate if self-guided imagery has the same effect as instructor-guided imagery does. Therefore, both instructor-guided imagery and self-guided imagery belong to the imagery group, but the reference within such group was instructor-guided imagery condition.

The best subjects for this study may be current Chinese astronauts. Unfortunately, it was impossible to have Chinese astronauts participating in this study for the limited number and the free time of them. In the future, some new astronauts will be selected from among scientists and engineers. Besides, most of Chinese astronauts are male. Thus, we recruited twenty-one male students from the astronautics department of Tsinghua University to meet the astronaut selection criterion from the aspect of education background and gender. They were randomly divided into two groups: imagery group ($n = 11$) and control group ($n = 10$). Their ages ranged from 21 to 26 years (Mean = 23.27, SD = 1.60).

Based on previous studies, sleep quality [19, 20] is related to emotion and working performance as well as the function of autonomic nervous system [21]. Therefore, sleep quality was controlled in the experiment. First of all, there were no reports on sleep disturbance among the subjects. Then, the subjects were required to sleep well in the night before experiment, and the experiment was conducted in the working hours. Subjects were also asked to avoid overexcitement activity and drinking alcohol and caffeine 24 hours before participating in the experiment.

The experiment environment factors were maintained the same between the two groups. In the first place, the environment was controlled strictly to make sure the illumination condition is constant (all light on and all curtain closed) and the noise was avoided. Second, the subjects were asked to sit in a chair fixed in the ground and to avoid abrupt and severe body movement. Only forearms and fingers were asked to finish the nine spaceflight operations. These controls generally reduce, if not eliminate, possible artefacts that could influence the HRV analyses.

There are various ways to practice mental imagery. Generally, mental imagery was guided by some instructions given by an experienced psychology expert [8, 11], which was defined in this study as instructor-guided imagery. In addition, we defined self-guided imagery as one way to practice mental imagery without instructions from a trainer. Since the way mental imagery practiced would decide if the image went thoroughly into the mind, the different impacts on physiological indices of the two guided imagery techniques were also investigated in this study. The imagery group practiced instructor-guided imagery and self-guided imagery at two consecutive sessions with intervals of 1 week.

2.3. Experiment Process and Intervention. Before the formal experiment, the two groups learned how to perform the nine spaceflight emergency tasks for 90 minutes to make sure the subjects established the correct mental operational model and reach a skill plateau. The nine spaceflight emergency tasks were chosen from the Chinese spaceflight operation handbook. One of the emergency tasks is a procedural activity to handle one malfunction of a spacecraft subsystem. Those activities only induced some minor body movements such as brief reporting, mouse clicking, or putting/loosening the button. The nine tasks appeared in a random sequence for each subject of one group. One subject took about 10 minutes to finish all the nine tasks and called one trail.

The formal experiment included two sessions. In session 1, the imagery group received instructor-guided imagery training, which was conducted by an experienced psychologist. Before guided imagery, the subjects were asked to review the operations. Then, the subjects were led to a quiet room where they lay down on a comfortable chair and closed their eyes. Firstly, the imagery group received intervention instructions and was guided to an image while staying in a welcoming, secure, and comfortable place, to experience some fine things and sceneries through visual, auditory, and body sensation in imagery. The guided words were developed by a Swedish psychological therapist and several clinical psychological experts in Astronaut Center of China. Then the subjects were guided to imagine the operations of the nine tasks. It generally took about half an hour for instructor-guided imagery training. After guided imagery, the subject practiced the nine tasks for two trials. And the physiological data was recorded when subjects were performing the nine spaceflight emergency tasks.

In session 2, self-guided imagery training was conducted by the subjects themselves in accordance with the experience of instructor-guided imagery. After self-guided imagery, the subject practiced the nine tasks for two trials and the physiology data was recorded.

Subjects in the control group also attend two session's experiment. In each session, they practiced the nine tasks for two trials as the imagery group without imagery training. And the physiology data was recorded at the corresponding trials.

2.4. Measurements. Self-reports were given by the subjects in imagery group after mental imagery training. The reports were about the effect imagery training had on the subjects.

Electrocardiogram (ECG) was recorded for all subjects by one dynamic multiparametric physiological detector called KF2 (BodyMon Ltd., China). KF2 recorded ECG with 3 leads at a rate of 250 Hz. KF2 was worn around the chest of each subject when performing the nine spaceflight emergency tasks. Disposable silver/silver chloride ECG electrodes were placed at the standard location for ECG recording. And the ECG data were stored on a Secure Digital Card for offline analysis by HRV processing software.

The HRV processing software provides HRV indices in time and frequency domains through the following steps. Firstly, ECG data was automatically corrected firstly using an artefact detection algorithm [22]. Then Fast Fourier Transform (FFT) method was used to calculate spectral power of heart rate variability using a Hanning window with 512 data points. The neighboring windows were overlapping with the 3/4 length of the whole window. Finally, the software generated the HRV results in excel format. The HRV processing software is widely used among Chinese researchers and its reliability and validity have been documented [23–25].

Heart rate variability was analyzed in time and frequency domains [26]. Time domain measurements included heart rate, Standard deviation of all normal NN interval (SDNN), root mean square of successive differences (RMSDD), the percentage of NN interval differences >50 ms from the preceding interval (PNN50), and coefficient of variation of NN interval (CV, calculated by standard deviation of NN intervals divided by mean of NN intervals). SDNN are thought to reflect changes of HRV mediated by both the influence of parasympathetic and sympathetic nerve. RMSSD and PNN50 are thought to reflect the changes of HRV mainly mediated by parasympathetic nerves [27]. Because of the moderate correlation between heart rate and HRV the coefficient of variation (CV) calculation is also reported which attempts to control for differences in heart rate [28].

Frequency domain (spectral) measurement of HRV was obtained by Fast Fourier Transform (FFT) which is one of spectral analysis methods to determine the power at different frequencies and helps to distinguish the contribution of the PNS and SNS to the variability in heart rate. Frequency domain measurements included very low frequency (VLF, 0.0033 to 0.04 Hz), low frequency (LF, 0.04 to 0.15 Hz), and high frequency (HF, 0.15 to 0.4 Hz) power, as well as normalized values (HFNU, LFNU), the total power (TP, 0.0033 to 0.4 Hz), and LF/HF ratio. The LF and HF components are considered as an index of sympathetic and parasympathetic modulation, respectively, and the LF to HF ratio reflects the global sympathovagal balance [3, 29]. Total power represents the total variability in the record. VLF power represents a measure of uncertain value. VLF power may indicate thermoregulation or vasomotor activity, although this has been disputed [30, 31]. It may involve a parasympathetic component [31] and possibly engage the rennin-aldosterone system [31–33].

2.5. Statistical Analysis. Stationarity is an important prerequisite in analyzing time series data such as heart rate. Therefore, we checked whether our data is stationary before carrying out the formal analyses. We used the widely used Augmented Dickey-Fuller test which seems to be more suitable as our time series data is quite long (almost 10 minutes, 800–1000 beats); therefore the parameters recommended by Magagnin et al. [34] might not be used properly to our data. The results suggest that the null hypothesis of a unit root (nonstationarity) was all rejected among the 42 RR interval time series samples. Therefore further analyses can be made without many distortions.

HRV indices of each subject were calculated over a short duration of 5 minutes by the HRV processing software. Before the statistical analysis, a homogeneity test of HRV between the imagery and control groups was conducted. The data were acquired from the last two trails of the 90 min practicing period before the formal experiment.

The Shapiro-Wilk test and Levene's test were used to test whether the given HRV data presented with a normal distribution. Two-way repeated measures ANOVA was used to assess the group effect (control group versus imagery group), the effect of training techniques, and interaction between them. All analyses were carried out in SPSS software Release 20 and all statistical tests with a $P < 0.05$ were considered significant. The power of the ANOVA was calculated as reported in this study.

3. Results

Homogeneity testing revealed that heart rate variability consisting of SDNN, RMSDD, PNN50, CV, VLF, LF, HF, LF/HF, and TP was equally distributed between the imagery group and control group.

Two-way repeated measures ANOVA was conducted on the HRV indices in the time domain including HR, RMSDD, SDNN, CV, and PNN50. The results showed that RMSDD,

Table 1: Summary of HRV indices in time domain of control group and imagery group with the two techniques.

Time domain HRV	Training techniques	Control group	Imagery group	P value of training technique	P value of imagery training	P value of interaction effect
HR (count/min)	IGI	78.82 ± 3.22	76.60 ± 3.02	0.813	0.106	0.344
	SGI	82.64 ± 3.03	74.30 ± 3.46			
RMSDD (ms)	IGI	33.54 ± 2.32	45.10 ± 5.50	0.935	0.002	0.255
	SGI	27.82 ± 2.19	51.70 ± 9.10			
SDNN (ms)	IGI	59.03 ± 3.34	83.89 ± 16.08	0.579	0.033	0.623
	SGI	58.45 ± 5.80	74.22 ± 7.64			
CV	IGI	0.077 ± 0.004	0.102 ± 0.017	0.564	0.061	0.440
	SGI	0.078 ± 0.007	0.089 ± 0.007			
PNN50/%	IGI	12.75 ± 3.02	24.13 ± 4.37	0.962	0.001	0.364
	SGI	8.67 ± 1.83	27.80 ± 6.66			

Note: (1) standard errors are shown in parentheses;
(2) IGI was short for instructor-guided imagery, and SGI was short for self-guided imagery.

Table 2: Summary of HRV indices in frequency domain of control group and imagery group with the two techniques.

Indices	Training techniques	Control group	Imagery group	P value of training technique	P value of imagery training	P value of interaction effect
VLF	IGI	473.1 ± 102.8	876.1 ± 171.8	0.279	0.011	0.676
	SGI	594.3 ± 150.8	1147.7 ± 266.8			
LF	IGI	491.0 ± 41.6	707.9 ± 118.4	0.540	0.044	0.715
	SGI	522.6 ± 92.5	832.6 ± 209.9			
HF	IGI	243.5 ± 26.9	421.9 ± 109.1	0.603	0.005	0.241
	SGI	176.9 ± 26.3	593.3 ± 174.5			
LF/HF	IGI	2.18 ± 0.26	2.00 ± 0.26	0.085	0.473	0.787
	SGI	3.00 ± 0.33	2.60 ± 0.65			
TP	IGI	1207.4 ± 112.9	2005.9 ± 304.0	0.334	0.004	0.477
	SGI	1294.1 ± 190.6	2573.8 ± 585.4			
LFNU	IGI	67.09 ± 2.10	65.40 ± 2.56	0.505	0.126	0.295
	SGI	72.91 ± 3.10	64.10 ± 5.11			
HFNU	IGI	32.91 ± 2.10	34.60 ± 2.56	0.505	0.126	0.295
	SGI	27.09 ± 3.10	35.90 ± 5.11			

Note: (1) standard errors are shown in parentheses;
(2) IGI was short for instructor-guided imagery, and SGI was short for self-guided imagery.

SDNN, and PNN50 of imagery group were significantly higher than those of control group ($P = 0.002$, 0.033, and 0.001, resp.; power = 0.900, 0.579, and 0.941, resp.), CV of imagery group was marginally significantly higher than that of control group ($P = 0.061$, power = 0.470), and HR of two groups has no statistical significance ($P = 0.106$, power = 0.364). The interaction effect of imagery training and training technique was not significant. Moreover, analysis of HR, RMSDD, SDNN, CV, and PNN50 showed that there was no statistical significance between the two techniques. Table 1 gives a summary of HRV indices in the time domain of the control group and imagery group with the two techniques.

Two-way repeated measures ANOVA was conducted on the HRV indices in frequency including VLF, LF, HF, LF/HF, TP, LFNU, and HFNU. The results showed that the effect of imagery training on the VLF, LF, HF, and TP was significant ($P = 0.011$, 0.044, and 0.005, resp.; power = 0.741, 0.529, and 0.827, resp.), and VLF, LF, HF, and TP of imagery group were higher than those of control group. The effect of the training technique on LF/HF was marginally significant ($P = 0.085$, power = 0.407); LF/HF of the subjects after instructor-guided imagery training was lower than that after self-guided imagery training. Table 2 gives a summary of HRV indices in frequency domain of the control group and imagery group with the two techniques.

Moreover, the imagery group received a subjective survey about the training effects. Participants of the imagery group listed several benefits they had received from guided imagery training, such as the following: "helped me feel confident in operation," "it helped me deal with stress better," and "I feel clearer about the operation procedure than before." 10 of 11 subjects in the imagery group reported no perceived barriers with instructor-guided imagery training. On the other hand, 9 of 11 thought that they were unable to enter a peaceful virtual-environment when they performed self-imagery training. But self-imagery training provided a chance for them to review the operations and therefore improve their skills. Overall, the subjects in imagery group thought that guided imagery provided an emotional support to them and released the operation tension.

4. Discussion

4.1. Study Outcomes. The purpose of this study was to investigate the effects of guided imagery on biologic measures of stress and effort in Chinese operators performing spaceflight emergency tasks.

In this study, HRV of the imagery and control groups before imagery training were at the same level and had no statistical difference. After guided imagery training, there was a statistically significant increase in RMSDD, SDNN, PNN50, VLF, HF, LF, and TP as well as marginally significant increase in CV in imagery group compared to that in control group. HR, LF/HF, and LFNU of imagery group decreased nonsignificantly compared with control group. HRV is a commonly used tool for assessing autonomic function of the heart [3], as well as stress [4, 35] and fatigue [36]. Previous studies demonstrated that HRV is significantly lower in cancer patients than the healthy population [37] and decreased HRV was associated with significantly shorter survival rates in cancer patients [38]. In the present study, SDNN and LF were improved with 2 weeks of guided imagery training, indicating that autonomic function of the heart was improved by guided imagery. From the current data, we can conclude that the training is at least effective during the 10-minute operations before which the astronauts were asked to do such imagery work either instructor-guided or self-guided.

The guided imagery uses verbal suggestions to create a flow of thoughts that focus the individual's attention on imagined visual, auditory, tactile, or olfactory sensations. This method can reduce the activity of autonomic nervous systems and increase the activity of parasympathetic nervous system both directly and indirectly. First, it directly regulates the respiratory rhythms and refocuses people's attention from environmental and persona stress to imagined stimuli which would lead to reduced arousal and increased relaxation [39]. Second, guided imagery may indirectly influence the two systems by improving the motor control skills of the subjects as the stimulated mental rehearsal of desired movements was indeed very similar to the brain activity that would accompany the actual motor movement [40, 41]. The combined effect can shift autonomic nervous system function toward increased parasympathetic nervous system (PNS) and reduced sympathetic nervous system (SNS) activity [42]. As suggested by a graded sympathetic activation protocol by Porta et al. [43], it means that guided imagery can result in an augmentation of the high frequency power of HRV, PNN50, and RMSSD [27], and HF power reflects HRV attributable to respiratory sinus arrhythmia and is regarded as a marker of vagal modulation of R-R intervals and a cardiac parasympathetic effect [3, 44]. It will also increase the total power (TP) of HRV as well as SDNN (total power and SDNN which is the measure of total heart rate variability reflecting both the parasympathetic and sympathetic cardiac modulation) [3].

These findings were supported by previous researches [8, 45] and added evidence to the effectiveness of guided imagery to reduce stress while performing spaceflight tasks. However, there is no clear explanation of how guided imagery brings about positive physical changes; one possible explanation has been provided by Bedford, who believes that perceptual processes are involved in imagery [46]. For this study, the imagery training combined six minutes of imagery relaxation and mind rehearsal of nine operations, and the result may contribute to two aspects. Firstly, as previous research proved, mental imagery relieved the tension of the operator, reducing the stress and anxiety caused by performing tasks and time pressure; therefore, HRV showed a rise in the imagery group in this study. This point was proved by other researches. Kong explored the effects of guided imagery intervention among coronary artery patients and found that SDNN, TP, and HF were increased [47]. Chuang et al. applied music therapy to breast cancer patients and reported that SDNN, TP, HF, and LF increased [48]. Secondly, the visual rehearsal is intended to train the subjects' minds and create the neural patterns in our brain by teaching the muscles how to operate [49]. This in-mind practice works on improving the operator's performance [10] and therefore decreases the operator effort and workload. As Aasman and Li pointed out that HRV indices were regarded as the representative of operator effort or mental workload [50–52], the increase of HRV indices in this study represented the decrease of the operator workload.

Compared with instructor-guided imagery, self-guided imagery showed a little different impact on HRV in the imagery group. LF in the self-guided imagery session was significantly higher than that in instructor-guided imagery. According to self-reports of the subjects, self-guided imagery could not lead them to a peaceful state but they could mentally visualize what they should do while performing the nine tasks. A possible explanation for this finding may be related to the combined effect of imagery in this study. A previous study concluded that imagery was related to focused breathing, relaxation, stress, and stress-related symptoms, as well as mental rehearsal [53]; thus, it would be no surprise that the stress induced by emergency conditions was counteracted by the effort or workload decrease with the increase of operational skill in session 2. This result implied that guided imagery had an immediate effect on decreasing operation stress, which potentially may impact mental workload and ultimately operation performance.

Heart rate variability (HRV) is a marker of cardiac autonomic nervous system function and has been presented as a good tool to study physiological effects of work-related stress [18, 54] and work-related worries [55]. A number of studies and reviews (e.g., [21, 54]) have indicated that HRV is reduced in patients with depression and anxiety, even without cardiovascular disease. While studies have often focused on links between decreased HRV, negative emotions, and poor physical health, increased HRV is related to well-being [56] and reductions in negative affect [57–61].

4.2. Implications and Limitations. Guided imagery is a simple, easily taught, and acquired method, but it has rarely been implemented as a training method for spaceflight operations. It was typically used as a psychological intervention tool before a manned spaceflight mission or applied to astronauts when some negative emotional symptoms appear. Plessinger recommended that athlete training incorporates mental imagery along with physical practice [10]. Not only can mental imagery improve specific motor skills but also it seems to enhance motivation, mental toughness, and confidence, all of which will help elevate the performance level. The study went further, combining guided imagery with spaceflight operation training. But it should be additionally tested and researched to find the effect mechanism of guided imagery and the appropriate program to combine guided imagery and operation training.

It should be noted that this study has some limitations. First of all, small population size is a continuous worrisome issue for researchers like us whose job is to train a special group of operators. As performing the tasks in our research requires a complex simulation system which is quite costly to use, it is very difficult to use a large size of subjects. Specifically, subjects in this study were all students from the same university excluding the Chinese astronauts. Therefore, some of the results will be tested further in astronaut training and other experiments. Moreover, the effect of mental imagery is limited by the engagement of subjects, which was reported by subjective reports from subjects. Further investigation requires the combination of electroencephalogram (EEG) and other physiological indicators to evaluate the engagement of subjects and thus to objectively analyze the role of mental imagery and the mechanism itself. In addition, virtual reality technology can be used to design mental imagery training programs to improve the effect of imagery training.

5. Conclusions

The results of this study showed that guided imagery training significantly increased HRV indices in Chinese subjects while performing spaceflight emergency tasks. It implied that guided imagery training is one effective way to decrease stress and therefore improve operation performance. From the current data, we can conclude that the training is at least effective during the 10-minute operations before which the astronauts were asked to do such imagery work either instructor-guided or self-guided. As concluded from this study, guided imagery training seems promising and beneficial to ensure astronauts well-being and stable performance in orbit. Hence, a program with operation practice combined with imagery training was recommended for astronaut operation training. In practice, self-guided imagery was applied to the astronauts in Shenzhou Nine and Shenzhou Ten before they conducted Manually Rendezvous and Docking. The effect of imagery was committed by the astronauts.

Conflict of Interests

The authors declare that there is no conflict of interests regarding the publication of this paper.

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Research Article

An Exploratory Analysis of the Relationship between Cardiometabolic Risk Factors and Cognitive/Academic Performance among Adolescents

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This exploratory study examines the relationship between cardiometabolic risk factors (blood pressure, waist circumference, BMI, and total cholesterol) and cognitive/academic performance. In this study, 1297 Taiwanese tenth-grade volunteers are recruited. Scores from the Basic Competency Test, an annual national competitive entrance examination, are used to evaluate academic performance. Cognitive abilities are accessed via the Multiple Aptitude Test Battery. The results indicate that systolic blood pressure is significantly, negatively associated with academic performance, both in male and female subjects. BMI and waist circumference are associated with verbal reasoning performance with an inverse U-shaped pattern, suggesting that both low and high BMI/waist circumference may be associated with lower verbal reasoning performance.

1. Introduction

Blood pressure, waist circumference, BMI, and serum cholesterol level are important predictors of the cardiovascular disease and metabolic syndrome. There is increasing interest in the effects of aforementioned cardiometabolic risk factors on human cognitive performance, mainly because the incidence of cardiovascular disease and metabolic syndrome has increased dramatically in adults, in adolescents, and even more remarkably in children over the past few decades [1, 2]. Furthermore, human cognitive performances are usually affected by physiology activity and environment factors or vice versa. Understanding the impact of physical activity in cognition behavior could provide information for development of promising prevention and treatment strategies.

The correlation between blood pressure and cognitive impairment in patients has already been established [3]. Evidence revealed that both hypertension and hypotension play a part in the development and progression of cognitive impairment and dementia. Compared with normotensive population, patients with hypertension showed poorer performance on tasks of attention, learning and memory, executive functions, visuospatial skills, psychomotor abilities, and perceptual skills [4, 5]. Subjects with hypotension performed poorer on tasks of verbal short-term memory, mental arithmetic tasks, executive function, selective attention, and verbal recognition tasks [6].

Both obesity and underweight have been suggested as risk factors for dementia and worse cognitive performance.

Studies in older adults have found an association between obesity and poor cognitive performance [7] and between underweight and poor cognitive performance [8], in several population-based investigations [9]. Several studies reported that long-term obesity and long-term underweight in adulthood are associated with lower cognitive scores in midlife [10, 11]. Meta-analysis data showed there was a significant U-shaped association between BMI and dementia, with dementia risk being increased for obesity and underweight [12].

Relationship between hyperlipidemia and cognitive functioning is currently a matter of debate. Some studies have found a correlation between hyperlipidemia and both vascular dementia and Alzheimer's disease in cross-national surveys, whereas other studies have not [13, 14]. In a sample of 1894 cohorts, Elias et al. [15] found that lower total cholesterol levels are associated with poorer performance on cognitive measures. However, Anstey et al. [16] conducted a systematic review and concluded that higher cholesterol is a risk factor for dementia and cognitive decline.

Literature, over the past decade, suggests that the hyper/hypotension, obesity, underweight, and hyperlipidemia are associated with cognitive decline in patients; however, the mechanism(s) by which abnormal blood pressure, body weight, and dyslipidemia affect human cognition remains unexplored. Studies on the relationship between cardiometabolic risk factors and cognitive function in normal population could provide researchers with evidence to establish relative mechanisms [17]. Previous exploratory studies with sampling from general population appear to be mainly based on evidence from adult, yet rarely in young persons. Besides, these studies revealed inconsistent results in investigating the association between cardiometabolic risk factors and cognitive performance. For blood pressure instance, cross-sectional studies have shown different relationship between hypertension and cognitive abilities in middle-aged and elderly adults, including positive linear, inverse relation, J-curve, U-curve, or no associations. A limited number of studies have provided evidence that excess weight in adolescents will alter cognitive functions selectively. For example, Alosco et al. [18] suggest that obesity in children and adolescents is associated with decreased volume of frontal and limbic cerebral gray matter regions. Li et al. [19] observed 2519 children and adolescents (aged 8–16) and reported that increased body weight is independently associated with decreased visual-spatial organization and general mental ability. A similar finding also reported that extremely obese adolescents exhibited deficits in many cognitive domains, including impairment in attention and executive functions [20]. However, Gunstad et al. [21] indicated that underweight might be a risk factor for reduced memory performance in females. Datar et al. [22] concluded that worse performances in cognitive task scores by overweight status were explained by parental education and home environment rather than overweight status per se. To our best knowledge, few studies have been conducted to explore the correlation between lipidemia and cognitive performance, especially in the normal adolescent population.

As mentioned by Lyngdoh et al. [17], data from randomized controlled trials could provide convincing evidence to explore the mechanisms of the impact of cardiometabolic risk factors on cognitive function. Studies on the relationship between cardiometabolic risk factors and cognitive function in adolescent are rare. As cognitive abilities usually impact academic performance significantly, education researchers may be concerned with the issue of whether cardiovascular factors are associated with cognitive abilities in adolescents. Few studies have investigated the correlation among cardiometabolic risk factors, cognitive abilities, and academic performance. This study attempted to fill this gap. We hypothesized that cardiometabolic risk factors are associated with learners' cognitive abilities and academic performance. It is our hope that this research will clarify future directions for the investigation of behavioral mechanisms for researchers in various fields.

2. Methodology

2.1. Participants. In Taiwan, students who wish to attend secondary-level education, after junior high school, must take the annual Basic Competency Test (BCT), a national standardized test that measures educational achievement, in order to enroll in a senior high school. In general, more than 300,000 examinees (equal to 95% of this age group) take the BCT each year. In order to select a nationally representative sample in terms of academic achievement, three public senior high schools were selected (one in southern Taiwan, one in the middle of Taiwan, and the other in northern Taiwan). A total of 1297 tenth-grade volunteers, 464 male and 833 female, all of whom being Han Chinese, were recruited for this study. The mean age of the subjects was 16.8 years (SD, 0.3; age range: 16-17 years). Statistical analysis of goodness-of-fit showed that when the scores of these senior high-school students were combined, they gave a good representation (simulation) of the national probability distribution (χ^2 = 21). The volunteers and their parents were all informed explicitly about the plan, protocol, and procedure for the study, and written consent was obtained prior to the study being performed. This study was approved by the institutional review board of the National Taiwan University Hospital.

2.2. Academic Achievement Scores. The Basic Competency Test (BCT) consists of a 2-day written test program that covers six subjects: Chinese, English, mathematics, science, social science, and writing. Subtests within the BCT consist of 34–63 multiple choice questions, which include testlets and simple items. Examinees have 70 minutes to complete each subtest. Item response theory (IRT) models [23, 24] are used to convert the examinees' raw scores to a score scale (for the writing test the range is 0–10; for the other subtests the range is 0–60).

2.3. Cognitive Abilities Assessment. Cognitive abilities were assessed via the Multiple Aptitude Test Battery (MAT) [25, 26], which is commonly used, thoroughly standardized, and suitable for assessment of the diversity of cognitive abilities in adolescents. The Chinese version of MAT was revised from the Differential Aptitude Tests (DAT, [25]), aimed to provide an integrated, scientific, and well-standardized procedure for measuring the cognitive abilities of Taiwanese adolescents. In theory, aptitude testing can provide more accurate predictions for learning and working performance than traditional intelligence tests [27]. The MAT consists of eight subtests: verbal reasoning, numerical ability, mechanical reasoning, perceptual speed and accuracy, space relations, abstract reasoning, verbal comprehension, and grammar and language usage. This test contains a total of 496 items and takes about 80 minutes for administration. Mao and Lu [26] reported the internal consistency reliability of the MAT ranged from 0.5 to 0.9.

2.4. Anthropometric and Biochemical Parameters. All the volunteers underwent clinical assessments, including the measurement of systolic blood pressure (SBP) and diastolic blood pressure (DBP), which were measured in accordance with Joint National Committee VII guidelines. Measurements were performed in triplicate with 2-minute intervals of quiet seated rest, and the average values were calculated.

Body mass index (BMI) was calculated as weight (kilogram) divided by height (meters) squared. Weight was measured with light clothing, using a precision electronic scale, recorded to the nearest 0.1 kg, and height was measured without shoes, with a fixed stadiometer, recorded to the nearest cm. A venous blood sample was taken from each participant after 12 hours of fasting to measure total serum cholesterol level.

2.5. Statistical Analysis. Two-tailed t-test analyses were performed on the results of the variables, including cardiometabolic risk factors, cognitive abilities, and academic performance, between males and females. Pearson correlations were conducted as an exploratory analysis to examine bivariate associations between the variables. The level of confidence was set at the 0.05 significance level. Permutation tests (with $N = 1000$ randomizations) [28] were performed to correct for multiple comparisons. To meet contemporary calls for improvement in the interpretation and reporting of quantitative research [29], we have reported the practical significance (effect size) along with each statistical significance test. In a larger sample size, it is more likely to observe a statistical significance, even if there is little practical effect. According to Cohen's rough characterization, for Pearson correlation analysis, $r = 0.1$ is deemed to be a small effect size, $r = 0.3$ a medium effect size, and $r = 0.5$ a large effect size. We also tried to test the linear/curvilinear relationships between variables. Tests of the assumptions and inferential statistical analyses were performed using SPSS version 18.0 (Chicago, IL, USA).

3. Result

Demographic and clinical characteristics of the participants are outlined in Table 1. Some differences between males and females were observed. Male subjects in this study perform better in BCT, mechanical reasoning, space relations, and abstract reasoning subtests, whereas female subjects perform better in verbal comprehension and grammar and language usage subtests. Male subjects had higher mean SBP BMI and waist circumference.

In this study, we performed analyses by sex separately because cardiometabolic factors and cognitive abilities were different between males and females. As shown in Tables 2 and 3, bivariate correlations revealed that systolic blood pressure was significantly negatively correlated with academic performance (BCT), in both males ($r = 0.21$, $P < 0.001$, small to medium effect size) and females ($r = 0.12$, $P < 0.01$, small effect size). After 1000 permutation tests were performed, the results were not altered (males: mean of $r = 0.21$, SD of $r = 0.03$; females: mean of $r = 0.12$, SD of $r = 0.03$). No significant associations in the other cardiometabolic risk factors and academic performance were observed. Academic achievement was positively associated with cognitive abilities.

With regard to the cognitive performance, BMI and waist circumference (WC) were positively associated with verbal reasoning, both in males (BMI: $r = 0.13$, $P < 0.01$; WC: $r = 0.13$, $P < 0.01$) and in females (BMI: $r = 0.12$, $P < 0.01$; WC: $r = 0.10$, $P < 0.01$), with small effect size. After 1000 permutation tests were performed, the results were not altered (males: BMI $r = 0.13$, SD = 0.03; WC: $r = 0.13$, SD = 0.04; females: BMI $r = 0.12$, SD = 0.03; WC: $r = 0.10$, SD = 0.03). No consistent evidence of an association between cognitive abilities and other cardiometabolic risk factors was observed.

Systolic blood pressure was positively associated with diastolic blood pressure (males: $r = 0.42$; females: $r = 0.58$, permutation tests: males: $r = 0.42$, SD = 0.01; females: $r = 0.57$, SD = 0.02), BMI (males: $r = 0.28$; females: $r = 0.29$, permutation tests: males: $r = 0.28$, SD = 0.03; females: $r = 0.29$, SD = 0.02), and waist circumference (males: $r = 0.32$; females: $r = 0.20$, permutation tests: males: $r = 0.32$, SD = 0.03; females: $r = 0.21$, SD = 0.03). BMI was highly correlated with waist circumference (males: $r = 0.93$; females: $r = 0.89$; permutation tests: males: $r = 0.93$, SD = 0.01; females: $r = 0.89$, SD = 0.01).

We further tried to test the linear/curvilinear relationships between systolic blood pressure and BCT, BMI and verbal reasoning, and waist circumference and verbal reasoning outcomes. The result suggested that the linear specification fitted the data (male: $R^2 = 0.04$, $P < 0.01$; female: $R^2 = 0.01$, $P = 0.01$) better than the curvilinear when testing the relationship between systolic blood pressure and BCT. When testing the relationship between BMI and verbal reasoning, both inverse U curve and linear specification were fitting the data significantly, but the inverse U curve had better explanation rate (for inverse U-curve shaped male: $R^2 = 0.02$, $P < 0.01$; female: $R^2 = 0.02$, $P < 0.01$; for linear specification: $R^2 = 0.015$, $P < 0.05$; female: $R^2 = 0.015$, $P < 0.01$). Inverse U curve was also shown to fit the data better than linear specification when testing the relationship between waist circumference and verbal reasoning outcome (for inverse U-curve shaped male: $R^2 = 0.02$, $P < 0.01$; female: $R^2 = 0.02$, $P < 0.01$; for linear specification: $R^2 = 0.018$, $P < 0.05$; female: $R^2 = 0.01$, $P > 0.05$).

Table 1: Distribution of selected characteristics among participants.

	Male	Female	P
Age (yrs)	16.8 (0.32)*	16.8 (0.30)	
Academic performance			
BCT	245.9 (19.69)	235.8 (20.61)	<0.01
Cognitive abilities			
Verbal reasoning	21.5 (5.31)	21.9 (5.16)	
Numerical ability	11.1 (3.56)	10.90 (3.37)	
Mechanical reasoning	14.3 (3.91)	13.3 (3.46)	<0.01
Space relations	17.1 (4.49)	15.4 (4.49)	<0.01
Abstract reasoning	20.2 (4.81)	19.1 (4.95)	<0.01
Verbal comprehension	21.5 (6.14)	22.2 (5.91)	<0.05
Grammar and language usage	17.9 (5.04)	18.5 (5.00)	<0.05
Perceptual speed and accuracy	67.2 (21.33)	68.1 (20.19)	
Cardiometabolic factors			
Systolic BP (mmHg)	124.4 (12.27)	113.93 (11.36)	<0.01
SBP range	88–162	70–151	
Diastolic BP (mmHg)	70.8 (9.32)	70.8 (7.97)	
DBP range	47–100	51–96	
Cholesterol (mg/dL)	172.3 (35.21)	171.9 (30.04)	
Range	111–268	99–258	
BMI (kg/m^2)	21.6 (3.77)	20.3 (3.21)	<0.01
BMI range	15.6–33.5	14.6–33.6	
Waist circumference (cm)	73.90 (10.23)	66.17 (7.81)	<0.01
WC range	58–108	50–99	

*Mean (SD).

4. Discussion

The factors that impact academic achievement of substantial importance are not yet understood, nor explored fully [30]. As shown in Table 2, the results of this study indicated that systolic blood pressure was negatively associated with subjects' BCT scores, in both males and females. Since no significant associations between systolic blood pressure and cognitive abilities were observed, the evidence of the current study revealed that cognitive abilities did not play important moderator or mediator roles between systolic blood pressure and BCT. In other words, the cognitive abilities did not involve in the major mechanism of systolic blood pressure on students' BCT performance (and vice versa).

It is possible that the academic performance of students in the BCT might be influenced substantially by the beneficial emotional effects of the blood pressure. As mentioned above, the annual BCT in Taiwan is a high-stake test that is used to determine which students can enter senior high school and which school they will be assigned to. Therefore, students are subjected to intense pressure due to the competition and long-term preparation for this examination and the impact that it will have on their future educational opportunities. A number of studies indicated higher blood pressure was associated with anger, anxiety, and depression [31–35]. Ewart and Kolodner [33] reported that trait anger and negative effect were accompanied by higher blood pressure in adolescents. Chen and his colleagues [32] also found that depression was significantly associated with undetected hypertension. At the educational level, previous studies have reported that affective factors, such as testing and learning anxiety, the negative impact of emotional vulnerability, and academic stress, can have a major influence on academic performance [36–38]. In conclusion, the significant correlation between systolic blood pressure and students' BCT performance might result from the influence of stress and emotional vulnerability. However, due to the lack of measurement of the participants' emotion factors, the current study cannot establish the relationship among systolic blood pressure, emotion factors, and BCT performance via regression analysis [39, 40]. In subsequent studies, it would be of interest to perform rigorous hypothesis testing regarding this issue by recording and analyzing more complete information.

The results of this study also revealed that BMI and waist circumference were associated with verbal reasoning with small effect size, in both males and females. The inverse U curve fitted the relationship data better than linear specification, suggesting that both low and high BMI/waist circumference may be associated with lower verbal reasoning performance. Although the role of extreme obesity and underweight in cognitive function in adults has been reported [7, 8, 10, 12], to our best knowledge, few studies have examined the association between BMI/waist circumference and cognitive function in adolescents. Li et al. [19] reported that increased body weight is associated with decreased general mental ability in adolescents, whereas Gunstad et al.

Table 2: Intercorrelations between study variables in female subjects.

	1	2	3	4	5	6	7	8	9	10	11	12
(1) BCT (academic performance)	—											
Cognitive abilities												
(2) Verbal reasoning	0.26^{*}	—										
(3) Numerical ability	0.35^{**}	0.25^{**}	—									
(4) Mechanical reasoning	0.21^{*}	0.32^{**}	0.29^{**}	—								
(5) Space relations	0.13^{*}	0.26^{**}	0.25^{**}	0.33^{**}	—							
(6) Abstract reasoning	0.12^{*}	0.28^{**}	0.31^{**}	0.35^{**}	0.46^{**}	—						
(7) Perceptual speed and accuracy	0.22^{*}	0.36^{**}	0.27^{**}	0.38^{**}	0.20^{**}	0.36^{**}	—					
Cardiovascular factors												
(8) Systolic BP	-0.12^{*}	0.03	−0.06	−0.06	−0.03	0.04	0.06	—				
(9) Diastolic BP	−0.06	0.01	0.03	−0.07	−0.01	0.04	0.04	0.58^{***}	—			
(10) BMI	−0.04	0.12^{*}	0.04	0.01	0.03	0.04	0.04	0.29^{**}	0.18^{*}	—		
(11) Waist circumference	−0.08	0.10^{*}	0.06	0.10^{*}	−0.01	0.08	−0.01	0.20^{**}	0.11^{*}	-0.89^{***}	—	
(12) Cholesterol	−0.03	−0.01	−0.01	−0.01	0.02	0.03	0.07	0.03	0.07	−0.01	0.10^{*}	—

$^{*}P < 0.05$; $^{**}P < 0.01$.

Table 3: Intercorrelations between study variables in male subjects.

	1	2	3	4	5	6	7	8	9	10	11	12
(1) BCT (academic performance)	—											
Cognitive abilities												
(2) Verbal reasoning	0.10^{*}	—										
(3) Numerical ability	0.01	0.44^{**}	—									
(4) Mechanical reasoning	0.04	0.40^{**}	0.39^{**}	—								
(5) Space relations	−0.04	0.47^{**}	0.35^{**}	0.39^{**}	—							
(6) Abstract reasoning	0.06	0.42^{**}	0.38^{**}	0.35^{**}	0.45^{**}	—						
(7) Perceptual speed and accuracy	0.11	0.41^{**}	0.48^{**}	0.42^{**}	0.44^{*}	0.46^{**}	—					
Cardiovascular factors												
(8) Systolic BP	-0.21^{*}	−0.02	0.02	−0.03	0.04	0.04	−0.02	—				
(9) Diastolic BP	−0.03	−0.04	0.02	−0.03	0.01	0.04	0.05	0.42^{**}	—			
(10) BMI	−0.09	0.13^{*}	0.07	0.05	0.07	0.02	0.05	0.28^{**}	0.08	—		
(11) Waist circumference	−0.02	0.13^{*}	0.05	0.05	0.07	0.01	0.04	0.31^{**}	0.11^{*}	0.93^{***}	—	
(12) Cholesterol	−0.07	0.07	0.06	0.03	0.04	0.06	0.05	0.06	0.11^{*}	0.26^{**}	0.28^{**}	—

$^{*}P < 0.05$; $^{**}P < 0.01$.

[21] indicated that underweight might be a risk factor for reduced memory performance. A recent study showed that adolescents with BMI in the normal range performed better than their peers in the underweight and obese weight ranges [41]. These studies provide evidence that both obesity and underweight may be associated with worse cognitive abilities. Our result revealed the association between BMI and verbal reasoning was consistent with those of the meta-analysis study conducted by Beydoun et al. [12], showing a significant U-shaped association between BMI and dementia.

In this study, no significant associations in the other cardiometabolic risk factors and cognitive abilities/academic performance were observed. With respect to the blood pressure, previous exploratory studies with sampling from general population revealed inconsistent results in investigating the association between blood pressure and cognitive performance. The finding of this study parallels recent evidence, in large adolescent populations, that there is no consistent association between BP and cognitive performance [17, 42]. It is important to note that Lande et al. [42] reported children with elevated systolic BP (SBP $\geqq$ 90th percentile, $n = 288$) had lower average scores compared with normotensive children (SBP < 90th percentile, $n = 4789$) for digit span, block design, and mathematics in a nationally representative sample of 5077 children aged 6–16 years in the US (NHANES III). From a statistical perspective, it is quite common to observe a statistical significance with a large sample size, even if there is little practical effect. We found there was no significant effect between SBP and cognitive abilities after calculating the effect size from the result of NHANES III data (Cohen's d of block design, digit span, and mathematics outcomes are 0.13, 0.15, and 0.17, resp.; according to Cohen's rough characterization (1988, pp. 284–288), $d = 0.2$ is deemed to be a small effect size, 0.5 a medium effect size, and 0.8 a large effect size). Our findings are partly in agreement with the Lande et al. [42] study (NHANES III) with nearly a small effect size for the negative association between SBP and numerical performance.

Relationships between cholesterol level and cognitive functioning have been less consistent. Few studies have measured the correlation between cholesterol level and cognitive abilities/academic performance in the general population. The result of this study shows no significant association between cholesterol level and cognitive abilities. A possible reason is that mild change in cardiometabolic risk factors may not be enough to trigger manifestations of cognitive decline [17]. A complex and dynamic network exists among cardiometabolic risk factors, cognitive abilities, and academic achievement. We have only examined the correlation of some variables. It is possible that associations between cardiometabolic risk factor and cognitive abilities/academic performance could be influenced by accumulation/interactions of emotion, cultural difference, physical activity, social-economic level, dietary habits, genes regulation, and so forth. At the same time, we must also reflect on the limitations of this study and some improvements that could be made. A potential limitation is that most of the participants were relatively physically healthy. Since cardiometabolic risk factors are affected by the interaction of multiple factors, it will be more difficult to attain statistical/practical significance with respect to the association between physiological activity and cognitive/academic performance. However, since it is more difficult to observe a statistical significance with a normal population, statistically significant results with only small to medium effect sizes in this study might be useful for researchers in their further exploration of relevant mechanisms at the neural/molecular levels.

During the learning process, students who do not perform as well academically as others due to poor cognitive abilities or emotional self-control show a decreased willingness to learn. The integration of physiology and psychology data might have the potential advantages to understand learning mechanisms and then find strategies for promoting learning. For example, the evaluating of physiology and serum biochemistry (such as cardiometabolic risk factors) of students could give strategic educationists an understanding of the possible change of cognitive abilities. They could then give priority to provide appropriate learning environment and monitor the cognitions and emotions of the student in learning. In this way, the student's interest in learning and achievement could be increased. We envisage that the integration of cognition and physiology study will provide researchers in different fields with evidence that can be used to untangle the complicated relationships/mechanisms of behavior.

Conflict of Interests

The authors declare that there is no conflict of interests regarding the publication of this paper.

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Research Article

The Meditative Mind: A Comprehensive Meta-Analysis of MRI Studies

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Over the past decade mind and body practices, such as yoga and meditation, have raised interest in different scientific fields; in particular, the physiological mechanisms underlying the beneficial effects observed in meditators have been investigated. Neuroimaging studies have studied the effects of meditation on brain structure and function and findings have helped clarify the biological underpinnings of the positive effects of meditation practice and the possible integration of this technique in standard therapy. The large amount of data collected thus far allows drawing some conclusions about the neural effects of meditation practice. In the present study we used activation likelihood estimation (ALE) analysis to make a coordinate-based meta-analysis of neuroimaging data on the effects of meditation on brain structure and function. Results indicate that meditation leads to activation in brain areas involved in processing self-relevant information, self-regulation, focused problem-solving, adaptive behavior, and interoception. Results also show that meditation practice induces functional and structural brain modifications in expert meditators, especially in areas involved in self-referential processes such as self-awareness and self-regulation. These results demonstrate that a biological substrate underlies the positive pervasive effect of meditation practice and suggest that meditation techniques could be adopted in clinical populations and to prevent disease.

1. Introduction

Mind and body practices such as yoga, meditation, progressive relaxation, or guided imagery use mental and physical abilities to improve health and well-being. Over the past decade these practices have received increasing attention in different fields of study in which the physiological mechanisms underlying the beneficial effects observed in trained individuals have been investigated. Increased knowledge about the physiological effects of mind and body practices makes it possible to explore their therapeutic potential, identify adverse effects, and safely integrate these techniques into standard therapeutic approach.

Meditation is a complex process aimed at self-regulating the body and mind and is often associated with psychological and neurophysiological modifications [1]. Meditation practices can be oriented toward the concentration of attention on a particular external, corporal, or mental object, while ignoring all irrelevant stimuli (focused attention meditation), or toward techniques that try to enlarge the attentional focus to all incoming sensations, emotions, and thoughts from moment to moment without focusing on any of them (open monitoring meditation) [2]. In any case, most meditation approaches use both types of practices complementarily [3, 4].

Meditation practice has been found to promote well-being by fostering cognitive and emotional processes [5, 6]. Specifically, it has been found to improve working memory and attentional processes [7–9] as well as perceptual abilities [10]. It has also been found to promote prosocial behavior [11] and emotional regulation [12]. The potential contribution of meditation to cognitive and emotional processes can be appreciated in the context of the model proposed by Lutz and colleagues [13, 14]. These authors posited that meditation practice induces enhancement of at least four different abilities: sustained attention, monitoring faculty (to detect mind wandering), the ability to disengage from a distracting object without further involvement (attentional switching), and the ability to redirect focus to the chosen object (selective attention). A recent systematic review by Chiesa and colleagues [15] allowed drawing some important conclusions about the positive effect of meditation on cognitive functions. Executive functions, attention, and memory were the main targets of meditation practice. In particular, as compared to the control group, meditators showed improved sustained attention [16], conflict monitoring [7], and reduced attentional blink [17]. Meditators also performed better than controls in the classical working memory paradigms [16, 18]. Concerning memory, significant improvement was found in meta-awareness [19] and in specific autobiographical memories [20] after meditation training. Ortner and colleagues [21] also found that meditation groups showed reduced interference from unpleasant pictures, suggesting that meditation also has a positive effect in decreasing emotional interference during performance of a cognitive task.

Interestingly, the current literature suggests that meditation has a potential effect on age-related cognitive decline [22, 23], probably due to the regulation of glucocorticosteroids, inflammation, and serotonin metabolism [23]. Furthermore, it has been hypothesized [24] that the stress reduction promoted by meditation contrasts hippocampal vulnerability to neurotoxicity [25] and leads to increased hippocampal grey matter volume due to neuron preservation and/or neurogenesis. Meditation has also been found to reduce a number of psychological and physical symptoms in clinical populations [26, 27]. King and coworkers [28] found that mindfulness-based cognitive therapy was an acceptable brief intervention therapy for combatting PTSD: indeed, it reduced avoidance symptoms and PTSD cognitions. There is also evidence that, compared to standard care, mindfulness-based cognitive therapy almost halves the risk of relapse in people who are currently well but who have experienced at least three prior episodes of depression [29, 30] and is comparable to antidepressant medication in reducing risk of relapse [31].

The effects of meditation on brain structure and function have received increasing attention in neuroimaging studies (MRI, fMRI, and PET) and the number of published studies is steadily growing [32]. Specifically, the findings of neuroimaging investigations have allowed linking the positive effects of meditation to specific brain modifications. Neuroimaging studies of brain modification can be roughly divided into those investigating (1) neurofunctional correlates of meditation, (2) neurofunctional modifications after meditation training, and (3) structural brain modifications in expert meditators.

Functional studies on the brain correlates of meditation have assessed neural activation during meditation by requiring participants to undergo fMRI scans during meditation tasks. These studies have reported increased activation in areas associated with attention, mind wandering, retrieval of episodic memories, and emotional processing during meditation [33]. Specifically, increased activation in the prefrontal cortex [34], parietal areas [35], middle cingulate cortex, and hippocampal and parahippocampal formations [36] has been reported.

Studies of *functional brain modifications after meditation training* have focused on functional and the metabolic changes after meditation training and/or in expert meditators compared with control participants. These studies adopted different paradigms (Table 1): the affective Stroop task [37], pain-related tasks [38–41], attentional paradigms [42–44], emotional provocation [45], and meditation tasks [36, 46, 47]. The results of these studies are very intriguing because they shed more light on the possible link between neurofunctional changes and the positive effect of meditation on different aspects of cognitive and emotional processes, such as perceptual and attentional processes [7–10] as well as social behavior [11] and emotional regulation [12].

The studies that investigated *structural brain modifications* in expert meditators (Table 2) focused on brain structural changes after meditation training and/or in expert meditators compared with control participants; they primarily assessed grey matter changes with whole-brain voxel-based morphometry or cortical thickness mapping of MRI data [24, 48–54]. These studies principally found that, compared with control participants, expert meditators showed increased grey matter volume at the level of the posterior cingulate cortex, temporoparietal junction, angular gyrus, orbitofrontal cortex, hippocampus, and subiculum in the medial temporal lobe and the brainstem.

Previous neuroimaging studies on the effects of meditation on brain structure and function adopted different meditation techniques and recruited participants with different meditation training. For example, some studies recruited Buddhist practitioners [44] and others recruited participants with experience in SOHAM meditation [47] or ACEM meditation [33]. Several studies reported that different meditation techniques require different cognitive processes and thus produce different neural effects [55, 56]. But, despite differences in meditation techniques and underlying cognitive processes, it has been proposed that all meditation techniques share a central process that supports their common goal, that is, inducing relaxation, regulating attention, and developing an attitude of detachment from one's own thoughts [57]. Evidence from a recent meta-analysis of ten neuroimaging studies [57] seems to suggest that the caudate body, entorhinal cortex, and medial prefrontal cortex have a central role in supporting the general aspects of meditation effects.

The large amount of data collected over the past decade allows drawing some definite conclusions about the neural effects of meditation practice and allows discussing the positive effects of meditation practice from a biological point of view.

The main aim of the present study was to draw some definite conclusions about the neural network activated during meditation tasks and to explore functional (fMRI) and structural (sMRI) changes in expert meditators. To pursue this aim we adopted a meta-analytic approach based on activation likelihood estimation (ALE) analysis, which allows performing coordinate-based meta-analyses of neuroimaging data [58].

Table 1: Functional changes in meditators.

Paper	N	Contrast	Experience	Meditation
Allen et al., 2012 [37]	61	AFT, task > passive view	6 weeks	MT
Allen et al., 2012 [37]	61	AFT, negative > neutral	6 weeks	MT
Allen et al., 2012 [37]	61	AFT, task by emotion	6 weeks	MT
Brefczynski-Lewis et al., 2007 [44]	41	EM > NM during meditation	—	Buddhist practitioners
Brefczynski-Lewis et al., 2007 [44]	41	EM > INM during meditation	—	Buddhist practitioners
Brefczynski-Lewis et al., 2007 [44]	41	EM > INM meditation > rest, group by task	—	Buddhist practitioners
Creswell et al., 2007 [86]	27	Neural areas associated with MAAS	—	—
Davanger et al., 2010 [34]	4	ACEM meditation > control task	23 years	ACEM
Ding et al., 2014 [87]	32	IBMT > RT	10 days	IBMT
Engström et al., 2010 [36]	8	Meditate	14 months	ACEM and Kundalini
Engström et al., 2010 [36]	8	Word	14 months	ACEM and Kundalini
Engström et al., 2010 [36]	8	Silent mantra	14 months	ACEM and Kundalini
Farb et al., 2007 [42]	27	Experiential focus, MT > controls	8 weeks	MBSR
Farb et al., 2010 [88]	36	Sadness provocation, MT > controls	8 weeks	MBSR
Farb et al., 2013 [89]	36	Interoception > exteroception, MT > controls	8 weeks	MBSR
Grant et al., 2011 [38]	22	Pain, EM > controls	—	Zen
Grant et al., 2011 [38]	22	Hot > warm, EM	—	Zen
Grant et al., 2011 [38]	22	Pain, EM > controls	—	Zen
Guleria et al., 2013 [47]	14	Meditation > control	5.8 ± 0.9 years	SOHAM
Hasenkamp et al., 2012 [43]	14	AWARE-MW	>1 year	FAM
Hasenkamp et al., 2012 [43]	14	SHIFT > MW	>1 year	FAM
Hasenkamp et al., 2012 [43]	14	FOCUS > MW	>1 year	FAM
Hasenkamp et al., 2012 [43]	14	MW > SHIFT	>1 year	FAM
Hasenkamp et al., 2012 [43]	14	Correlations with practice time, AWARE	>1 year	FAM
Hasenkamp et al., 2012 [43]	14	Correlations with practice time, SHIFT	>1 year	FAM
Hasenkamp et al., 2012 [43]	14	Correlations with practice time, FOCUS	>1 year	FAM
Hölzel et al., 2007 [12]	30	Mindfulness > arithmetic, EM	>2 years	Vipassana
Hölzel et al., 2007 [12]	30	EM > controls	>2 years	Vipassana
Ives-Deliperi et al., 2011 [90]	10	Mindfulness > control in EM	8 weeks	MBSR
Jang et al., 2011 [91]	68	EM > controls	39.88 ± 25.58 months	BWVM
Kilpatrick et al., 2011 [92]	32	Auditory/salience	8 weeks	MBSR
Kilpatrick et al., 2011 [92]	32	Medial visual	8 weeks	MBSR
Kilpatrick et al., 2011 [92]	32	Lateral visual	8 weeks	MBSR
Kilpatrick et al., 2011 [92]	32	Sensorimotor	8 weeks	MBSR
Kilpatrick et al., 2011 [92]	32	Executive control	8 weeks	MBSR
Lee et al., 2012 [93]	44	CPT in FAM	>5 years	FAM/LKM
Lee et al., 2012 [93]	44	EPT-happy in FAM	>5 years	FAM/LKM
Lee et al., 2012 [93]	44	EPT-happy in LKM	>5 years	FAM/LKM

Table 1: Continued.

Paper	N	Contrast	Experience	Meditation
Lee et al., 2012 [93]	44	EPT-sad in FAM	>5 years	FAM/LKM
Lee et al., 2012 [93]	44	EPT-sad in LKM	>5 years	FAM/LKM
Lutz et al., 2008 [14]	28	Meditation > resting states, EM > controls	10000 to 50000 hours	Buddhist practitioners
Lutz et al., 2009 [94]	22	Meditation > resting states, EM > controls	10000 to 50000 hours	Buddhist practitioners
Lutz et al., 2013 [39]	28	Hot > warm, EM > controls	>10000 hours	Buddhist practitioners
Lutz et al., 2013 [39]	28	EM > controls	>10000 hours	Buddhist practitioners
Manna et al., 2010 [56]	8	FAM > rest, in EM	Mean 15750 hours	Buddhist monks
Manna et al., 2010 [56]	8	OM > FAM, in EM	Mean 15750 hours	Buddhist monks
Manna et al., 2010 [56]	8	OM > rest, in EM	Mean 15750 hours	Buddhist monks
Mascaro et al., 2013a [40]	29	Self pain task, pain > no pain	8 weeks	CBCT
Mascaro et al., 2013a [40]	29	Other pain tasks, pain > no pain	8 weeks	CBCT
Mascaro et al., 2013b [41]	29	RME, emotion > gender	8 weeks	CBCT
Monti et al., 2012 [95]	8	Post- > pretreatment	8 weeks	MBAT
Monti et al., 2012 [95]	8	Post- > pretreatment, MBAT > controls	8 weeks	MBAT
Orme-Johnson et al., 2006 [96]	24	Post- > pretreatment	31.3 ± 2.3 years	TMT
Taylor et al., 2011 [45]	22	Positive > neutral pictures	1000 hours	Zen
Tang et al., 2013 [46]	60	IBMT > RT	10 sessions	IBMT
Tang et al., 2013 [46]	60	IBMT, post > pre	10 sessions	IBMT
Wang et al., 2011 [97]	10	Meditation 1 > control	30 years	Kundalini
Wang et al., 2011 [97]	10	Meditation 2 > control	30 years	Kundalini
Wang et al., 2011 [97]	10	Meditation 2 > Meditation 1	30 years	Kundalini
Wang et al., 2011 [97]	10	Baseline 2 > Baseline 1	30 years	Kundalini
Xu et al., 2014 [33]	14	NDM > rest	27 ± 9 years	ACEM
Xu et al., 2014 [33]	14	Concentrative practicing > rest	27 ± 9 years	ACEM
Xu et al., 2014 [33]	14	NDM > concentrative practicing > rest	27 ± 9 years	ACEM

Notes. AST: affective Stroop task; MT: mindfulness training; EM: expert meditators; NM: novice meditators; INM: incentive novice meditators; MAAS: Mindful Attention Awareness Scale; IBMT: integrative body-mind training; RT: relaxation training; MBSR: mindfulness-based stress reduction; BWVM: brain-wave vibration meditation; FAM: focused attention meditation; LKM: loving-kindness meditation; CPT: continuous performance test; EPT: emotion-processing task; OM: open monitoring meditation; CBCT: cognitively based compassion training; RME: reading the mind eyes test; MBAT: mindfulness-based art therapy; TMT: transcendental meditation technique; NDM: nondirective meditation; MW: mind wondering.

Table 2: sMRI studies on expert meditators.

Paper	N	Contrast	Experience	Meditation
Kang et al., 2013 [49]	92	Meditators versus controls	41.23 ± 27.57 months	BWV
Wei et al., 2013 [54]	40	Meditators versus controls	14 ± 8 years	TCC
Hölzel et al., 2011 [48]	16	Pre- to post-MBSR training	8 weeks	MBSR
Kurth et al., 2014 [50]	100	Meditators versus controls	19.8 ± 11.4 years	—
Kurth et al., 2014 [50]	100	Correlation with meditation practice	19.8 ± 11.4 years	—
Leung et al., 2013 [51]	25	Meditators versus controls	>5 years	LKM
Luders et al., 2009 [6, 52]	44	Meditators versus controls	24.18 ± 12.36 years	—
Luders et al., 2009 [6, 52]	44	Meditators versus controls	24.18 ± 12.36 years	—
Luders et al., 2013 [24]	100	Meditators versus controls	19.8 ± 11.4 years	—
Vestergaard-Poulsen et al., 2009 [53]	20	Meditators versus controls	16.5 ± 5.1 years	Tibetan Buddhism

Notes. BWV: brain-wave vibration; TCC: Tai Chi Chuan; MBSR: mindfulness-based stress reduction; LKM: loving-kindness meditation.

2. Method

2.1. Inclusion Criteria for Papers. The database search on PubMed was performed using the following string: (((((((MRI) AND meditation) NOT Alzheimer's) NOT Parkinson's) NOT EEG) NOT MEG) NOT mild cognitive impairment). A total of 93 papers emerged. From this collection, we selected only papers that (1) included whole-brain analysis performed using magnetic resonance imaging (MRI), (2) provided coordinates of activation foci either in Montreal Neurological Institute (MNI) or in Talairach reference space, (3) studied young and healthy participants, (4) reported activation from group studies, (5) included meditators or required participants to perform a meditation task, and (6) used no pharmacological manipulation. We selected 57 papers: 42 reported fMRI studies and 15, sMRI studies. Out of the 42 fMRI studies, 5 were excluded because they did not provide coordinates of activation foci; out of the 15 papers on sMRI studies, 6 papers were excluded for the same reason and one paper was excluded because it did not include expert meditators.

In line with the aims of the present meta-analysis, individual experimental studies from selected papers were divided according to three main axes: papers reporting (a) functional magnetic resonance imaging studies (fMRI) during meditation training, (b) functional magnetic resonance imaging studies (fMRI) that studied neural modifications after meditation training, and (c) structural MRI studies (sMRI). Note that the fMRI studies on neural modifications after meditation (see Table 1) included those that adopted different paradigms. These studies also reported the results of comparisons between pre- and posttreatment or results of comparisons between expert meditators and naïve participants. A meta-analytic approach, which models the probability distributions centered at the coordinates of each activation focus, allows obtaining a general picture of functional neural modifications in meditators.

We included 37 individual fMRI experimental studies on functional activations during meditation tasks (642 participants), 63 fMRI experimental studies (see Table 1 for more details) on functional changes ascribable to meditation (1,652 participants including both meditators and controls), and 10 experimental sMRI studies (Table 2) on structural changes ascribable to meditation (581 participants).

2.2. Activation Likelihood Estimation (ALE). Activation likelihood estimation (ALE) analyzes the probability that a voxel will contain at least one of the activation foci; it is calculated at each voxel and results in a thresholded ALE map. In other words, ALE assesses the overlap between foci by modeling the probability distributions centered at the coordinates of each one [58].

Our first aim was to provide a general picture of areas activated during meditation tasks. Thus, we carried out an ALE analysis of fMRI studies on functional activations during meditation tasks. Then, we performed two ALE analyses to determine whether meditation produces consistent modifications in brain structure and function. In the first analysis we included sMRI studies, and in the second analysis we included fMRI studies on neural modifications after meditation training.

The ALE meta-analysis was performed using GingerALE 2.1.1 (http://brainmap.org/) with MNI coordinates (Talairach coordinates were automatically converted into MNI coordinates by GingerALE.). Following Eickhoff et al.'s modified procedure [58], the ALE values of each voxel in the brain were computed and a test was performed to determine the null distribution of the ALE statistic of each voxel. The FWHM value was automatically computed because this parameter is empirically determined [58].

For the fMRI studies, the thresholded ALE map was computed using P values from the previous step and a false discovery rate (FDR) at the 0.05 level of significance (Tom Nichol's FDR algorithm). Moreover, a minimum cluster size of 200 mm^3 was chosen. A cluster analysis was performed on the thresholded map.

For the sMRI studies, the thresholded ALE map was computed using P values from the previous step and a cluster level correction at the 0.05 level of significance, with a minimum cluster size of 200 mm^3. A cluster analysis was performed on the thresholded map.

The ALE results were registered on an MNI-normalized template (http://brainmap.org/) using Mricro (http://www.mccauslandcenter.sc.edu/mricro/index.html).

3. Results

3.1. Brain Areas Activated during Meditation Tasks. ALE meta-analysis of fMRI studies carried out during meditation revealed a network of areas spanning from the occipital to the frontal lobes that was more highly activated during the meditation condition than the control condition. This network included the caudate nuclei and insula bilaterally, the precuneus, middle and superior temporal gyrus, and precentral gyrus in the left hemisphere, and the anterior cingulate cortex, superior frontal gyrus, parahippocampal gyrus, inferior parietal lobule (angular gyrus), and middle occipital gyrus in the right hemisphere. We also found that left posterior cerebellum, specifically the declive, was more highly activated during meditation than the control condition (Figure 1).

3.2. Functional Modifications in Meditators. We found that meditation practice (see Table 1) was associated with increased functional activation in a wide network of areas including the bilateral middle frontal gyrus, precentral gyrus, anterior cingulate cortex, insula, and claustrum. In the left hemisphere we also found increased activation at the level of the inferior frontal gyrus, precuneus, caudate nucleus, and thalamus; and in the right hemisphere we found increased activation in the medial frontal gyrus, parahippocampal gyrus, middle occipital gyrus, inferior parietal lobule, and lentiform nucleus (Figure 2).

3.3. Structural Modifications in Meditators. We found that meditation practice was associated with increased grey matter volume in the frontal lobe, at the level of the right anterior

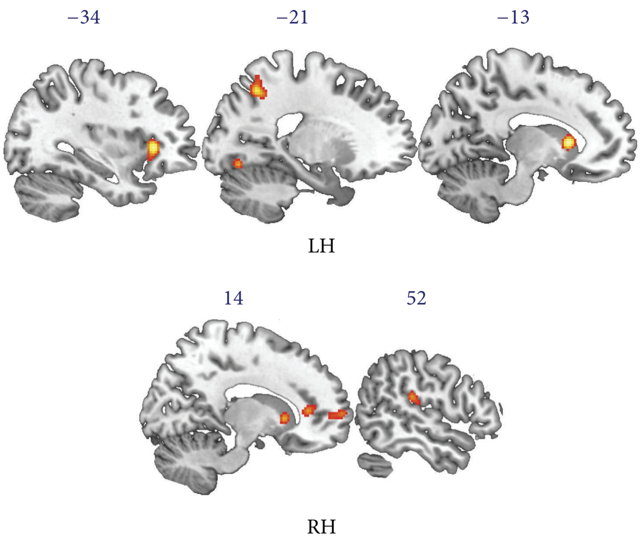

Figure 1: Results of ALE analysis on fMRI studies of meditation. The ALE map shows brain areas activated during meditation, encompassing bilaterally the caudate nuclei and insula, precuneus, middle and superior temporal gyrus, and precentral gyrus in the left hemisphere (LH) and the anterior cingulate cortex, superior frontal gyrus, parahippocampal gyrus, inferior parietal lobule, and middle occipital gyrus in the right hemisphere (RH).

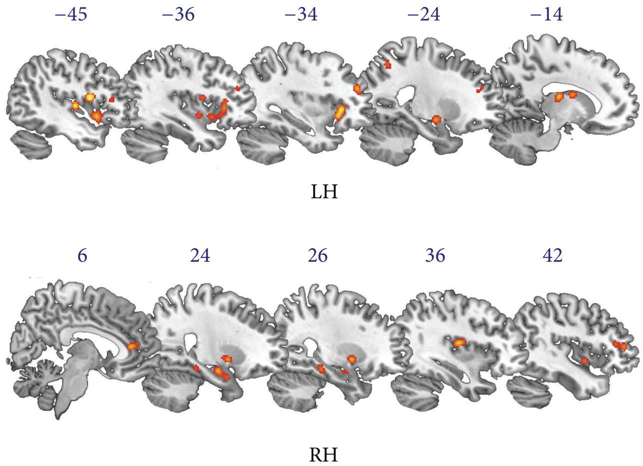

Figure 2: Results of ALE analysis on functional modifications in meditators. The ALE map shows brain areas that are more highly activated in meditators than controls. This network includes bilaterally the middle frontal gyrus, precentral gyrus, anterior cingulate cortex, insula, and claustrum. In the left hemisphere (LH) we found activation of the inferior frontal gyrus, precuneus, caudate nucleus, and thalamus, and in the right hemisphere (RH) we found activation in the medial frontal gyrus, parahippocampal gyrus, middle occipital gyrus, inferior parietal lobule, and lentiform nucleus.

cingulate cortex and left middle and medial frontal gyrus. We also found increased grey matter volume in meditators at the level of the left precuneus and fusiform gyrus and the right thalamus (Figure 3).

4. Discussion

The main aim of the present study was to identify the neural network activated during meditation and to explore structural and functional brain modifications in expert meditators. We also aimed to explore the relationship between meditation practice and the neural mechanisms that allow maintaining the positive effects of meditation training. For this purpose we adopted ALE analysis, a technique used widely in coordinate-based meta-analyses of neuroimaging data [58]. The results of this study shed light on the neural underpinnings of the positive effects of meditation practice and suggest the existence of a neural network responsible for these effects in meditators' everyday life.

The first question we tried to answer was *which* brain areas were activated during mediation. We used ALE analysis to identify the neural networks activated during meditation tasks and carried out the coordinate-based meta-analysis on experimental studies that required participants to meditate during the fMRI scan, regardless of their previous experience. We found that a set of brain areas spanning from the occipital to the frontal lobes was more highly activated during the meditation condition than during the control condition. This network included areas involved in processing self-relevant information, such as the precuneus [59], in processing self-regulation, focused problem-solving, and adaptive behavior, such as the anterior cingulate cortex [60], in interoception

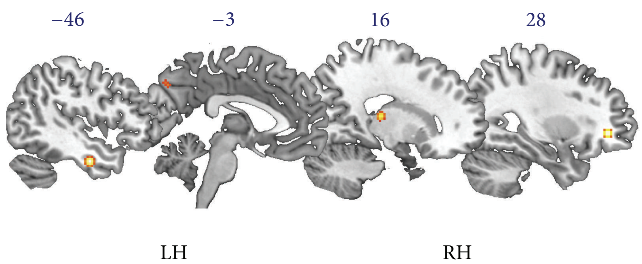

Figure 3: Results of the ALE analysis of structural modifications in meditators. The ALE map shows increased grey matter volume in meditators in the right hemisphere (RH) at the level of the anterior cingulate cortex and thalamus and in the left hemisphere (LH) at the level of the middle and medial frontal gyrus, precuneus, and fusiform gyrus.

and in monitoring internal body states, such as the insula [61], in reorienting attention, such as the angular gyrus [62], and in processing the "experiential enactive self," such as the premotor cortex and superior frontal gyrus [63]. It is not surprising that meditation induces higher activation in all of these areas, because the mental state during meditation is mainly characterized by full attention to internal and external experiences as they occur in the present moment [15].

As previously described, meditation practice has been found to promote well-being by fostering cognitive and emotional functioning [6]. Indeed, the positive effects achieved during the training sessions were generalized to everyday life, enhancing both cognitive (i.e., memory, attention, problem-solving, and executive functions) and emotional (i.e., prosocial behavior) functioning in expert meditators. Using the

ALE method, we tried to address the question about the brain underpinnings of pervasive positive effects of meditation in expert meditators' daily lives. We carried out an ALE analysis that included studies which compared activations in expert meditators and control participants in a wide range of cognitive and emotional domains (Table 1). Results of the ALE analysis showed that meditators, as compared with controls, showed greater activation in a wide network of areas encompassing bilaterally the frontal, parietal, and temporal regions. In addition to areas also activated during meditation (i.e., the middle occipital gyrus, inferior parietal lobule, precuneus, anterior cingulate cortex, precentral gyrus, insula, and caudate nuclei), this network of areas also included thebilateral middle frontal gyrus, inferior frontal gyrus, and thalamus in the left hemisphere and the medial frontal gyrus and lentiform nucleus in the right hemisphere. The network of areas we found more highly activated in expert meditators than in nonmeditators has recently been hypothesized to be part of the enactive experiential self network, which integrates efferent and reafferent processes concerning exteroception, proprioception, kinesthesia, and interoception [63]. Furthermore, it was previously thought that these areas were involved in self-referential processes [64–66], perspective taking [67], cognitive distancing [68–71], and sustained attention [72]. In fact, they were found to be more highly activated in Buddhist meditators [1]. Expert meditators also showed higher activations in the parahippocampal cortex, which has repeatedly been found to be involved in memory formation and retrieval [73, 74] as well as in high-level perception, especially in perceiving complex and ambiguous visual stimuli [75, 76]. The higher activation we found in expert meditators may account at least in part for enhanced attention, memory, and perceptual abilities reported in previous studies [15].

Results of the ALE analysis of sMRI studies showed increased grey matter volume in meditators compared to control groups in the right anterior cingulate cortex, left middle and medial frontal gyrus, left precuneus and fusiform gyrus, and right thalamus. It could be that the increased grey matter volume in the anterior cingulate cortex of meditators accounts for the improvement of specific abilities such as self-regulation, self-control, focused problem-solving, and adaptive behavioral responses under changing conditions [60], which are strictly associated with the functioning of the anterior cingulate cortex. Furthermore, the anterior cingulate cortex has recently been proposed to mediate the positive effects of meditation on prosocial behavior [63]. Nevertheless, it is difficult to state whether this difference as well as many other aspects of cognitive functioning is due to meditation practice or to previous individual predisposition. Studies comparing individuals before and after meditation training may help to clarify this point. Hölzel and colleagues [48] found increased grey matter concentration from pre- to post-MBSR training at the level of the temporoparietal junction, cerebellum, and posterior cingulate cortex. Furthermore, Kurth and colleagues [50] found a shifting in brain asymmetry at the level of the precuneus that was significantly correlated with number of years of practice. These results, taken together with results of the present ALE meta-analysis, which also found structural change in precuneus volume in meditators compared to controls, suggest that while structural differences at the level of the anterior cingulate cortex dispose to meditation, structural changes after meditation are strongly associated with changes in the posterior cingulate cortex and precuneus. The precuneus, which is located in the posteromedial portion of the parietal lobe, was recently found to be involved in a wide range of highly integrated tasks such as visuospatial imagery, episodic memory retrieval, and self-processing operations [59]. It shows widespread connectivity patterns with cortical and subcortical brain regions, such as the prefrontal cortex, anterior cingulate cortex, claustrum, caudate nucleus, and putamen [59]. The wide range of precuneus connections could account for its involvement in many high-level cognitive tasks. Specifically, involvement of the precuneus in self-referential processing could explain why it is so important in meditation practice. The precuneus was found to be involved in self-relevant information processing when self-relevant traits were compared with self-irrelevant traits [77]. It was also found to be involved during the performance of goal-directed actions when compared with passive stimulus viewing [78], the conscious resting state [79, 80], and the enhanced consciousness state of yoga meditation [55]. All of this evidence converges to suggest that the precuneus has a pivotal role in sustaining the positive effects of meditation practice especially because of its involvement in gathering self-relevant information and in representing the self and the external world [59].

Regarding the differences among meditation techniques, as reported above, meditation practices can be grossly divided into two different approaches: focused attention meditation and open monitoring meditation. Anyway, most meditation approaches use both types of practices complementarily [3, 4] and it has been proposed that all meditation techniques share a central process that supports their common goal, that is, inducing relaxation, regulating attention, and developing an attitude of detachment from one's own thoughts [57]. Our results strongly support the existence of a dedicate brain network that supports the general aspects of meditation effects. Actually, other than confirming the role of the caudate body, entorhinal cortex, and medial prefrontal cortex [57], the present study, using a large sample of experimental studies, sheds some light on other sets of brain areas which may be essential in supporting the general aspects of meditation effects.

5. Conclusions

Overall, results of the present ALE analysis suggest that meditation practice induces functional and structural brain modifications, especially in areas involved in self-referential processes, including self-awareness and self-regulation [63], as well as in areas involved in attention, executive functions, and memory formations [76]. Structural and functional modifications in this network may be the biological substrate of the pervasive effect of meditation practice in everyday life. These findings, taken together with previous ones, are leading to new applications of meditation practice in clinical populations and in disease prevention, especially in at-risk groups such as the elderly. In light of recent findings on the potential effect of meditation on age-related cognitive decline [22, 23], it could be intriguing to understand whether neurobiological changes promoted by meditation practice contribute to forming the so-called "Cognitive Reserve" [81]. Possible applications to a wide range of mental disorders affecting self-regulation and self-awareness, such as mood disorders [82, 83], anxiety disorders [84], and substance abuse [85], have also to be considered. In any case, further investigations comparing both psychological and neural effects of meditation practice are needed before any conclusions can be drawn.

Conflict of Interests

The authors declare that there is no conflict of interests regarding the publication of this paper.

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Research Article

In Sync: The Effect of Physiology Feedback on the Match between Heart Rate and Self-Reported Stress

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Over the past years self-tracking of physiological parameters has become increasingly common: more and more people are keeping track of aspects of their physiological state (e.g., heart rate, blood sugar, and blood pressure). To shed light on the possible effects of self-tracking of physiology, a study was conducted to test whether physiology feedback has acute effects on self-reported stress and the extent to which self-reported stress corresponds to physiological stress. In this study, participants executed several short tasks, while they were either shown visual feedback about their heart rate or not. Results show that self-reported stress is more in sync with heart rate for participants who received physiology feedback. Interactions between two personality factors (neuroticism and anxiety sensitivity) and feedback on the level of self-reported stress were found, indicating that while physiology feedback may be beneficial for individuals high in neuroticism, it may be detrimental for those high in anxiety sensitivity. Additional work is needed to establish how the results of this study may extend beyond immediate effects in a controlled lab setting, but our results do provide a first indication of how self-tracking of physiology may lead to better body awareness and how personality characteristics can help us predict which individuals are most likely to benefit from self-tracking of physiology.

1. Introduction

Recent developments in mobile sensors and wearable devices allow for ubiquitous 24/7 tracking of individual activity and physiological states. Although these technologies are already well-known in specific application areas of mobile health (see, for example [1, 2]) and (semi-)professional sports (see, for example, [3, 4]), the worldwide growth in the use of smartphones and tablets has accelerated these developments. Data can now be generated on a broad range of physiological and behavioral indices, including a person's movement, location, social behavior, and even tone of voice. Applications are being introduced that prompt us to record data about our moods, sleep patterns, menstrual cycles, diet, exercise habits, stress levels, and so on. But is all this self-tracking and feedback really helpful, or healthy? A record of day-to-day variation in physiology may provide important health parameters for people as they manage a chronic illness or as indicators to a healthy person about their well-being. At the same time though, we need to consider the possibility that continuous health feedback may feed health anxiety, and thereby stress, rather than ameliorate it. Through continuous health data entry as well as health feedback, an excessive self-focus and preoccupation with one's health may be induced or strengthened. Thus, paradoxically, technology-based body awareness may become a catalyst of rumination and worry about one's health, a self-tracking version of the so-called "white coat syndrome." The extent to which such an effect may or may not occur is an empirical question that, to date, has not been sufficiently addressed. The current paper aims to address this topic by experimentally investigating the relationship between continuous physiology feedback (i.e., heart rate information) and self-reported stress levels. In addition to gauging immediate effects of physiology feedback, potential moderating effects of personality variables are also explored.

Many existing mind-body practices involve a component of body awareness [5]. These mind-body practices are believed to have positive effects; in a review, Astin, Shapiro, Eisenberg, and Forys conclude that there is considerable evidence for the positive effects of several mind-body practices on diseases and symptoms ranging from headaches and insomnia to coronary artery disease [6]. The kind of body awareness practiced in these interventions, however, is different from the awareness created in self-tracking in two ways. First, these practices specifically teach a nonjudgmental awareness, where sensations are observed without appraisal, analysis, or judgment [5]. This is not typically the case in self-tracking of physiology. In fact, analysis and interpretation of data is often encouraged in self-tracking systems. Second, the body awareness promoted by these practices is based on interoception and proprioception: perception of internal processes (e.g., heart beats) and body positioning by means of internal cues. This is in line with the idea that these interventions seek to increase a sense of "embodiment" [5], the natural integration of the body as part of the self. The body awareness created in self-tracking of physiology is more indirect, as it is achieved by externalizing objective measurements of physiological signals. This seems to be opposed to the idea of embodiment, focusing rather on the dichotomy between body and self than on the unison of the two.

Biofeedback is a special case in the world of mind-body medicine when it comes to body awareness. Biofeedback, including biofeedback-assisted relaxation, has been found to be efficacious in treating problems ranging from headaches, anxiety, and motion sickness to attention deficit hyperactivity disorder (ADHD) and epilepsy (see [7] for a review). As is the case in self-tracking of physiology, biofeedback promotes awareness of internal signals by measuring them objectively and then presenting them via some external channel. There is, however, a crucial difference between self-tracking of physiology and biofeedback in terms of body awareness. In biofeedback, body awareness is not a goal in itself, but rather a stepping stone, which helps people learn to voluntarily control and improve the physiological parameters being measured. In line with this, the feedback about the person's physiological state during the training sessions is constant and immediate, so any changes in physiology are immediately observable. This helps the person learn to deliberately affect the physiological process in question. In contrast, this training in control over physiological processes is generally not included in self-tracking systems.

As things stand, it is unclear what the effects of exposure to one's own physiological measurements are. There is evidence that other interventions that promote body awareness have positive effects, but there are important differences between those interventions and self-tracking of physiology that make it difficult to determine whether the positive effects found will generalize to self-tracking of physiology. As a first step toward investigating the effects of self-tracking, we focus on the acute effects of physiology feedback. We have therefore performed a study where some participants were given feedback about their heart rate while performing several small tasks, while other participants performed the same tasks, but they were not given physiology feedback.

We hypothesize that participants may (consciously or otherwise) use physiology feedback to inform (reports about) their subjective experience of the tasks. To investigate this possibility, we collected momentary self-reported stress levels after each task. Stress was chosen here for several reasons: firstly, there is an intuitive connection between stress and heart rate. Secondly, (long-term) stress is an important factor in psychosomatic illness and is believed to be the cause of many health complaints. As such, stress is seen as an aspect of wellness that is of significant societal importance, and the significance of stress is intuitively understood by most.

In addition to momentary reports of stress, retrospective reports of the same are of interest here since retrospective self-report normally tends to deviate from momentary self-report, the latter often being more closely related to physiological measures [8]. If physiology feedback makes participants more aware of their stress level in the moment, it may also help them to remember and compare those stress experiences in hindsight, bringing retrospective self-report closer to momentary self-report and physiological measurements.

Finally, we hypothesize that the effects of physiology feedback may not be the same for all individuals but may be moderated by certain personality variables. Two personality variables were selected as possible moderators. The first is neuroticism, which represents emotional instability, or the tendency to experience negative emotions [9]. As those high in neuroticism believe that they are easily stressed, this expectation may moderate the effect of physiology feedback, especially if the feedback relates to stress. The second personality variable included in this study is anxiety sensitivity, which reflects the tendency to experience anxiety or fear in response to (benign) body sensations associated with anxiety and believing these sensations to be harmful or a reflection of serious illness [10]. If physiology feedback about stress is either seen as a sign of anxiety or results in a heightened body awareness, those high in anxiety sensitivity may show heightened levels of anxiety in response to physiology feedback about stress.

2. Method

Besides the actual content of the feedback, the interpretation of that information may also play a role in the effect of the feedback. Some terms or parameters may be easier for participants to interpret. For instance, the significance of a high stress score is probably more easily understood by most than a low heart rate variability (even though this is also considered an indicator of stress [11]). In addition the physiological measurement itself may affect people. Medical settings and measurements are known to cause anxiety in many, as illustrated by phenomena like white-coat hypertension (i.e., over 20% of people show increased blood pressure when measured in a doctor's office [12]). To tease these different aspects of physiology feedback apart, different levels of feedback were used.

2.1. Design. A 3 by 20 mixed design was used, comprising 20 different tasks as a within-subjects factor and 3 feedback types as a between-subjects factor.

Participants performed 20 brief (1 minute) tasks. For descriptions of the tasks, see Table 1. Half the tasks were designed to be mildly stressful, the other half more relaxing. To avoid a build-up of stress as a result of having many stressful tasks in a row, stressful tasks were alternated with

Table 1: Brief descriptions of all 20 tasks used in the experiments. The time limit of tasks was restricted to one minute, sometimes by the length of the stimulus (e.g., sound or video clips) and sometimes by sounding a bell after 1 minute and having the software automatically continue with the next step of the experiment.

Number	Category	Task description
1	Stressful	Mental arithmetic: calculate the result of 1149 minus 17, subtract 17 again from the result, etc.
2	Stressful	Read a scenario about standing in traffic, illustrated with a video.
3	Stressful	Play a computer game under time pressure, where falling cards need to be caught before they reach the bottom of the screen.
4	Stressful	Memorize a list of common English words (memory for the words is not tested afterward).
5	Stressful	Listen to a sound clip containing silence randomly interspersed with sharp bursts of noise.
6	Stressful	Count the red cars passing by in a video clip of a busy intersection.
7	Stressful	Relive a self-chosen memory that evokes frustration or anger.
8	Stressful	Make a to-do list.
9	Stressful	Watch a video clip of a throng of people getting pushed and pulled at a crowded subway station.
10	Stressful	Record a voicemail message for a job application.
11	Relaxing	Self-relaxation with eyes open.
12	Relaxing	Watch a video clip showing a quiet beach.
13	Relaxing	Play a simple computer game, where two cards with the same number need to be matched.
14	Relaxing	Watch a video of smooth, sparse traffic.
15	Relaxing	Read an article about "perfect summer weather."
16	Relaxing	Watch a video clip showing a forest.
17	Relaxing	Read a scenario about taking a relaxing road trip, illustrated with a video.
18	Relaxing	Do a guided breathing exercise.
19	Relaxing	Relive a memory that evokes happiness or relaxation.
20	Relaxing	Listen to a sound clip containing some smooth jazz.

relaxing ones. To counterbalance the order of the tasks as well as possible within this scheme, a set of 10th order digram-balanced graecolatin squares were used [13], resulting in a design where (a) all stressful tasks appear in every position equally often, (b) all relaxing tasks appear in every position equally often, (c) every possible order of two consecutive stressful tasks occurs equally often, (d) every possible order of two relaxing tasks occurs equally often, and (e) every combination of stressful and relaxing tasks occurs equally often.

To better understand what aspect of physiology feedback affects participants, we divided our participants into three groups: a "stress-feedback" group, who were told the physiology feedback reflected their stress level; a "HR-feedback" group, who were told the physiology feedback reflected their heart rate; and a "measurement-only" group, who wore ECG devices, but did not get physiology feedback.

2.2. Participants. The experiment was conducted in accordance with the Declaration of Helsinki (1964). All participants were informed in full about the experiment prior to participation and gave their informed consent. Participants were allowed to withdraw at any time during the experiment, without any adverse consequences. The experiment was approved by the local ethics committee at Eindhoven University of Technology, Human-Technology Interaction Group.

A total of 74 participants participated in the experiment (38 male, 36 female). The age of participants ranged from 18 to 67 years (average 27 years). Participants were recruited from a local participant database. People with a history of cardiac disease and/or mental illness were excluded from participation, by noting this point in both the invitation to participate and the informed consent. Participants were instructed beforehand not to smoke, engage in rigorous exercise, or drink caffeinated or alcoholic beverages in the 2 hours preceding the experiment. At the end of the experiment they were asked if they had indeed refrained from doing these things.

2.3. Stimuli. Descriptions of the tasks used in the experiment can be found in Table 1. The tasks were pretested to ensure they evoke a wide enough range in self-reported stress and average heart rate.

For the physiology feedback, a custom application was used consisting of two parts (see Figure 1). On the left, a graph was shown that displayed the participant's heart rate over approximately the last 3 minutes; the horizontal axis of the graph was automatically readjusted when the graph approached the end of the currently shown time window. On the right, the current heart rate was shown in beats per minute, calculated as a moving average over the last 20 beats to avoid rapid fluctuations in the signal. The physiology feedback window was shown in the top-right corner of

Table 2: The four statements posed after every task. Responses were given on a 7-point Likert scale ranging from “disagree completely” (1) to “agree completely” (7).

Number	Statement
1	I felt stressed during this task.
2	I felt calm during this task.
3	I felt relaxed during this task.
4	I felt tense during this task.

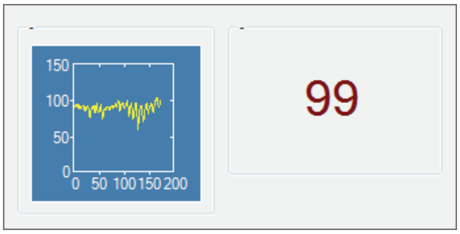


Figure 1: Screenshot of the physiology feedback window.

the screen and did not overlap with the software used to present the tasks.

2.4. Measurements. Both physiological data and subjective data were gathered during the experiment.

2.4.1. Physiological Measurements. For collection of ECG data, three Kendall H124SG ECG electrodes were used in the standard lead-II placement: the ground on top of the collar bone near the left shoulder, one electrode under the collar bone near the right shoulder, and one electrode underneath the ribs on the left side of the torso. A sampling frequency of 1024 Hz was used. From the raw ECG data, RR intervals were extracted and the average heart rate was subsequently calculated for each task.

2.4.2. Subjective Experience. After each task, subjects responded to four custom items about their experience of that task (see Table 2): “I felt (stressed, calm, relaxed, and tense) during this task.” A 7-point Likert scale ranging from “disagree completely” (1) to “agree completely” (7) was used for each item. A factor analysis revealed only one underlying factor (note that items 2 and 3 were reverse-coded). This seems to warrant the use of these questions as a single scale. A reliability test showed that Cronbach’s Alpha for this scale is high ($\alpha = 0.949$). For the remainder of the analyses we therefore use the average (again, with items 2 and 3 reverse-coded) of these four items as a single momentary stress score.

After subjects completed all tasks, they again rated all tasks on stressfulness, but this time in a retrospective and comparative way. The scale here ranged from 0 (“not at all stressful”) to 100 (“very stressful”) and participants added the tasks to the scale one by one, while the placement of earlier tasks remained visible to facilitate comparison of the tasks and consistent use of the scale. See Figure 2 for a screenshot of this rating task.

2.4.3. Personality Factors. After the tasks and rating task were completed, participants filled out two personality-related questionnaires: firstly, the 8 items on neuroticism from the Big Five Personality Inventory [9], reflecting emotional instability, or the tendency to experience negative emotions, and secondly the 16-item Anxiety Sensitivity Index [10], reflecting the tendency to experience anxiety or fear in response to (benign) body sensations associated with anxiety and believing these sensations to be harmful or a reflection of serious illness. These scales were included as possible moderators of effects of physiology feedback.

Overall scores for neuroticism and ASI were calculated for each participant, as the average of individual item scores of the relevant questionnaire (with reverse coding for the appropriate items in the neuroticism questionnaire). The neuroticism questionnaire showed a high reliability in our sample (Cronbach’s $\alpha = 0.807$), as did the Anxiety Sensitivity Index (Cronbach’s $\alpha = 0.841$).

2.4.4. Manipulation Check. To assess whether the feedback type manipulation had worked, participants who received physiology feedback during the experiment were asked at the end of the experiment how often they had looked at the feedback, on a scale from 1 (“not at all”) to 7 (“very much”).

2.5. Procedure. When participants came into the lab, an informed consent was administered. After signing the informed consent, participants first performed a practice task at a computer, where they were instructed to relax as much as possible, while keeping their eyes open (the same as task 11 from the main experiment). The practice task was followed by the same four stress self-report items as the tasks in the main experiment.

Participants were then asked to apply the necessary electrodes for the ECG measurement. The ECG recording software was started, and for the HR-feedback and stress-feedback groups the feedback application was started as well. The HR-feedback group were told the feedback application would show their heart rate, while the stress-feedback group were told the application would show their stress level.

The 20 tasks were then presented to all participants via a computer program, each followed by the stress self-report items. After all 20 tasks were completed, participants filled out the postquestionnaires (task stressfulness ratings, neuroticism and anxiety sensitivity scales, and manipulation check). Finally, all participants were paid and thanked for their participation.

3. Results

In our analyses, we tested the effects of feedback type on several dependent variables. Firstly, does feedback type affect the self-reported level of momentary and retrospective stress? Secondly, does feedback type affect the extent to which momentary and retrospective stress self-report are aligned? And thirdly, does feedback type affect the extent to which (momentary or retrospective) self-reported stress is in line with heart rate?

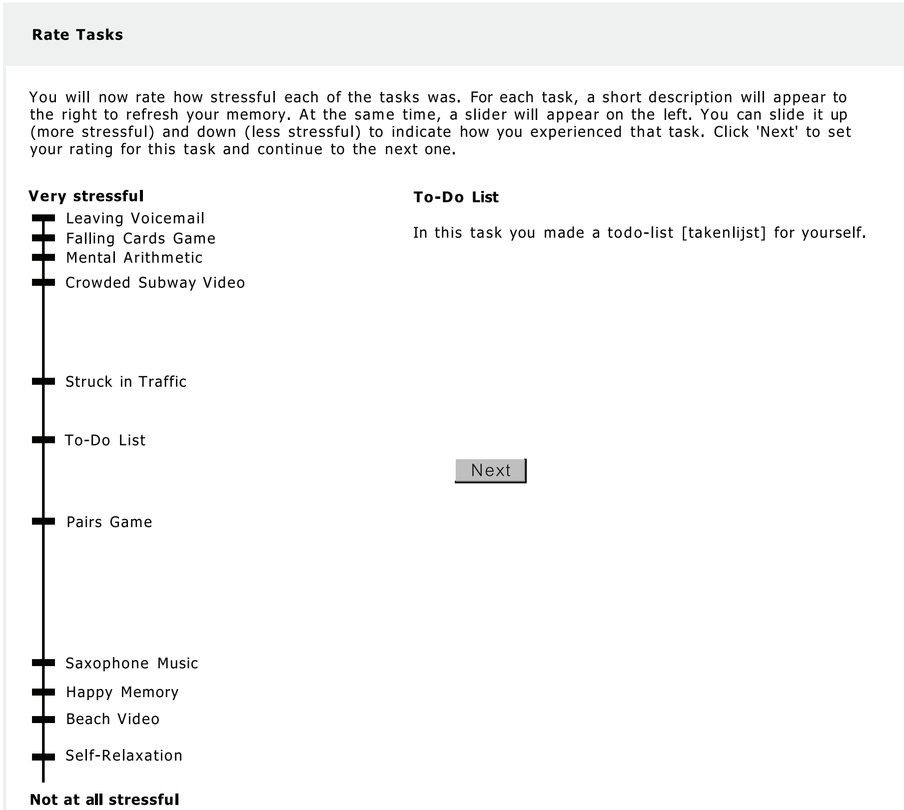


Figure 2: Screenshot of the task stress rating, which was administered after all tasks were completed. Each task was presented with a brief description. The participant could then place the task on the scale by sliding the relevant marker up or down. Once the participant proceeded to placement of the next task, placement of the previous task was fixed and could no longer be altered.

The last two dependent variables are both related to a "match" between two different measures of stress. We have devised two different measures to operationalize this concept of a match between two variables. The first measure is calculated on the individual level and consists of taking, for each participant, the correlation between the two relevant variables (i.e., momentary and retrospective stress, or heart rate and momentary stress, or heart rate and retrospective stress). An intrapersonal correlation is used here, as individual differences may exist in both baseline and variability on the different measures of stress.

The second measure is calculated on the task level. To this end we converted the raw heart rate and stress scores to a more comparable form by transforming them into z-scores, using within-person averages and standard deviations of the relevant variable. The absolute differences between the heart rate z-scores and stress z-scores, as well as between momentary and retrospective stress z-scores, were then calculated for each task, for each participant. These difference scores are a lower-is-better representation of the match between the two relevant variables.

3.1. Outliers. Data from a total of 8 participants had to be excluded for a number of reasons. For two participants, the ECG data could not be preprocessed, likely due to an electrode being faulty or not properly connected. One participant seemed to have misunderstood the intended use of the retrospective stressfulness scale, simply leaving the markers for all tasks at the place they were initially presented. One participant showed an exceptionally low (>4 standard deviations below the mean) correlation between momentary and retrospective stress (a parameter that is to be used in one of our analyses). Finally, 4 additional participants reported having exercised or consumed caffeine before the experiment. All data from these 8 participants was excluded from further analysis. This brought the total number of participants in the data set used for analysis to 66.

3.2. Manipulation Check. Results from the manipulation check show that the manipulation was successful: on average, participants in the feedback groups reported that they had looked at the physiology feedback quite often (an average of 5.27 on a scale from 1, not at all, to 7, very often). No one claimed never to have looked at the feedback.

3.3. Effects of Feedback Type on Momentary Stress and Retrospective Stress. To analyze the effect of feedback type on the levels of momentary and retrospective self-reported stress, a series of multilevel models was used. The data we have is hierarchical in nature: there are 3 feedback type groups, each containing several participants, each of whom performed 20 tasks. Multilevel models are aimed at modeling these different

Table 3: Parameter estimates, 95% confidence intervals and significance levels for the different levels of the interactions of feedback type and personality factors on momentary self-reported stress.

Parameter	Estimate	95% CI	Sig.
Measurement-only ∗ ASI	0.05	−0.12–0.21	0.598
HR-feedback ∗ ASI	0.09	−0.12–0.29	0.406
Stress-feedback ∗ ASI	0.25	0.08–0.42	0.004*
Measurement-only ∗ neuroticism	0.15	0.01–0.28	0.030*
HR-feedback ∗ neuroticism	0.11	−0.04–0.25	0.143
Stress-feedback ∗ neuroticism	−0.05	−0.25–0.16	0.649

Dependent variable: momentary stress.
*Significant at $\alpha = 0.05$.

Table 4: Parameter estimates, 95% confidence intervals and significance levels for the different levels of the interactions of feedback type and personality factors on retrospective self-reported stress.

Parameter	Estimate	95% CI	Sig.
Measurement-only ∗ ASI	−1.57	−4.99–1.85	0.368
HR-feedback ∗ ASI	2.79	−1.35–6.92	0.186
Stress-feedback ∗ ASI	3.58	0.15–7.01	0.041*
Measurement-only ∗ neuroticism	3.07	0.36–5.79	0.027*
HR-feedback ∗ neuroticism	2.11	−0.78–5.00	0.151
Stress-feedback ∗ neuroticism	−1.70	−5.84–2.45	0.422

Dependent variable: retrospective stress.
*Significant at $\alpha = 0.05$.

levels of the hierarchy. Separate models were estimated for momentary stress and retrospective stress. The initial model included "feedback type" as a fixed factor and "task" as a repeated measure. This model showed no significant main effect of feedback type on momentary stress for either momentary ($F(2, 587) = 1.575$, $P =$ ns) or retrospective stress ($F(2, 840) = 0.194$, $P =$ ns).

In a second iteration, two interaction terms ("neuroticism ∗ feedback type" and "ASI ∗ feedback type") were added to the model to test the moderating effects of the personality factors. This addition significantly improved the fit of the overall model, as indicated by the change in −2 Log Likelihood ($\chi^2(6) = 21.786$, $P < 0.005$ for momentary stress, $\chi^2(6) = 18.346$, $P < 0.01$ for retrospective stress). For both momentary and retrospective stress, the parameter estimate (conceptually similar to a regression coefficient, see Tables 3 and 4) for the "neuroticism ∗ feedback type" interaction was positive and significant specifically in the measurement-only group, indicating that in this group, but not the other groups, participants with a higher level of neuroticism generally reported higher levels of momentary ($t(583) = 2.868$, $P = 0.004$) and retrospective ($t(1086) = 2.050$, $P = 0.041$) stress. The parameter estimate for the "ASI ∗ feedback type" interaction was positive and significant specifically in the stress-feedback group, indicating that in this group, but not the other groups, participants who score higher on ASI generally reported higher levels of momentary ($t(583) = 2.172$, $P = 0.030$) and retrospective ($t(1086) = 2.219$, $P = 0.027$) stress.

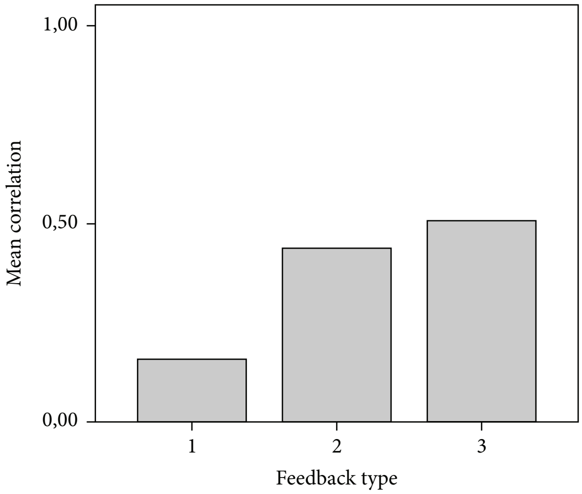
3.4. Match between Heart Rate, Momentary Stress, and Retrospective Stress. To test how feedback type affects the extent to which participants' subjective stress levels are in line with their heart rate and how well participants remember their self-reported stress levels, a MANOVA was used. In this analysis, feedback type was the independent variable and the correlation coefficients between each combination of two stress measures were dependent variables (see the beginning of Section 2 and Figure 3).

The analysis showed that the average intrapersonal correlation between heart rate and both momentary and retrospective stress was significantly different for different feedback types ($F(2, 63) = 12.074$, $P < 0.001$ for momentary stress, $F(2, 63) = 16.424$, $P < 0.001$ for retrospective stress). A series of LSD post-hoc tests revealed that, for both momentary and retrospective stress, the correlation with heart rate was significantly higher in the HR-feedback group than the measurement-only group ($P = 0.001$ for momentary stress, $P < 0.001$ for retrospective stress), but there was no significant difference between the stress-feedback and the HR-feedback groups in terms of the correlation with heart rate. The analysis showed no significant effect of feedback type on the correlation between momentary and retrospective stress ($F(2, 63) = 2.309$, $P =$ ns).

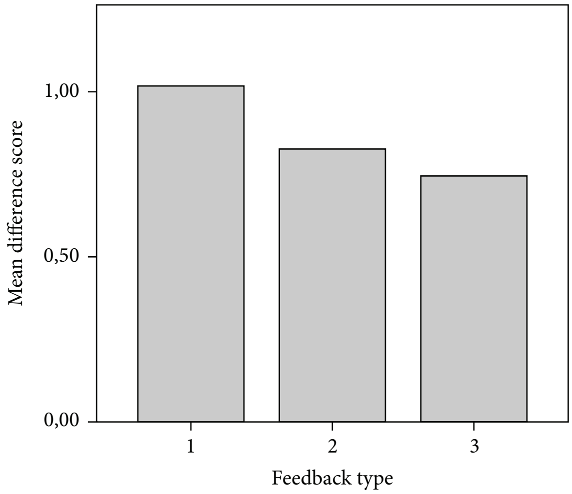
The downside of the analysis described above is that, by collapsing the data into correlation coefficients per person, an aspect of the data is lost: the variability between tasks. As mentioned before, multilevel models can be used to model the different levels in our hierarchical data. For these multilevel models, a measure similar to the correlations used above is needed that can be calculated at the level of individual tasks for each person. The difference scores described in the beginning of Section 3 were used for this purpose.

To reestablish the significant results obtained in the MANOVA for the correlations between both momentary and retrospective stress and heart rate, a simple model ignoring the hierarchical nature of the data was first tested. This model included only "feedback type" as a fixed factor. Separate analyses were performed for the HR versus momentary stress difference score and the HR versus retrospective stress difference score. As expected, the "feedback type" factor had a highly significant effect on both the HR versus momentary stress difference score ($F(2, 1320) = 19.742$, $P < 0.001$) and the HR versus retrospective stress difference score ($F(2, 1320) = 21.360$, $P < 0.001$).

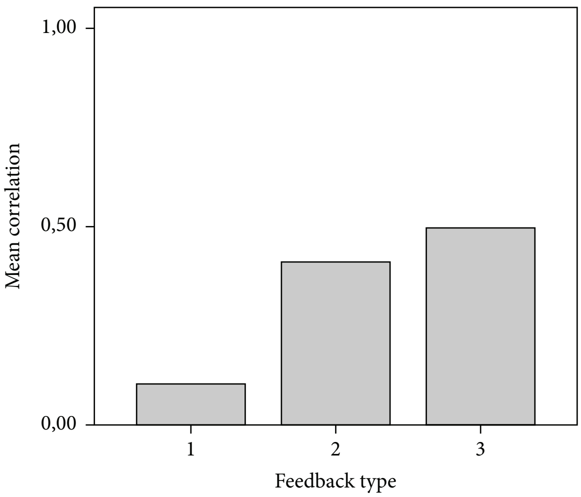
In a second iteration, "task" was added to the model as a repeated measure. This addition significantly improved the fit of the overall model, as indicated by the change in −2 Log Likelihood ($\chi^2(19) = 67.744$, $P < 0.001$ for HR versus momentary stress, $\chi^2(19) = 67.744$, $P < 0.001$ for HR versus retrospective stress). The "feedback type" factor was still significant for both dependent variables: $F(2, 1204) = 17.342$, $P < 0.001$ for HR versus momentary stress, with a significant contrast between the measurement-only and HR-feedback groups ($P < 0.001$) and a marginally significant contrast between the HR-feedback and stress-feedback groups



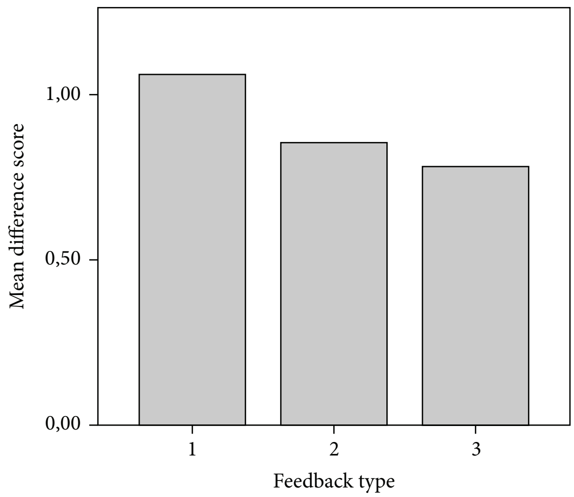
(a) Correlation between heart rate and momentary stress



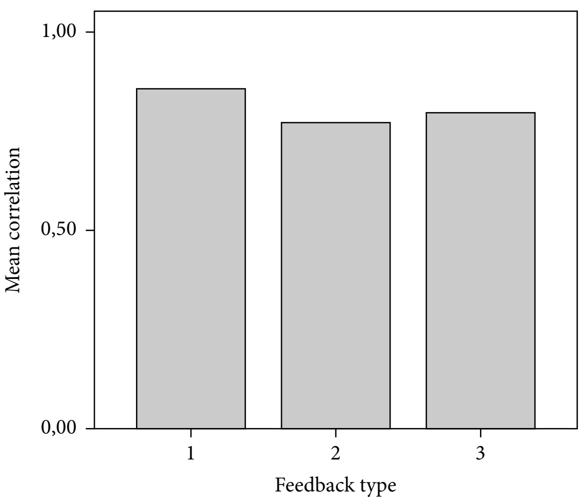
(b) Difference score for heart rate and momentary stress



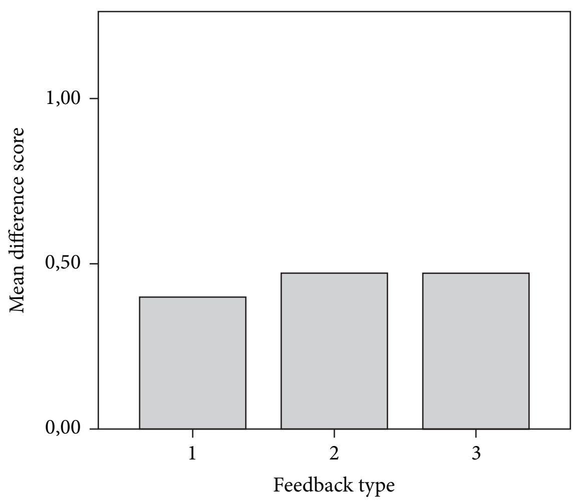
(c) Correlation between heart rate and retrospective stress



(d) Difference score for heart rate and retrospective stress



(e) Correlation between momentary and retrospective stress



(f) Difference score for momentary and retrospective stress

Figure 3: Average correlations (left) and difference scores (right) between different variables for the different feedback types. A higher correlation means a stronger match between two variables, while the reverse is true for the difference scores. For the sake of readability, feedback types are coded as 1 = measurement-only, 2 = HR-feedback, and 3 = stress-feedback.

($P = 0.057$); and $F(2, 1234) = 20.105$, $P < 0.001$ for HR versus retrospective stress, with a significant contrast between the measurement-only and HR-feedback groups ($P < 0.001$) and a marginally significant contrast between the HR-feedback and stress-feedback groups ($P = 0.063$).

In a third iteration, the personality factors were included in the model by adding two interaction terms ("neuroticism ∗ feedback type" and "ASI ∗ feedback type"). The fit of the model was not significantly improved by these additions ($\chi^2(6) = 6.961$, $P =$ ns for HR versus momentary stress, $\chi^2(6) = 7.589$, $P =$ ns for HR versus retrospective stress), indicating that the effect of the feedback was not significantly different for different scores on the personality factors.

4. Discussion

The goal of this study was to assess some of the acute effects of physiology feedback, to better understand the effects self-tracking of physiology might have. Specifically, we investigated to what extent physiology feedback would affect the match between participants' physiological stress and their self-reported stress. In addition, the effect of physiology feedback on participants' memory for self-reported stress (i.e., the match between momentary and retrospective stress) was investigated. Finally, we examined whether physiology feedback might affect the self-reported stress level itself and explored the role of two personality variables (neuroticism and anxiety sensitivity) in this respect.

Our results show that when participants are given feedback about their heart rate, their estimates of their stress level become more in tune with their heart rate: when their heart rate is high, they report a high stress level, and when their heart rate is low, they report a low stress level. The effect seems to be stronger in the stress-feedback group compared to the HR-feedback group (although the effect was only marginally significant), suggesting that the instructions given about how to interpret the feedback might be important.

There are at least two explanations for the fact that physiology feedback resulted in a better match between stress self-report and heart rate. The first is that the physiology feedback helps people to become more aware of their body and that this heightened awareness then informs their subjective stress reports. Alternatively, people may see the feedback as a more objective and more accurate source of information about their stress level than their own experience. This might mean that when their subjective experience does not match the feedback, they use the feedback rather than their own experience to inform their reports about stress. The current study cannot provide conclusive evidence either way, but a follow-up study using false heart rate feedback might: if the second explanation is true, false heart rate feedback should cause self-report to become more in tune with the false feedback; if the first explanation is true, false heart rate feedback either might have no effect (if false feedback is not effective at triggering body awareness) or might cause stress self-report to become more in tune with one's own heart rate.

Physiology feedback was found not to affect the extent to which retrospective self-reported stress matches momentary self-reported stress. This implies that although physiology feedback made subjective reports of stress more in tune with heart rate, it did not help participants to better remember their stress levels. Although this finding may well represent a true effect, it may also have been caused by a ceiling effect: the correlation between momentary and retrospective stress self-report was already quite high ($r = 0.8$ on average) for almost all participants in the measurement-only group, leaving little room for improvement. This may have been due to the limited time interval between the momentary and retrospective reports: even for the first task, the momentary and retrospective assessment were typically no more than 25 minutes apart. A longer interval might give rise to different results as a consequence of temporal decay of short-term memory, as well as other effects that could influence delayed recall.

Our results did not show an effect of physiology feedback on self-reported stress, indicating that, on average, physiology feedback did not cause participants to become more or less stressed. The interaction between neuroticism and feedback on self-reported stress levels, however, was significant. Specifically, it was found that, in the measurement-only condition, a higher score on neuroticism predicted higher stress levels, while this effect was not present in the feedback conditions. Most items in the neuroticism questionnaire are related to whether participants see themselves as tense, nervous, or easily upset. Those who score high on this scale presumably believe they experience relatively high levels of stress. This might explain why those who score high on neuroticism report higher stress levels than low-neuroticism individuals in the measurement-only condition. For individuals with a high score on neuroticism, the physiology feedback may provide good news, in the sense that their objective, physiological stress response may be less strong than they expected. This might explain why the difference in self-reported stress between higher- and lower-neuroticism individuals disappears in the HR-feedback and stress-feedback conditions.

The interaction between anxiety sensitivity and feedback on self-reported stress was also found to be significant. In the stress-feedback group, individuals who scored higher on anxiety sensitivity were shown to report higher levels of stress. Individuals with a high level of anxiety sensitivity tend to experience anxiety when they detect anxiety-related body sensations [10]. For these individuals, physiology feedback might draw their attention to benign physiological responses, thereby causing them to become more anxious and report higher levels of stress. This may explain our results and suggests that self-tracking of physiology might have adverse effects for individuals with a high level of anxiety sensitivity. Note that the effect was only found in the stress-feedback and not in the HR-feedback condition, suggesting again that the explanation given about the meaning of the feedback parameter may be important in certain contexts.

On a general note, there are several differences between our lab setting and self-tracking in the field that limit the generalizability of our results: firstly, the pervasive feedback used in this study is different from the physiology feedback obtained in self-tracking, which is generally available on demand, rather than being presented constantly. Secondly, self-tracking of physiology involves other interactions with one's data besides the real-time physiology feedback used in this study (e.g., feedback after the fact, viewing data aggregated over longer periods of time). Finally, this study only assessed acute effects of physiology feedback, precluding any conclusions about longer-term effects. Still, even though this study does not yet paint a complete picture of the effects of self-tracking of physiology, it does provide insight into how self-tracking of physiology may lead to better body awareness and how individual differences in personality characteristics may moderate the effects of self-tracking on stress.

5. Conclusion

A study was conducted to test whether physiology feedback has acute effects on self-reported stress and the extent to which it is in sync with physiological stress. In this study, participants executed several short tasks, while they were either shown visual feedback about their current and past heart rate or not. The group who received feedback was further subdivided into a group who were told the feedback represented their heart rate and a group who were told the feedback represented their stress level.

Results show that self-reported stress is more in sync with heart rate for participants who received physiology feedback. This implies that either the feedback helps these participants to better detect their own physiological stress or they use the external feedback to inform their reports of experienced stress. Either way, these results suggest that physiology feedback increases body awareness on a subjective—if short-term—level.

Physiology feedback was found not to affect participants' stress levels. However, interactions between two personality factors and feedback on stress levels were found. Firstly, participants with a high score on neuroticism were found to report more stress than those with a low score on neuroticism when no physiology feedback was given, but this difference disappeared when physiology feedback was provided. This may reflect a belief-based bias, as neuroticism reflects the degree to which people believe they are prone to episodes of stress, tension, and upset. This in turn suggests that physiology feedback may be effective at reducing self-reported stress when it gives "good news." Secondly, individuals high in anxiety sensitivity were found to report higher levels of stress in the condition where physiology feedback about stress was given, suggesting that self-tracking of physiology may be less suitable for these individuals.

The results found in this study are based on experiences in a lab setting which, although well-controlled, lacks the longitudinal nature and richness of interaction of real-world self-tracking. How the results of this study translate to long-term effects of self-tracking on general health and well-being is therefore a matter that will require additional work. Nevertheless, our findings give a first indication of how self-tracking of physiology may lead to better body awareness and how personality characteristics can help us predict which individuals are most likely to benefit from self-tracking of physiology.

Conflict of Interests

The authors declare that there is no conflict of interests regarding the publication of this paper.

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Review Article

The Influence of Buddhist Meditation Traditions on the Autonomic System and Attention

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Cognitive and neuroscience research from the past several years has shed new light on the influences that meditative traditions have on the meditation practice. Here we review new evidence that shows that types of meditation that developed out of certain traditions such as Vajrayana and Hindu Tantric lead to heightened sympathetic activation and phasic alertness, while types of meditation from other traditions such as Theravada and Mahayana elicit heightened parasympathetic activity and tonic alertness. Such findings validate Buddhist scriptural descriptions of heightened arousal during Vajrayana practices and a calm and alert state of mind during Theravada and Mahayana types of meditation and demonstrate the importance of the cultural and philosophical context out of which the meditation practices develop.

1. Introduction

Providing scientific conceptualizations of meditation practices has been one of the major concerns of recent scientific studies of meditation [1–4]. One of the first scientific conceptualizations of meditation was proposed by Herbert Benson, who defined meditation as a technique that generates a "relaxation response" [5, page 56]. Benson conducted his studies on Transcendental Meditation (TM), where the meditator recites a mantra provided to him or her by the meditation instructor, as well as on Mindfulness meditation, which is a form of meditation that emphasizes the stabilization of attention by acknowledging discursive sensory events as momentary, and observing them without affective reaction or attachment. Benson showed that TM and Mindfulness meditation result in physiological changes indicative of a heightened activation of the parasympathetic nervous system and lowered sympathetic activity, such as decreased oxygen consumption and carbon dioxide elimination, lowering of heart and respiratory rates, and a marked decrease in arterial blood lactate concentration (e.g., [6, 7]), as well as psychological outcome measures that indicate relaxation (e.g., [8]). As these physiological and psychological results are characteristic responses that occur during relaxation, Benson termed the responses that occur during meditation as a relaxation response. Although Benson discovered the relaxation response by investigating TM and Mindfulness, he assumed that it applies to meditation in general and that it is useful to decontextualize different types of meditation from their religious and cultural basis: "to understand the psychophysiological aspects of meditation, it should first be conceptually denuded of its cultural and religious biases" [9, page 2]. Importantly, the attainment of a relaxation response during meditation has been confirmed by many subsequent studies and consistently reported in the scientific literature (e.g., [10–13]).

Based on Benson's approach, an evolutionary theory was proposed by Young and Taylor [14], where meditation was characterized as a "wakeful hypometabolic state of parasympathetic dominance" [14, page 149]. The hypometabolic state during meditation is a state of deep rest, which is similar to hibernation, but where the practitioner remains awake and vigilant [14, 15]. The state of being awake and vigilant was later termed "tonic alertness," which indicates a state of optimal vigilance where attention is sustained for a prolonged period of time [16]. The state of "parasympathetic dominance" is generated by the increased activity of the parasympathetic branch of the autonomic nervous system, often referred to as the “rest and digest” system, which slows down the heart rate, lowers blood pressure, increases intestinal and gland activity, and relaxes sphincter muscles [17].

It is important to note that even though the characterization of meditation as a wakeful hypometabolic state is supported by empirical findings (e.g., [10–12]), the scientific studies that have led to this classification were conducted on very specific types of meditation. Specifically, most previous scientific studies have been conducted on TM and types of meditation from the Theravada and Mahayana traditions, such as Shamatha, Vipassana, or modern Mindfulness meditation. In particular, a large number of scientific studies were conducted on Shamatha or Vipassana [18, 19] that emphasize avoiding discursive thought by letting the practitioner concentrate on an object of meditation (Shamatha) or examine and generate insight out of his/her own mental activity (Vipassana) [20]. Also, many studies were conducted on Mindfulness meditation (e.g., [10, 12, 21]), which was developed by Jon Kabat-Zinn, who defined it as “mostly Vipassana practice... with a Zen attitude” (Kabat-Zinn email cited in [22], page 238), where elements from Theravada and Mahayana practices are taught alongside Vipassana meditation in order to create a secularized practice that would appeal to people who might not possess a genuine interest in Buddhist culture or philosophy [22]. (In accordance with this definition, Gilpin [22], who analyzed the influence of Buddhist traditions on Mindfulness, based on descriptions given by the developers of Mindfulness practices (Kabat-Zinn and John Teasdale), concluded that Mindfulness practice is mainly derived from Vipassana. Similar conclusions can be made by examining the practice of Mindfulness itself, which similarly to Vipassana, stresses avoiding discursive thought through nonjudgmental concentration on the content of one’s momentary mental activity [23, pages 141-142]). A number of studies have also been conducted on Zen concentration meditation [24, 25], which similarly to Shamatha requires the meditator to continually focus on a single object of meditation [26, page 97].

Along with the large number of studies that confirmed that certain types of meditation can lead to a relaxation response, recent scientific evidence suggests that the generation of a relaxation response might not characterize meditative practices of other traditions. Specifically, meditative practices of the Vajrayana and Hindu Tantric traditions, which will be detailed in a subsequent section of the review, have been demonstrated to elicit a state of arousal and not relaxation [27–29]. In contrast to relaxation, arousal is a physiological and psychological state of being awake and reactive to stimuli. It is characterized by an increase in the activity of the sympathetic system, which is followed by the release of epinephrine and norepinephrine from the endocrine system [30–32] and results in the state of phasic alertness, a significant temporary boost in the capacity to respond to stimuli [16, 33, 34]. Moreover, while tonic alertness can happen concurrently with relaxation and a recent review of the literature showed that it can occur during Theravada and Mahayana styles of meditation [25], phasic alertness is a result of the activity of the sympathetic system and therefore inconsistent with the state of relaxation.

The goal of this review is to show that different types of Buddhist meditation techniques can lead to relaxation or arousal depending on the type of meditation that is practiced. We also plan to show that while some types of meditation generate increased tonic alertness, or vigilance, along with a state of relaxation and parasympathetic activation, other types of meditation lead to increased phasic alertness and generate an immediate and dramatic increase in cognitive performance on visual tasks, consistent with the state of arousal and sympathetic activation. In the following sections, we will first provide an overview of the autonomic system and the manner in which it underlies psychological and physiological states of relaxation and arousal and influences attentional processes that relate to phasic and tonic alertness. We will proceed with a review of scientific studies that demonstrate a relaxation response during Theravada and Mahayana types of meditation, which will be followed by a review of studies that demonstrate tonic alertness during these practices. Lastly, we will review studies that demonstrate an arousal response, as well as phasic alertness, during Vajrayana and Hindu Tantric practices.

2. Measuring Relaxation and Arousal, as well as Tonic and Phasic Alertness

Anatomically, the autonomic nervous system (ANS) consists of neurons from within both the central nervous systems (CNS) and the peripheral nervous system (PNS) and receives input from anatomic regions that integrate information from within the body and the external environment, such as the hypothalamus, nucleus of the solitary tract, reticular formation, amygdala, hippocampus, and olfactory cortex [35]. The functional role of the ANS is to monitor important visceral processes that operate largely below the level of conscious awareness, such as heart rate, breathing, and digestion [35].

The ANS is comprised of two major neurobiological subsystems that function both independently and in concert: the parasympathetic nervous system and the sympathetic nervous system. These two systems often elicit opposing actions, so that when one system enhances or activates a physiological response, the other system inhibits it. The sympathetic nervous system is often called the “fight or flight” system, which accelerates the heart rate, constricts blood vessels, and raises blood pressure in order to enable a quick and mobilizing response, often as a reaction to an immediate threat. On the other hand, the parasympathetic system is often referred to as the “rest and digest” system, which slows down the heart rate, lowers blood pressure, increases intestinal and gland activity, and relaxes sphincter muscles [17]. As mentioned, the increased capacity to respond to stimuli that is generated by the sympathetic system has been termed phasic alertness [16, 33, 34]. Therefore, phasic alertness requires the activation of the sympathetic system and cannot co-occur with a physiological state of parasympathetic dominance, which is the relaxation response. On the other hand, although tonic alertness is inconsistent with drowsiness and sleep, it can nevertheless occur concurrently with a moderate level of parasympathetic activation and, as described below, can also occur during relaxed states.

There are numerous experimental methods that have been used to demonstrate the activity of the sympathetic (arousal) and parasympathetic (relaxation) systems. One commonly used method is related to the heart rate variability (HRV), which is determined by the autonomic system [30] and is assessed through electrocardiographic measures (abbreviated as EKG or ECG). HRV can be measured through time domain methods or frequency domain methods. The EKG frequencies that are used as autonomic activity measures are high frequencies (HF), typically between 0.15 and 0.4 Hz [36–40], and the ratio between low and high frequencies (LF/HF) [30]. While some researchers proposed that low frequencies (LF), typically between 0.04 and 0.15 Hz [36–40], can be used as a marker of sympathetic modulation [41–44], others attribute LF to both sympathetic and parasympathetic influences [45, 46]. In contrast, increases in HF are universally attributed to the activity of the parasympathetic system [41, 45, 47]. Under ordinary circumstances, HF decreases indicate decreased parasympathetic and increased sympathetic activation [36, 48, 49], although it should be noted that in some extreme cases (e.g., physical exercise or extreme stress), increases in HF could accompany an increase in sympathetic response [36, 48]. A measure that is associated with HF is the respiratory sinus arrhythmia (RSA), which measures vagal modulations on heart rate and is correlated with the activity of the parasympathetic nervous system [50, 51]. Studies also investigated the heart rate pressure product—the product of the systolic blood pressure and the heart rate—and the double product—the product of the mean blood pressure and the heart rate—which index the myocardial oxygen consumption and load on the heart and are increased due to sympathetic system activation [52].

Another commonly used measure of autonomic activation is the galvanic skin response (GSR), where increases in GSR typically indicate increased sympathetic activation, and decreased GSR increased parasympathetic activity [53, 54]. Additionally, body temperature increases, or thermogenesis, are also determined by the sympathetic system [55, 56]. Also, several studies have used changes in blood pressure in order to investigate the state of the autonomic system. As described above, decreases in blood pressure (mean, systolic, and diastolic) are caused by the parasympathetic nervous system and blood pressure increases by the sympathetic system [17]. Moreover, relaxation responses were measured through self-report scales that are correlated either with negative emotions such as distress that indicate reduced relaxation (e.g., Global Severity Index (GSI), [57]) or positive emotional states that indicate increased well-being and relaxation (e.g., Positive States of Mind (PSOM), [58]).

Previous findings demonstrated that during arousal, there is a significant temporary boost in the capacity to respond to stimuli, indicative of phasic alertness, which is manifested by improved performance on a number of visual and memory tasks [59–61]. Hence, phasic alertness was determined to occur during states that lead to immediate improvements in performance on cognitive tasks [27, 29]. In order to determine the occurrence of tonic alertness, previous studies have used both neuroimaging and behavioral measures. In terms of behavioral measures, psychological studies have shown that performance on target detection tasks can improve with increased tonic alertness [62]. In terms of neuroimaging studies, neuroscience research has shown that tonic alertness is associated with neural activity in right hemisphere cortical areas and subcortical networks, particularly the dorsal anterior cingulate cortex (dACC), the dorsolateral prefrontal cortex (DLPFC), the anterior insula, the inferior parietal lobule, the thalamus, and the brain stem [34, 63, 64].

3. Meditation Traditions

There are three main Buddhist traditions that exist today: Theravada, Mahayana, and Vajrayana. Theravada has been the predominant religion of continental South Asia, and the *Tipitaka*, or *Pali Canon* [20], is its canonical text, which contains the earliest record of Buddha's teachings. The most prevalent meditative techniques of the Theravada tradition are Shamatha and Vipassana, which emphasize avoiding discursive thought by letting the practitioner concentrate on an object of meditation (Shamatha) or his/her own mental activity (Vipassana) [65]. In Buddhist scriptures, Shamatha practice relates to training in the concentration of attention, so that the practitioners are instructed to place undistracted attention on the object of meditation, while withdrawing their focus from other objects [65, 66]. Vipassana refers to insight into the true nature of reality, entailing an understanding of the impermanence of everything that exists, which is coupled with pacification (serenity) of the mind [67, pages 1287-1288 (IV.1410)].

The Mahayana tradition incorporated the canonical texts of the Theravada tradition, but also introduced a vast corpus of philosophical and devotional texts, with the most distinctive feature being the "great compassion," an inherent component of enlightenment, which is manifested in bodhisattvas (enlightened beings). The Mahayana tradition is the largest major tradition of Buddhism and is prominent in North Asia. Mahayana Buddhists perform an assortment of different types of meditation practices, many of which are rooted in Shamatha and Vipassana practices, particularly types of meditation from the Tiantai Mahayana tradition [68]. Moreover, Zen concentration meditation is similar to Shamatha in the sense that it is also performed through prolonged concentration on an object of meditation, most commonly on the breath, in order to experience one-pointedness of mind or Samadhi [26, pages 57, 97].

The third tradition is Vajrayana Buddhism, which is often called Tantric Buddhism, and is a central tradition of Tibetan Buddhism that adopted elements of Hindu Tantric methods and Mahayana Buddhism [69, 70]. Although a number of practices in Vajrayana Buddhism originated in Mahayana (e.g., training in compassion/Six Paramitas) and Theravada (e.g., renunciation, impermanence, elements of Shamatha and Vipassana), they are practiced and integrated in a Vajrayana context [71]. There are three streams of Vajrayana practice: *Generation, Completion with Sign, and Completion without Sign*. Generation or development practices are performed during the first stage of the meditation practice [72]. A central generation practice that will be discussed in this review is self-generation-as-Deity practice (Tibetan "Kyerim"; hereafter referred to as Deity meditation), which involves visualizing oneself as a particular Deity, and holding the focus of attention on the internally generated image surrounded by his or her entourage. The completion stages are divided into completion practices "without sign" that include Rig-pa meditation, a practice during which the meditator visualizes the dissolution of the Deity and its entourage into emptiness and aspires to achieve a state of awareness that is devoid of conceptualization [73, 74]. Completion "without sign" are advanced tantric practices called "the six Yogas of Naropa" [75], one of which is g-Tummo, which will be discussed in this review. The g-Tummo Vajrayana practice is also called "psychic heat," since it is associated with intense sensations of bodily heat in the spine [76–78] and involves breathing and muscle exercises, as well as visualization techniques that enable the meditators to generate and maintain mental images of flames at specific bodily locations that are accompanied by an intense sensation of heat in the spinal area.

Vajrayana practices are related to Hindu Tantric practices which were developed within ancient Hinduism and described in the Yoga-Sutras [79]. Hindu Tantric practices also distinguish different stages of practice. In the Dharana stage, the meditation consists of concentrative techniques of absorption in a single object of meditation, often in objects with religious significance such as deities [80, Chapter 8, page 2]. The practice of Dharana precedes Dhyana, during which the meditator disengages from a single object of meditation to a complete absorption in meditation, which leads to a nonconceptual state of consciousness [81, 82]. Hindu and Buddhist Tantric practices share some commonalities in the sense that both practices place an emphasis on concentrative visualization techniques on religious objects or deities, both describe similar stages of practice, and both place an emphasis on achieving a nonconceptual state of consciousness.

While meditative techniques of all Buddhist teachings stress liberation from all conceptual delusions, the means of achieving it are quite different. Specifically, Buddhist texts state that Theravada styles of meditation, such as Shamatha, Vipassana, or Mindfulness, are techniques that emphasize "internally steadying" or stabilize the "unstable mind" and cultivate the state of quiescence and tranquility, through which the nature of the mind could be seen without obstruction [67, pages 1287-1288 (IV.410)] [83, pages 152-153 (I.165), 335 (II.290)]. Similarly, certain Mahayana practices such as Zen concentration meditation also place an emphasis on one pointed concentration as well as calmness [26, pages 57, 97]. Vajrayana scriptures, by contrast, emphasize the training "which is not exactly the same as keeping the mind still and quiet" [84, page 118] but rather aims at the realization of "self-existing wakefulness" or "an awake quality" of the mind, free from dualistic thoughts, which is "like a radiant flame of a candle which exists all by itself" [84, page 88]. Furthermore, Vajrayana teaching emphasizes that the preoccupation with "being too calm" blocks "the recognition of self-existing wakefulness," and that in a Vajrayana context, "it is sometimes said that stillness is not absolutely necessary..." [84, pages 85-86]. Thus, from a Vajrayana perspective, the conceptualization of meditation as a relaxation response seems to be incongruent with Tibetan views of Vajrayana Tantric practices, which do not presuppose relaxation but contain descriptions that are more consistent with the generation of an arousal response.

4. Relaxation and Tonic Alertness during Meditation

As alluded to the above, Buddhist texts describe Theravada types of meditation as practices that promote not simply a relaxed state of mind, but a state of relaxation and alertness [23]. Moreover, certain Mahayana practices, notably Zen concentration meditation, place a special emphasis on calmness [26, page 57]. Indeed, empirical evidence that some meditation practices generate a relaxation response can already be found in Benson's studies from the 1970s and 1980s (e.g., [8, 85]). Since then, dozens of studies have demonstrated that certain types of meditation from the Theravada and Mahayana traditions elicit a relaxation response, even after a brief period of meditation (e.g., 20 minutes: [86, 87]). Most of these studies investigated Mindfulness meditation, although there have been studies on Zen concentration and Vipassana as well (e.g., [10–13]). Such findings have been replicated many times in the past, and it is now widely accepted that Mindfulness meditation can be reliably used to alleviate the effects of stress and depression and to increase relaxation. In fact, before the term "Mindfulness Based Stress Reduction (MBSR)" was introduced to describe interventions that implement Mindfulness in order to reduce stress, these interventions were explicitly called "Stress Reduction and Relaxation Programs" (e.g., [88]). Moreover, based on Buddhist scriptures that emphasize not only relaxation, but also warn against the hindrances of drowsiness and sleep during the practice [89, 90], Britton et al. [25] hypothesized that meditation would promote not only relaxation but also a state of tonic alertness. In line with this hypothesis, Britton et al. [25] reviewed over 20 studies that demonstrate that certain types of meditation, mostly from the Theravada and Mahayana traditions, can activate neural areas that are associated with tonic alertness. Their review incorporated mostly Mindfulness and Zen practices, but also a Vipassana and Shamatha meditation study, as well as studies on non-Tantric Tibetan practices that are different from Vajrayana (e.g., focusing on a single dot: Brefczynski-Lewis et al. [91]), and Loving-Kindness Meditation that is practiced in all Buddhist traditions and is not specific to Theravada, Mahayana or Vajrayana [65, 84]. Importantly, Britton et al. [25] reviewed studies that showed that Theravada and Mahayana types of meditation can activate the dACC, DLPFC, the anterior insula, the inferior parietal lobule, the thalamus, and the brain stem, which are areas that are implicated in tonic alertness [25, 63].

4.1. Relaxation Response during Theravada and Mahayana Meditation. Several studies have used physiological measures in order to demonstrate increased parasympathetic activation during Theravada and Mahayana types of meditation. An influential and highly cited study in this regard was conducted by Tang et al. [92], who compared two groups of participants without Mindfulness meditation experience who were randomly assigned to one of two experimental conditions: half the subjects were required to perform "integrative body-mind training (IBMT)," which incorporates aspects of Mindfulness training for 20 minutes during a 5-day period, and the other half underwent a form of relaxation training that involved squeezing and relaxing individual muscle groups. Tang et al. [92] measured HRV and GSR before, during, and after training in either meditation or relaxation and showed that the participants in the meditation group demonstrated significantly more parasympathetic activation and less sympathetic activation than the relaxation control. Specifically, the IBMT group demonstrated increases in HF and lower GSR relative to the relaxation control, leading the authors to conclude that the meditation group significantly increased the activity of the parasympathetic system and decreased the activity of the sympathetic system relative to the relaxation control. Similarly, Ditto et al. [93] recruited 32 experimental subjects without meditation experience who were randomly assigned to either a type of Mindfulness meditation that involved body scanning, a control condition during which subjects performed muscle relaxation exercises, or a waiting-list control group. The authors measured respiratory sinus arrhythmia (RSA) through a vagal tone monitor, which, as mentioned, is a measure of respiration that is synchronized to the HRV and generated by the parasympathetic nervous system. Ditto et al. [93] showed that RSA was increased for the participants who performed Mindfulness meditation relative to the control subjects, indicating that the parasympathetic system was activated during the meditation, and a relaxation response occurred. Similar findings were demonstrated by Krygier et al. [94], who observed increases in HF and decreases in LF/HF during Vipassana meditation relative to a rest baseline, for 36 participants who participated in a Vipassana retreat. Moreover, recent physiological measures that were obtained during Zen concentration meditation also demonstrated an increase in the activity of the parasympathetic system during this practice as well. For example, Wu and Lo [86] compared the EKG activity of a group of 10 experienced meditators (an average of 6 years of experience) who performed a type of meditation called "Zen Chakra," where practitioners concentrate on a "Chakra"—a nonphysical "energy point"—located inside the third ventricle of the human brain, to the EKG activity of a group of 10 participants without meditation experience. Wu and Lo [86] measured the EKG activity during 2 sessions, a 10-minute rest condition for both meditators and nonmeditators and a 20-minute condition of either meditation (for the meditators group) or rest (for the control group), and showed that the meditation resulted in an HF increase as well as decreased LF/HF relative to the nonmeditation control group. These results were interpreted to indicate that Zen Chakra meditation "appears to push the sympathovagal balance to parasympathetic dominance" [86]. In another study, Takahashi et al. [87] measured the EKG activity of 20 participants who were taught to perform Su-soku meditation, which is a Zen concentration practice that is performed by silently counting one's breaths, so that one inhales naturally and exhales when the numbers are recited. If other thoughts occur during the meditation, the participant is instructed to let them pass, and direct his or her attention back to the counting. As a control condition, participants were trained to breath at a rate of 0.25 Hz in tempo with the sound of a metronome, in order to account for the respiratory frequency influences on HRV. Takahashi et al. [87] measured the EKG activity during both the meditation and control condition and observed an increase in HF as well as a decrease in LF/HF, in the meditation relative to the control condition, which was interpreted to mean that the parasympathetic system was more active during the meditation relative to the control.

In addition, a multitude of studies have demonstrated that Mindfulness meditation can elicit a relaxation response using self-reports that are correlated with relaxation, and clinical stress reduction programs that implement Mindfulness meditation have been shown to reduce stress and increase relaxation even after 4 to 5 weeks of training [95, 96]. In one such study, Jain et al. [96] introduced a clinical intervention program that incorporated 5 sessions of Mindfulness meditation that was conducted in 4 sessions of 1.5 hours and an additional 6-hour session, over a period of 4 weeks. The participants who performed meditation were compared to participants in a "somatic relaxation (SR)" intervention that was performed over an identical time period and number of sessions, where they performed muscle relaxation techniques and breathing and imagery exercises, as well as to a waiting list control group. They found that the participants' ratings of psychological well-being significantly increased following the meditation intervention in comparison to SR, indicating an enhancement in positive emotional states and decreased stress. Similarly, in Mackenzie et al. [97], 30 participants were randomly assigned to a short 4-week Mindfulness meditation intervention or a waiting list control group, and they were instructed to practice meditation for at least 10 minutes a day, 5 days a week. The intervention and control participants completed a battery of questionnaires before and immediately after the 4-week training program that assesses the emotional and overall well-being. Mackenzie et al. [97] found that reported well-being, life satisfaction, and relaxation increased for the intervention group but remained stable for the control group, demonstrating increased relaxation as a consequence of Mindfulness meditation. Similar findings have been consistently reported dozens of times in previous research where Mindfulness meditation was typically practiced for an 8-week period (e.g., [10–12]), and the ability of Mindfulness meditation to alleviate stress, induce relaxation, and regulate anxiety is now a widely accepted phenomenon in scientific research as well as clinical contexts (e.g., [12, 98–101]).

Furthermore, several Yoga practices that emphasize relaxation techniques (e.g., Yoga Nidra), as well as concentration on a single object of meditation, such as the breath for a prolonged period of time (and are therefore similar to Theravada and Mahayana forms of meditation) also lead to increased relaxation and a reduction in stress. Just as in the case of Theravada and Mahayana types of meditation, the ability of these types of Yoga practices to induce relaxation and relieve stress has been found in previous studies and extensively discussed in the scientific literature [102–104].

4.2. Tonic Alertness during Theravada and Mahayana Meditation. As reviewed in Britton et al. [25], neuroimaging studies have shown that the activity in brain regions related to tonic awareness can be enhanced during Theravada and Mahayana types of meditation. As mentioned, tonic alertness is associated with neural activity in the dACC, DLPFC, the anterior insula, the inferior parietal lobule, the thalamus, and the brain stem [34, 63, 64]. In a study that demonstrated tonic alertness in both Vipassana and Shamatha, Manna et al. [105] measured the fMRI BOLD signal in 8 Theravada monks with an average of over 15000 hours of Shamatha and Vipassana meditation experience as well as in 8 novices with 10 days of meditation experience. Both groups of participants performed 3 experimental blocks inside the fMRI scanner, each of which began with a 3-minute rest condition and was followed by 6 minutes of Shamatha meditation where they focused on their breathing, and 6 minutes of Vipassana meditation. They found stronger BOLD activation in brain areas related to tonic alertness in highly experienced meditators (monks) that performed both Shamatha and Vipassana, and in novices that performed Vipassana meditation. Specifically, Manna et al. [105] found that when monks performed Shamatha, the fMRI BOLD signal in the left and right dACC, DLPFC, and anterior insula was stronger than during the rest control condition. Moreover, for the monks, Vipassana meditation led to an increased signal in the DLPFC area. On the other hand, for the novice meditators, Shamatha meditation did not show an increased BOLD signal that is related to tonic alertness, possibly due to insufficient expertise with this practice, but Vipassana meditation led to increased activation in the left dACC, indicative of enhanced tonic alertness.

Allen et al. [106] recruited 61 participants without any meditation experience, who were randomly assigned to either a 6-week Mindfulness meditation course, or a 6-week "active-control" condition that involved group readings and discussions. This control condition was hypothesized to "cultivate absorption and thought related processes into an imaginary narrative, in contrast to the present-centered and open-monitoring aspect of mindfulness" [106]. Allen et al. [106] found increased DLPFC activation in the meditation group relative to the control and also found that the amount of meditation practice positively correlated with the level of dACC activation that occurred during the meditation. As reviewed by Britton et al. [25], similar findings of increased activation in neural areas related to tonic alertness have been observed in additional studies on Vipassana (e.g., [107, 108]), Mindfulness (e.g., [109]), and Zen meditation (e.g., [110, 111]).

Additional evidence that Theravada types of meditation lead to tonic alertness was obtained by several recent studies that have shown that Mindfulness (e.g., [112, 113]) and Shamatha [114] types of meditation can lead to a decrease in the activity of neural structures that are more active during unfocused activity than during attention demanding tasks [115–117]. These areas include the ventral medial prefrontal cortex, posterior cingulate, inferior parietal lobule, and the dorsal medial prefrontal cortex, which have been collectively termed the brain's "default network" [118].

Furthermore, recent studies have investigated the influence of meditation on tonic alertness using behavioural tasks that are specifically designed to measure alerting attention. In Jha et al. [119], the authors utilized the "attentional network test" (ANT), where in each trial, participants are presented with an arrow target that is surrounded by distractor arrows that point in either the same direction (congruent flankers) or a different direction (incongruent flankers) as the target. Moreover, the target is preceded by one of three cue conditions: a valid cue, a spatially neutral central cue, a spatially neutral double cue, or a no cue condition. Importantly, the efficiency of alerting attentional processes is assessed by the ANT as the reaction-time (RT) difference between the double cue and the no cue conditions. Jha et al. [119] assessed changes in tonic alertness in 3 groups of participants: one group participated in an intensive Shamatha retreat for 30 minutes a day for 8 weeks. The second group practiced Shamatha for 30 minutes a day for 8 weeks, and a third group did not undergo any meditation training. They compared tonic alertness at the beginning of the study (Time-point 1) and following the intervention (retreat or meditation program: Time-point 2). Jha et al. [119] showed that although the efficiency of alerting attention did not differ at Time-point 1 between the three groups of participants, at Time-point 2, the alerting attentional mechanisms of participants who attended the retreat became significantly more efficient (the RT difference between the no cue and double cue conditions was reduced relative to Time-point 1), and the magnitude of the improvement in alerting attention was correlated with the meditation experience of the retreat participants. Moreover, the increase in alerting efficiency was driven by a decrease in RT to no cue trials and suggests that the meditators became more vigilant and their tonic alertness increased.

In MacLean et al. [120], the authors measured the influences of Shamatha meditation on tonic alertness using a sustained-attention task, where single lines were presented at the centre of the screen while participants fixated on a small yellow dot. The lines could be either long (90% of the time) or short (10% of the time), and the participants were required to respond to the short lines by pressing a response button. They recruited 29 participants [120] with an average experience of 2668 hours of meditation, who participated in a 3-month Shamatha meditation retreat that consisted of 5 hours of meditation training per day. The sustained attention test was administered before, at the midpoint, and after the meditation retreat. The nonparametric index of perceptual sensitivity, A', was calculated from the hit rates and false alarm rates for each of the 8 120-trial experimental blocks of the sustained attention task. Since the decline in A' was largest during the first 4 blocks, MacLean et al. [120] defined improvements in tonic alertness as positive changes in the slope of A' during the first four blocks. MacLean et al. [120] showed that the slope of A' was more positive at the midpoint and after the meditation retreat, in comparison to the pre-retreat baseline, demonstrating that Shamatha meditation reduced the decrement in A' that occurs during the sustained attention task and therefore increased tonic alertness. The authors interpreted their results to indicate that meditation training can "decrease resource demands and thus improve vigilance (tonic alertness)" [120].

Hence, the findings of studies that investigated tonic alertness through behavioural measures complement neuroimaging studies, and together they demonstrate that certain Theravada and Mahayana types of meditation can increase the activity in neural areas related to tonic alertness, which in turn leads to improvements on tasks that require tonic alertness. The recent findings of tonic alertness during Theravada and Mahayana meditation are important because they complement the picture portrayed by Buddhist scriptures, which describe meditation as a practice that generates both a relaxed and an alert state of mind [23, 26]. Moreover, our review is consistent with previous findings and reviews that consistently demonstrated a relaxation response during Theravada and Mahayana types of meditation [10–13].

5. Arousal and Phasic Alertness in Vajrayana Practices

As opposed to Theravada meditative practices, Vajrayana practice does not cultivate relaxation but an arousal response. Vajrayana Buddhist scriptures emphasize the realization of "self-existing wakefulness" or "an awake quality" of the mind and warn against excessive tranquility [84], in contrast to Theravada scriptures that emphasize quiescence and tranquility [67, pages 1287-1288 (IV.410)], as well as Mahayana meditation instructions that also emphasize calmness (e.g., [26], page 57). Furthermore, empirical evidence also suggests that arousal is generated during specific meditative practices. For instance, the generation of arousal during meditation has been observed in Hindu Tantric practices (e.g., [121, 122]) as well as in several Vajrayana practices (e.g., [27, 28]), although overall there have been far fewer studies on Vajrayana and Hindu Tantric practices than on Theravada and Mahayana.

Based on Theravada Buddhist scriptures that emphasize calmness and relaxation and Vajrayana scriptures that emphasize "wakefulness," Amihai and Kozhevnikov [27] hypothesized that Deity and Rig-pa practices of the Vajrayana tradition would generate cognitive and physiological responses of arousal, while Vipassana and Shamatha practices of the Theravada tradition would generate a relaxation response. In order to investigate the autonomic activation that is generated during these types of practices, Amihai and Kozhevnikov [27] compared the EKG activity of experienced Theravada and Vajrayana meditators (with 8 and 7.4 years of meditation experience, resp.) as they practiced meditation. The Theravada types of meditation that were investigated were Vipassana meditation and Kasina meditation, which is a visualization type of Shamatha meditation in which the meditator focuses his or her attention on "Kasina objects" that are described in the Pali Tipitaka and are typically colored disks. The Vajrayana practices studied were Deity and Rig-pa practices. In this study, the participants performed a 10-minute rest condition that was followed by Shamatha and Vipassana meditation (15 minutes each) for the Theravada meditators, and Deity and Rig-pa meditation (15 minutes each) for the Vajrayana meditators. Moreover, the participants' EKG activity was monitored throughout the experiment. Amihai and Kozhevnikov [27] showed that Theravada types of meditation elicited increased HF (Vipassana) and decreased LF/HF (both Vipassana and Kasina) relative to the rest control condition, which is consistent with a relaxation response. On the other hand, Vajrayana practices produced increased arousal, as indexed by decreased HF (both Deity and Rig-pa) during the meditation relative to the control condition. Moreover, Kozhevnikov et al. [29] and Amihai and Kozhevnikov [27] presented experienced Theravada (an average of 8–12.3 years of experience) and Vajrayana meditators (an average of 7.4–13 years of experience) with 2 visual tests (the Mental Rotation Test (MRT) and Visual Memory Test (VMT: [123]), see [29] for details), which were performed before and immediately following a 20-minute session of Theravada meditation (Vipassana and Kasina: Amihai and Kozhevnikov [27]) or Vajrayana practices (Deity: Kozhevnikov et al. [29] and Rig-pa: Amihai and Kozhevnikov [27]). As mentioned, the dramatic improvements on visual tasks immediately following a stimulus or activity are indicative of enhanced phasic alertness. Hence, the authors hypothesized that improved performance on the visual tests immediately after the meditation practice would indicate that phasic alertness occurred during the meditation and that such an improvement would be observed following Vajrayana practices. In line with this hypothesis, the experimental results showed that only Vajrayana practices led to a large and immediate increase in performance on these tasks, while Theravada meditators did not demonstrate any improvement in their performance following the practice. Hence, these studies demonstrate that Vajrayana practices and not Theravada types of meditation, lead to an arousal response and phasic alertness.

Additional studies that demonstrated that Vajrayana practices can increase the activity of the sympathetic system and generate an arousal response were conducted on practitioners of g-Tummo meditation, which, as mentioned, is associated with intense sensations of bodily heat in the spine. Interestingly, Benson himself reported a phenomenon that was unclear to him at the time, that two of the three g-Tummo practitioners that participated in his study exhibited an activation of the sympathetic system as evidenced by increased metabolism and oxygen consumption [124], which is consistent with arousal and not a relaxation response. Moreover, in Kozhevnikov et al. [28], it was demonstrated experimentally that g-Tummo meditation can indeed raise the temperature of the body, which indicates a sympathetic response. Nonshivering generation of body heat—thermogenesis—is mediated by the sympathetic nervous system [55, 56]. In humans, thermogenesis is caused mainly by brown adipose tissue, which shunts the energy obtained from the oxidation of free fatty acids into heat, which is then distributed throughout the body via the adipose tissue vasculature [56]. Importantly, brown adipose tissue activity in humans is stimulated by the sympathetic nervous system [55]. Specifically, an increased discharge from supraspinal sympathetic premotor pathways results in the sympathetic activation of brown adipose tissue, which leads to thermogenesis [56]. By attaching a small thermometer in the armpit of highly experienced g-Tummo meditators (6–32 years of experience), Kozhevnikov et al. [28] were able to demonstrate for the first time that g-Tummo meditators can increase not only their peripheral but, more importantly, core body temperature during the meditation, demonstrating that the activity of the sympathetic nervous system significantly increases as a consequence of this practice. Notably, the thermogenesis induced during g-Tummo was so substantial that it raised the body temperature of the meditators above the normal body temperature range and into the range of slight or moderate fever (up to 38.3°C), reflecting an enhanced arousal response due to sympathetic activation. It should be noted that increases in the peripheral body (meditators' fingers and toes) temperature during g-Tummo were also found in Benson et al. [125]; however, the authors did not attribute such changes to increased sympathetic activation. In contrast, Benson et al. [125] speculated that increased sympathetic activation during meditation is "unlikely," as it would be inconsistent with the parasympathetic activation that they observed in Theravada and TM types of meditation.

In addition to Vajrayana practices, several studies conducted on Hindu Tantric meditators demonstrated increased arousal. In an early but influential and often cited study, Corby et al. [121] recorded the GSR and heart rate during a Dharana type of meditation called Ananda Marga, which incorporates a focus on breathing while repeating a two-syllable word and ignoring external stimuli. They recruited 30 experienced Ananda Marga meditators (an average of 2.1 years and 3.1 hours of practice a day) as well as 10 subjects without meditation experience that served as controls. The GSR and heart rates were recorded during 3 experimental conditions: (1) a relaxation control; (2) an Ananda Marga meditation preparation condition, which involves paying attention to the breath while ignoring external stimuli; (3) Ananda Marga meditation, where the subjects were told to ignore external stimuli, pay attention to their breathing, and silently repeat a two-syllable word in phase with their breathing. In the control group, the participants chose their own word, while meditators used a personal mantra that they received from their meditation instructor. The results of Corby et al. [121] demonstrated that a state of arousal occurred during Ananda Marga meditation: (1) skin conductance (GSR) increased from the relaxation baseline to the meditation condition, but only for the meditators group; (2) a small heart rate increase was observed during the meditation condition relative to the baseline for the meditators group. Both of these measures indicated that sympathetic activation occurred during the meditation, demonstrating an arousal response.

Additionally, Telles and Desiraju [122] measured heart rate and GSR during a different type of meditation which requires concentration on a light source while contemplating a universal force. They recruited 18 experienced meditators (with an average of 10.1 years of experience) and compared the physiological measures obtained during meditation to those obtained by the same subjects during a control condition, which was similar to the meditation condition, but where random thinking was allowed and effortful concentration was not required. The findings of Telles and Desiraju [122] demonstrated that although there were no significant changes in GSR, an increase in heart rate occurred during the meditation condition, but not during the nonmeditation condition, relative to the baseline heart rate obtained prior to each condition. Hence, the findings of this study are indicative of increased sympathetic activation and an arousal response during this type of meditation.

To conclude this section, as opposed to Theravada and Mahayana types of meditation that demonstrate enhanced relaxation, investigations of Vajrayana and certain Hindu Tantric practices demonstrated increased arousal. This once again emphasizes the importance of philosophical and cultural influences on meditation and demonstrates that the term "meditation" is in many ways too general when used as a unified descriptor of all Buddhist and Hindu contemplative practices. These findings show that the supposition that "to understand the psychophysiological influences of meditation, it should first be conceptually denuded of its cultural and religious biases [9, page 2]" is highly misleading. The diametrically opposed findings, of relaxation in Theravada and Mahayana practices, and arousal in Vajrayana and Hindu Tantric practices point to the opposite conclusion. Namely, in order to understand the psychophysiological aspects of meditation, one needs to carefully examine its cultural and religious sources.

6. Conclusions and Future Directions

The aim of this review was to examine the scientific studies of meditation while focusing on the unique influences that different types of meditative traditions have on the activation of the autonomic system and attentional mechanisms. We have presented evidence, summarized in Table 1, which shows that Theravada and Mahayana types of meditation lead to increased parasympathetic activation that underlies a relaxation response, while Vajrayana and certain Hindu Tantric practices elicit enhanced sympathetic activation that underlies a robust arousal response. In addition, we outlined the cultural and philosophical motivations that have influenced these meditative practices. While Theravada and Mahayana scriptures emphasize that the purpose of meditation is to cultivate tranquility along with mental stability, Vajrayana scriptures describe practices whose purpose is to elicit states of enhanced arousal.

It is important to stress that the influences of Vajrayana and Hindu Tantric practices on physiology and behavior are only beginning to receive their due attention from the scientific community, and the long-term impact of Tantric practices is still not well understood. Hence, while it has been demonstrated that Vajrayana and Hindu Tantric practices can lead to immediate physiological changes that are coupled with improved cognitive performance, future studies should investigate the long-term cognitive and physiological changes that occur as a consequence of such practices. As previously mentioned, in contrast to Vajrayana and Hindu Tantric practices, many scientific studies have been conducted on Theravada or Mahayana types of meditation, and there is evidence that they can lead to long-term improvements on attentional tasks (e.g., [25, 120, 126]). It is thus prudent that

Table 1: Summary of meditation studies of autonomic activation and alerting attention.

Study	Meditation type	Findings
Tang et al. [92]	Mindfulness (IBMT)	Increased HF and decreased GSR
Ditto et al. [93]	Mindfulness	Increased RSA
Jain et al. [96]	Mindfulness	Increased perceived positive emotions and decreased perceived distress
Mackenzie et al. [97]	Mindfulness	Increased perceived well-being, life satisfaction, and relaxation
Wu and Lo [86]	Zen concentrative meditation	Increased HF and decreased LF/HF
Takahashi et al. [87]	Zen concentrative meditation	Increased HF and decreased LF/HF
Manna et al. [105]	Shamatha	Increased fMRI BOLD signal in the dorsal anterior cingulate cortex (dACC), dorsolateral prefrontal cortex (DLPFC), and anterior insula in meditation experts
Manna et al. [105]	Vipassana	Increased dACC activation in meditation novices
Allen et al. [106]	Mindfulness	Increased DLPFC and dACC activation
Jha et al. [119]	Shamatha	Increased alerting network efficiency
MacLean et al. [120]	Shamatha	Improvement in a sustained attention task
Amihai and Kozhevnikov [27]	Shamatha (Kasina visualization)	Decreased LF/HF
Amihai and Kozhevnikov [27]	Vipassana	Increased HF and decreased LF/HF
Amihai and Kozhevnikov [27]	Rig-pa (Vajrayana Tantric)	Decreased HF and increased performance in mental rotation (MRT) and visual memory (VMT)
Amihai and Kozhevnikov [27]	Deity (Vajrayana Tantric)	Decreased HF
Kozhevnikov et al. [29]	Deity (Vajrayana Tantric)	Increased MRT and VMT performance
Kozhevnikov et al. [28]	g-Tummo (Vajrayana Tantric)	Increased thermogenesis
Corby et al. [121]	Ananda Marga (Dharana)	Increased GSR and heart rate
Telles and Desiraju [122]	Hindu Tantric meditation	Increased heart rate

similar long-term studies would be conducted on Tantric practices.

Related to the above, another important research direction that has yet to be explored is the long-term influence of Vajrayana and Hindu Tantric meditation on stress and well-being. As mentioned, the finding that Theravada types of meditation produce relaxation has resulted in their incorporation into clinical practices as stress reduction techniques (e.g., [10, 21, 95, 96]). Conversely, the finding that Vajrayana and Hindu Tantric types of meditation produce arousal suggests that they could be more problematic for people who are under a high level of stress. However, it is also likely that as they gain additional meditation experience, Vajrayana and Hindu Tantric meditators develop unique strategies to help them cope with stressful situations that could arise during their meditation practice, for instance, by transforming their negative emotions into the positive emotional states of the visualized Deity. Such possibilities should be examined in future studies.

In addition, future studies should investigate the specific mechanisms that underlie ANS changes during meditation, in order to understand the precise factors that mediate the arousal and relaxation responses. One possible mediating factor could be respiration changes. In this context, previous studies on Hindu breathing exercises called Pranayama, which often serve as preparatory exercises for meditation [79, page 310], showed that specific breathing techniques can be used to activate the sympathetic or the parasympathetic nervous systems (e.g., [127]). A second factor that should be considered is the specific visualization or other content that is used for meditation. For instance, it is plausible that a visualized Tibetan Deity would lead to a high degree of arousal due to the emotional content that it holds in the eyes of a Tibetan meditator, while the inward and outward flow of the breath that is being attended to during Shamatha meditation would not evoke intense emotional reactions.

In conclusion, although the scientific examination of the nature of meditative practices is not new, it is only in recent years that cognitive scientists and neuroscientists have begun to investigate the influences of the specific cultural and philosophical contexts out of which meditation practices developed on the psychophysiological outcomes of the practices. Such investigations have led to experimental breakthroughs that corroborate ideas laid down in Buddhist scriptures about the purpose and effects of meditation. Specifically, the scriptural descriptions of heightened arousal during Vajrayana practices and a relaxed and alert state of mind during Theravada and Mahayana types of meditation received empirical support, as research from the past several years demonstrated that Vajrayana as well as certain Hindu Tantric practices lead to heightened arousal and phasic alertness, while Theravada and Mahayana types of meditation elicit a relaxation response coupled with enhanced tonic alertness.

Conflict of Interests

The authors declare that there is no conflict of interests regarding the publication of this paper.

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