Research Article

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Effects of mindfulness training on regulatory and academic abilities in preadolescents: Results from a pilot study

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Abstract: Regulatory abilities such as self-regulation and stress regulation are key predictors of essential developmental outcomes, including intellectual and socioemotional milestones as well as academic achievement. Preadolescence has been proposed as a period that is crucial for training these abilities. The present pilot study investigated the effects of mindfulness training on preadolescents‘ regulatory abilities and school-related outcomes. A group of 34 fifth graders received either mindfulness training (experimental group), Marburg Concentration Training (alternative treatment group), or no treatment (passive control group) and were monitored over a four-month intervention period. Regulatory abilities were assessed first, with two self-report questionnaires that operationalized impulsivity and coping with stress, respectively. Second, physical stress regulation was examined on the basis of diurnal cortisol as well as salivary α-amylase (sAA) profiles. Finally, school-related outcomes were measured with a paper-pencil based performance test of verbal memory. Results show that impulsivity increased in all groups over time, whereas there were no significant training effects on self-reported coping with stress. Both training groups showed more adaptive physiological stress regulation in terms of steeper diurnal cortisol slopes and marginally less pronounced sAA awakening responses, however, with respect to physiological measures, no data of the passive control group are available. With respect to school-related outcomes, the results indicate a slight superiority regarding verbal memory for the mindfulness training group compared to the Marburg Concentration Training group.

Keywords: mindfulness, Marburg Concentration Training, self-regulation, stress regulation, academic achievement, preadolescence

Introduction

The development of self-regulatory skills during childhood and adolescence is fundamental for achieving well-being and success, not only during youth, but also later in life. For instance, children's self-regulatory abilities help them to reach social and intellectual milestones such as conscience and prosocial behavior (Blair & Razza, 2007; Kochanska, 1997; Padilla-Walker & Christensen, 2011; Spinrad et al., 2006), and are essential predictors of physical health, substance dependence, criminal convictions and academic/occupational success (Clausen, 1995; Moffitt et al., 2011; Tangney, Baumeister, & Boone, 2004). Early and middle childhood has been proposed as a key period in the development of self-regulation (Berger, Kofman,

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Livneh, & Henik, 2007; Fjell et al., 2012; Marsh, Maia, & Peterson, 2009; Posner & Rothbart, 2009). While self-regulatory strategies employed by children are often relatively myopic and rigid (DeCicco, Solomon, & Dennis, 2012), the ability to employ complex, long-term strategies of self-regulation emerges during preadolescence (Rothbart, Sheese, Rueda, & Posner, 2011). On a neuronal level, this acquisition of complex intrinsic volitional methods of self-regulation is enabled by rapid maturational changes within the brain networks responsible for the control of attention and emotion (Berger et al., 2007; Posner et al., 2007). During these so-called "windows of plasticity", children are highly sensitive to environmental influences (Blair & Diamond, 2008) and hence susceptive to both detrimental and beneficial factors. For instance, growing up in a socially and emotionally deprived family environment can heighten stress reactivity (Blair, 2010; Fonagy & Target, 2002), which, in turn, can impair response inhibition (Evans & Kim, 2013) and thus increase the vulnerability for internalizing and externalizing psychopathological disorders (Blair & Raver, 2012; Davidson & McEwen, 2012; Gunnar & Fisher, 2006; Leve, Kim, & Pears, 2005). On the other hand, children who attend social and emotional learning programs during preadolescence show improved social and emotional skills and attitudes as well as a better academic performance (Durlak, Weissberg, Dymnicki, Taylor, & Schellinger, 2011).

The term self-regulation describes a set of skills that enhance goal-oriented behavior and adequate responses to mentally demanding stimuli through the effective control of cognition, emotion, and behavior (Fjell et al., 2012; Posner, Rothbart, Sheese, & Tang, 2007; Zelazo & Lyons, 2012). Executive functioning (EF) and emotion regulation are widely considered to be core components of self-regulation (e.g., Blair & Raver, 2015). Impulsivity, defined as "nonreflective stimulus-driven action when a later-rewarding goal-relevant response was also possible" (Nigg, 2017, p. 363), is a concept which has proven to be inversely linked with EF (Bickel, Jarmolowicz, Mueller, Gatchalian, & McClure, 2012; Fino et al., 2014; Romer, Betancourt, Brodsky, Giannetta, Yang, & Hurt, 2011), meaning that high impulsivity is usually a predictor of poor EF. Preventing impulsivity is of specific importance to youth, because adolescents show more impulsive behavior than any other age group (Leuker & van den Bos, 2016), with potential negative consequences such as being involved in car accidents (ibid.), risk behavior (Arce & Santisteban, 2006), gambling (Dussault, Brendgen, Vitaro, Wanner, & Tremblay 2011), and drug use (e.g., De Wit, 2009).

The construct of stress regulation is closely related to self-regulation, although both concepts have largely been investigated separately (De Ridder & De Wit, 2006). Stress regulation refers to behavioral, cognitive and physiological mechanisms that allow the individual to adapt to stressful situations where a discrepancy is perceived between situational demands and the psychosocial resources and competences available (McEwen, Gray, & Nasca, 2015; Ursin & Eriksen, 2004). We will use the term *coping* to refer to behavioral and cognitive stress regulation. On a physiological level, the hypothalamus-pituitary-adrenal (HPA) axis as well as the autonomic nervous system (ANS) regulate the adaptation to increased demands and enable the organism to maintain homeostasis under acute stress (Bellingrath & Kudielka, 2017; McEwen, Bowles, et al., 2015). Stress affects self-regulation in the following ways: On the one hand, high levels of physiological stress as indicated by cortisol, the main effector hormone released as a result of HPA axis activity as well as subjectively perceived stress impede EF on both the neuronal and behavioral levels (Orem, Petrac, & Bedwell, 2008; Stawski et al., 2011). Furthermore, failure to prevent resource depletion, a defining component of stress, can lead to self-regulatory failure (Heatherton & Wagner, 2011). Under conditions of chronic stress and self-regulatory failure, the originally adaptive physiological responses to stress can be disrupted. This may result, for example, in alterations in the diurnal secretion patterns of cortisol or in autonomic imbalance and associated adverse health effects, such as cardiovascular disease, diabetes, or depression (Backé, Seidler, Latza, Rossnagel, & Schumann, 2012; McEwen, 2007; Siegrist, 2013). Stress reduction and enhancement of well-being promote self-regulation in terms of EF (Williams, Suchy, & Rau, 2009). This effect seems to be even stronger when EF is promoted simultaneously, which suggests synergistic effects of stress reduction and improvement of EF (Diamond & Ling, 2016; Williams et al., 2009).

With respect to the impact of self-regulation on stress regulation, individuals with poor EF are assumed to be at risk for a trajectory of escalating difficulties in stress regulation, with the associated negative outcomes in mental and physical health (Williams et al., 2009). Higher EF, on the other hand, is associated with healthier daily cortisol profiles, probably due to an increase in skills that are useful in adapting to stressful situations and that temper immediate and prolonged reactions (Stawski et al., 2011). Thus, behaviors associated with successful self-regulation, such as healthy eating behavior (Baumeister & Heatherton, 1996) and health self-care (Gottfredson & Deary, 2004), can be assumed to protect the individual from the adverse health effects of chronic stress described above.

Taken together, there seems to be a positive reciprocal relation between stress regulation and self-regulation, such that successful stress regulation causes improvements in self-regulation and heightened self-regulation tends to support stress regulation, which results in decreased stress. Since both self-regulation and stress regulation are adaptive in nature and since both constructs appear to operate synergistically, we will use the term *regulatory abilities* to refer to both self-regulation and stress regulation (cf. Figure 1).

Looking at the range of benefits predicted by regulatory abilities, as outlined above, academic achievement is among the most important ones from the perspective of institutional education. Therefore, it is important to consider how self- and stress regulation are related to academic achievement with regard to the psychological processes involved: Achieving challenging goals – such as school success – requires both the willingness and the ability to work hard, which concerns EF as well as the ability to manage emotions associated with goal pursuit (Ivcevic & Brackett, 2014). For instance, the ability to suspend current personal preferences in terms of cognitive inhibition and/or delay of gratification is often necessary to conform to social expectations in the classroom (Wentzel, Weinberger, Ford, & Feldman, 1990). However, school success also requires the ability to regulate stress and emotions that are associated with social interactions and achievement-related experiences (Kaplan, Liu, & Kaplan 2005). Hence, school attainment can be understood as a challenging purpose which clearly benefits from self- and stress regulation. Instructional psychology typically accounts for the essential role of regulatory abilities using the term *self-regulated learning*, an "active, constructive process whereby students set goals for their learning and then attempt to monitor, regulate, and control their cognition, motivation and behavior, guided and constrained by their goals and the contextual features of their environment" (Pintrich, 2000, p. 453).

To sum up, enhancing regulatory skills in terms of self-regulatory abilities as well as stress management strategies during early and middle childhood appears to be conducive to an improvement of physical health and emotional as well as socio-economic outcomes, both during that period and later in life.

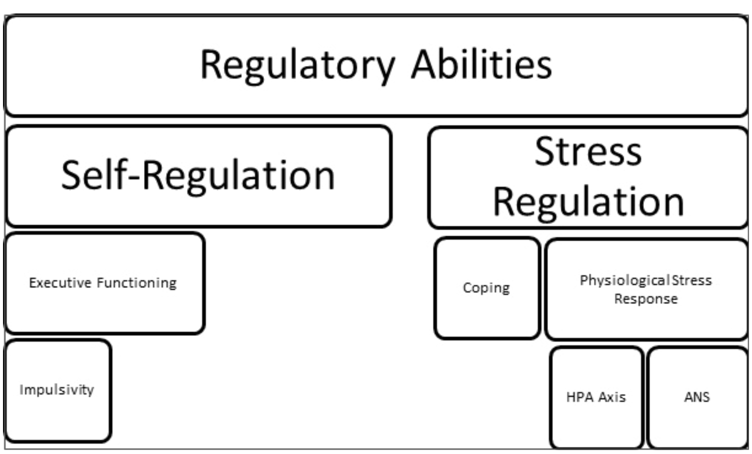

Figure 1. Hierarchical structure of regulatory abilities under investigation

Therefore, researchers as well as practitioners search for ways of promoting these valuable skills (e.g., Diamond & Ling, 2016). Over the last years, mindfulness-based programs have attracted considerable attention in this regard. Mindfulness is commonly defined as a state of "paying attention on purpose, in the present moment, and non-judgmentally to the unfolding of experience moment by moment" (Kabat-Zinn, 2003, p. 145). Mindfulness-based programs aim to foster this state by means of formal meditation practices and informal exercises which are to facilitate transfer to everyday life, as will be described below. In existing programs for preadolescents such as paws b (Mindfulness in Schools Project, 2015), MindUp

(Hawn Foundation, 2011), or the approach by Greenland (2010), exercises are typically practiced in multi-week group sessions and are sometimes assigned as additional homework. These approaches are generally assumed to promote a variety of self-regulatory skills such as EF, metacognitive awareness and emotion regulation, as well as stress regulation and its underlying physiology (Kaunhoven & Dorjee, 2017; Schonert-Reichl et al. 2015; Semple, Lee, Rosa, & Miller, 2010; Shapiro et al., 2015; Tang, Yang, Leve, & Harold, 2012). Learning skills and components of academic performance are not directly addressed in mindfulness-based programs, however the *School-Based Meditation Model* (Waters, Barsky, Ridd, & Allen, 2015) postulates a more indirect effect of mindfulness training in this regard, such that increased cognitive functioning and emotional regulation operate as mediators through which mindfulness- and meditation-based approaches positively influence student success.

A growing body of empirical studies, synthesized in two recent meta-analyses (Klingbeil et al., 2017; Maynard, Solis, Miller, & Brendel, 2017), investigated whether mindfulness-based programs indeed affect regulatory abilities and academic achievement in youth. Both meta-analyses examined measures related to regulatory abilities. Klingbeil et al. (2017) assessed metacognition and cognitive flexibility, emotional and behavioral regulation, attention as well as physical health. Maynard et al. (2017) concentrated on cognition, behavior and socioemotional results. Furthermore, school-related outcomes in terms of academic achievement/performance and school functioning were also included in both meta-analyses. Klingbeil and colleagues (2017) found Hedge's g effect sizes that ranged between .28 and .40 and reached significance for attention, physical health as well as emotional and behavioral regulation. Maynard et al. (2017) report small Hedge's g effect sizes ranging between .14 and .25, with significant effects for cognitive and socioemotional measures. With regard to school-related outcomes, effect sizes were small to medium and insignificant both in the study of Klingbeil et al. (2017; g's ranging from .32 to .39; k = 12 out of 76 synthesized studies), and in Maynard et al. (2017; g equals .27; k = 5 out of 35 synthesized studies). In a recent randomized controlled trial by Frank and colleagues (Frank, Kohler, Peal, & Bose, 2017), sixth and ninth graders received either a yoga- and mindfulness-based social-emotional wellness promotion program (N= 159) or treatment as usual, i.e., the normal school schedule. Students from the treatment group showed significant increases in emotion regulation, positive thinking, and cognitive restructuring in response to stress, but no changes in somatization and general affect. As for school-related outcomes, participation in the yoga- and mindfulness-based program was associated with significant reductions in unexcused absences, detentions, and with increases in school engagement, whereas no effects were found for suspensions and academic grades.

To sum up, initial evidence suggests that mindfulness-based programs are effective strategies to promote preadolescents' self-regulation. However, the existing studies suffer from methodological limitations, among them a lack of active control conditions (Kaunhoven & Dorjee, 2017; Zenner, Herrnleben-Kurz, & Walach, 2014) and a predominant operationalization of regulatory abilities in the form of questionnaires. This, however, does not cover the multi-faceted nature of regulatory abilities which comprise cognitive, behavioral and physiological processes. We therefore suggest a triangulating approach for investigating regulatory abilities which uses diverse methods of measurement.

The evidence regarding school-related outcomes, in comparison, does at present not support a significant impact of mindfulness training. However, the number of original studies investigating school-related outcomes is clearly below the amount of studies on regulatory abilities, which reduces the statistical power to detect existing effects. For instance, in the meta-analysis of Klingbeil and colleagues (2017), for physical health the effect size of $g = 0.28$ for controlled studies reached significance, whereas for academic achievement and school functioning the effect sizes of $g = 0.39$ for controlled studies, albeit indicating a stronger effect, failed to reach significance. This might go back to the lower number of original studies on academic achievement (5 controlled studies) than on physical health (14 controlled studies). Therefore, more studies need to be conducted before a conclusion regarding the influence of mindfulness training on school-related outcomes can be drawn.

Overview of the present study

The present paper presents non-overlapping additional data from a previously published pilot trial (Wimmer, Bellingrath, & von Stockhausen, 2016) that investigated effects on sustained attention, cognitive flexibility, cognitive inhibition, and data-driven information processing. Different from the earlier publication, it examines effects of mindfulness training on preadolescents' self- and stress regulation as well as school-related outcomes. The study used a partly randomized pre-post design including three groups: mindfulness training group, concentration training group (alternative treatment group), and passive control group (no intervention).

The alternative treatment group received the Marburg Concentration Training (MCT; Krowatschek, Krowatschek, & Reid, 2011; Krowatschek, Krowatschek, & Wingert, 2007), a behaviorally oriented training approach for improving self-regulation and coping skills that is widely used in the German-speaking area for improving concentration skills in school children (ibid.). Its efficacy has been shown by a couple of empirical studies (see below). Therefore, MCT seems to provide an ideal alternative treatment to mindfulness training.

Our sample consisted of fifth graders, novices to the training methods used, who attended a German "Gymnasium". In the German educational system, fifth grade is the first year of secondary school, with students between 10 and 11 years of age. Of the different types of secondary schools, Gymnasium is the one that prepares students for university entrance.

Self-regulation, stress regulation as well as school-related outcomes were assessed immediately before and after a four-month intervention period, following a multi-method approach. Measures related to regulatory abilities were first assessed with two self-report questionnaires that operationalized EF and coping with stress, respectively. Second, physical stress regulation was examined on the basis of diurnal cortisol as well as salivary α-amylase (sAA) profiles. Finally, school-related outcomes were measured with paper-pencil based performance tests of verbal memory and arithmetics.

Our prediction was that mindfulness-training with its practice of attention and emotion regulation as well as the concentration training based on behavioral techniques would yield improvements in regulatory abilities and school-related outcomes. Both intervention groups were expected to show better performance after the intervention than the control group without extra training. It was also hypothesized that effects on school-related outcomes would be mediated by improvements in regulatory abilities.

Materials and Methods

Ethical approval for the study was granted by the ethics committee of the University of Duisburg-Essen, Faculty of Engineering.

Participants

Due to the pilot character of the study and funding restrictions, the sample size was not determined by means of power analysis. Thus, a sample size of 34 children rather reflects practicability in terms of personnel and non-personnel costs, and availability of consenting students and parents. Two urban schools in North Rhine-Westphalia, Germany, were contacted via an invitation letter informing about the general aims and methods of the study. One school indicated interest to participate, hence two parallel classes from this school were selected for the study. Parents of these classes were informed about the training and were asked to consent to their children's participation in the research. Finally, 34 fifth graders (16 male and 18 female participants, mean age 10.80 years at the beginning of the training period, SD = 0.53) volunteered for the study. The children in the mindfulness and concentration training groups did not receive any rewards. As we were not able to offer training to the pupils in the passive control group after the post tests, the children in the passive control group received a book voucher worth € 25 after finishing the second series of assessments in exchange for their participation. Written informed consent was obtained from all parents and students.

Interventions

The first and the second author of this article led the interventions, while five tutors supported them when delivering the training to students. Three of the tutors were teacher trainees; two possessed an undergraduate or postgraduate degree in a pedagogic discipline. Since all tutors were unfamiliar to mindfulness before the project started, they received extensive training with regard to the theoretical concept, self-practice and teaching of mindfulness by the first and second author. The first author received formal MBSR training and had engaged in personal mindfulness meditation practice for one year before tutors received instruction. The second author had engaged in personal meditation practice in the Buddhist tradition for nine years before tutors were instructed. The first author was a PhD student in cognitive psychology and the second author was a professor of cognitive psychology at the time of instruction. Both had extensively studied the MCT manuals and research investigating its effectiveness. Fidelity of training delivery was ensured by the first or the second author attending the training sessions and by weekly team supervision sessions. During the supervision, written protocols and potential difficulties that came up in the previous training sessions were discussed. Furthermore, the program of the upcoming two sessions was finalized in detail and, if necessary, adapted. At least two instructors led each individual intervention session. The composition of teams changed after three sessions each, and instructors rotated across intervention groups so that instructor effects were minimized.

Mindfulness training

The mindfulness training was based on MBSR (Kabat-Zinn, 2005) and an adapted version for children by Greenland (2010).

One or two of the yoga exercises proposed by Kabat-Zinn (2005) were practiced at the beginning of each individual session. Next, a so-called informal exercise was performed. This kind of exercise draws attention to the relations between sensations, their evaluation, concurrent or resulting emotions and behavior and trains the re-orientation of attention from evaluations, emotions and behavioral impulses to mere sensations and acceptance. During the melting ice exercise (Greenland, 2010), for instance, children are holding an ice cube in their palms for as long as possible. Meanwhile, they observe the interplay between transient sensations, emotions, thoughts and behavioral tendencies without reflexively reacting to them, which is supposed to reduce impulsivity and to increase coping/stress regulation. After that, a formal meditation exercise (sitting meditation or bodyscan) followed. In sitting meditation the aim is to constantly focus on one's own breath while releasing upcoming thoughts or emotions. Meditators continuously observe their incoming and outflowing breath without interfering. The practice of maintaining awareness of the sensations connected with breathing is assumed to require as well as to foster *sustained attention* (Bishop et al., 2004). Sooner or later attention will inadvertently shift from the breath to other stimuli, such as emerging thoughts, emotions or bodily sensations unrelated to breathing. Due to self-monitoring, the source of distraction is supposed to be noted. The occurrence of mind wandering or arising emotions is accepted without judgment. The distracting stimuli are considered mere mental and passing events that are acknowledged as such, but not reflexively acted upon. This means that impulses of automatic responding and further elaborative processing are inhibited. Consequently, breathing meditation is assumed to support *cognitive inhibition* (ibid.) while reducing *impulsivity*, enhancing the ability to reduce dysfunctional uncontrolled mental processing such as mind wandering and rumination. Moreover, practicing an attitude of acceptance without responding to upcoming emotions is supposed to foster the *regulation of emotions and stress*. Once a distraction has been noticed, attention is disengaged from the distracting stimulus and shifted back to the object of interest. The practice of continuously re-directing attention to breath is assumed to promote attention switching or *cognitive flexibility* (ibid.). Whereas at the beginning of the intervention period, students practiced this exercise for three minutes, over the course of the training its duration was extended to ten minutes. When practicing the bodyscan, learners slowly guide their attention through the whole body, from the toes to the top of the skull. As the children appeared to be overwhelmed with an entire bodyscan, the exercise was split into a scan of the upper body and the lower body and these two were practiced alternately. These partial bodyscans were practiced for a duration between 5 and 15 minutes. The sessions were concluded with another informal exercise. Each lesson included a sitting meditation or a bodyscan, while all the other practices occurred only once or twice over the whole intervention period. The training took place twice a week, once for 60 minutes and once for 90 minutes, resulting in approximately 150 minutes of treatment per week. In order to ensure standardization, the children were not asked to practice at home. This was not explicitly monitored. However as children appeared to be clearly challenged by the exercises and no training materials (such as audio-taped instructions) were provided, it seemed highly unlikely that they would practice voluntarily, without the instruction to do so. Thus, we conclude that every child most likely had the same amount of training. Trainings were held during regular class time. The time slot of regular remedial teaching was used for one of the weekly sessions, the other one replaced an elective course. The exact training protocol is available from the authors upon request.

Concentration training

This intervention was based on MCT (Krowatschek et al., 2007, 2011). Here, principles from cognitive behavior therapy, observational learning through modeling, and instructional psychologoy are used in order to enhance self-regulation, autonomy, systematic problem solving and rational error treatment while decreasing impulsive behavior. Learning strategies, text comprehension, and memory are trained partly individually and partly in groups. MCT is complemented by relaxation exercises which are based on autogenous training and are supposed to foster stress reduction. In this approach, self-regulation is trained primarily via verbal self-instruction, which is to be acquired in five stages (cf. the method of self-instructional training; Meichenbaum, 1977). For example, a trainer serving as a role model performs a task and, while doing so, instructs herself or himself through speaking aloud. This behavior, i.e., task performance and self-instruction, is observed by children. In the second stage, children solve the same task while being instructed by the trainer. Third, children perform the task instructing themselves aloud, supported by the trainer. In the fourth stage, the learners again solve the task while instructing themselves, but only in a whisper. In the fifth and final stage, children perform the task while instructing themselves in inner speech. Verbalization is assumed to support the following components of learning (Schunk, 1986): focusing attention on important instead of irrelevant task features, coding and retention of information, and metacognitive monitoring. In addition, learners can indirectly receive the impression that they have acquired knowedge and skills, which leads to increased self-efficacy (Schunk, 1986). In contrast to mindfulness-based programs, Marburg Concentration Training explicitly addresses learning skills and components of academic performance, such as text comprehension or memory.

There is some empirical evidence that supports the effectiveness of MCT. Four studies were conducted: two randomized controlled trials (RCT) with an active control group (Dreisörner, 2004; Schäfer, 2011), one randomized waitlist-controlled trial (Krampen, 2008), and one study with a non-controlled within-group design (Hahnefeld & Heuschen, 2009). They investigated effects of MCT in children with attention problems, between six and 14 years of age. All studies found reductions in at least some ADHD symptoms after the training. To the best of our knowledge, there is as yet no study investigating the impact of MCT on stress regulation and school-related outcomes.

Following the authors' suggestion, each session was started off with a so-called dynamic exercise, a game that requires gross sensory motor skills and aims at reducing tension. This was followed by a relaxation exercise: The trainer read out a story with integrated elements of autogenous training. An exercise in verbal self-instruction such as "pattern continuation" or "picture matching" (see below) formed the next part of a session. In pattern continuation, learners are to continue a line pattern on a sheet of paper. In a picture matching task learners are presented with nine versions of one picture which differ in three features. Copies of these versions have to be assigned to the corresponding original. Self-regulated learning is promoted through self-instructions such as "What am I to do?", "I take one step after the other", "It is no problem if I make a mistake. I can still correct it", "I check whether I have done everything correctly". Self-praise is part of the self-instruction ("I did this well") and is supposed to reinforce consolidation of the strategy (Krowatschek et al., 2011) as well as confidence and perseverence when facing difficulties (Schunk, 1986).

Then, the students played a so-called Kim's Game which requires solving a task by focussing on one sensory channel. In the visual mode, for example, objects are to be located in a crowded picture, in the gustatory mode, samples of food have to be identified while being blindfolded. This was followed by another exercise in verbal self-instruction. The remaining time of a session was used for free play.

The training was based on the advanced exercises from the children's version of MCT (Krowatschek et al., 2011) and on the easier exercises from the adolescents' version (Krowatschek et al., 2007), as the present sample, in terms of age, was in between the target groups of both versions. The concentration training took place in time slots that paralleled the mindfulness training, i.e., twice a week, once for 60 minutes and once for 90 minutes, substituting regular remedial teaching and an elective course. The exact training protocol is available from the authors upon request.

Passive control group

To control for effects of maturation and schooling, we collected data on certain dependent measures in a control group that attended regular school lessons but did not receive any experimental treatment in addition to that. Specifically, EF, subjective stress regulation skills and school-related outcomes in terms of arithmetic were assessed in this group.

Materials

As a multi-method perspective on self-regulatory outcomes of mindfulness training and MCT was intended, the present study combined self-report questionnaires, psychophysiological indicators and paper-pencil based performance tests. A core aspect of EF was assessed on a more trait-like level in terms of dispositional impulsivity (see above, Introduction). Stress regulation was assessed, first in terms of subjectively implemented stress regulation strategies using a self-report questionnaire. Second, it was examined in terms of HPA axis activity using diurnal cortisol profiles, and third, in terms of sympathetic nervous system activity using diurnal profiles of sAA. School-related outcomes were operationalized with two paper-pencil based performance tests of verbal learning and memory, and arithmetic, respectively.

The materials also comprised six computer-based tests that assessed sustained attention, cognitive flexibility, cognitive inhibition, and data-driven information processing. The results were reported elsewhere (Wimmer et al., 2016), because they addressed a different research question.

Executive function in terms of impulsivity

To measure this fundamental aspect of EF we used the subscale impulsivity of the Inventory for Assessing Impulsivity, Risk Behavior and Empathy in 9- to 14-year-old children (IVE; Stadler, Janke, & Schmeck, 2004). This self-report questionnaire for children and adolescents is a German adaptation of Eysenck and Eysenck's (1980) impulsivity inventory 16. The 16-item subscale captures aspects of both cognitive and motivational impulsivity. Items are phrased as statements, such as "I often do and say something without having thought about it" ["Ich tue und sage oft etwas, ohne darüber nachgedacht zu haben"], which are to be agreed ("Yes") or disagreed ("No") with. The authors report internal consistency coefficients of $\alpha = .82$ for boys and $\alpha = .80$ for girls. High scores indicate a lack of foresight as to the consequences of one's actions, orientation towards immediately available positive consequences of one's actions and inadequate or little alignment to future goals as well as a fast and inaccurate working style. An enhancement of executive functioning would be indexed by a reduced impulsivity score.

Stress regulation

The subscale stress regulation strategies of the Inventory for Assessing Stress and Coping in Childhood and Adolescence (SSKJ 3-8; Lohaus, Eschenbeck, Kohlmann, & Klein-Heßling, 2006) was used as a subjective measure of stress regulation in terms of coping strategies. The self-report questionnaire covers the following stress regulation strategies: search for social support, problem-focused coping, avoidance-oriented coping (comprising behavioral and cognitive avoidance as well as cognitive reappraisal), constructive-palliative emotion regulation (introversive emotion-regulating activities), and destructive anger-related self-regulation (tension relief and extroversive activities of a rather destructive nature). First, two typical stress-evoking situations are described, namely homework and an argument with friends. The use of coping strategies is then assessed by having the child judge the frequency of six possible reactions per subscale on a five-point rating scale, ranging from "never", "rarely" and "sometimes" to "often" and "always", for each situation. An exemplary item is "If something like that happens to me, I tell someone from my family what was going on" ["... dann erzähle ich jemandem aus meiner Familie, was passiert ist."]. The sum scores of both situations are added to yield a composite score for each coping strategy. The manual reports retest-reliability coefficients between .56 und .82, coefficients of internal consistency range between .66 and .87. Improved stress regulation would be indicated by increased scores in search for social support, problem-focused coping, and constructive-palliative emotion regulation as well as decreased scores in avoidance-oriented coping and destructive anger-related self-regulation.

The activity of the HPA axis, as a physiological indicator of stress regulation, was examined with the help of diurnal cortisol profiles. Cortisol secretion typically follows a distinct circadian rhythm, with a marked increase (about 50-100%) during the first hour after morning awakening, the so called cortisol awakening response (CAR) in the majority of people (Wüst et al., 2000) and decreasing levels over the remaining day. This circadian rhythm is not only found in healthy adults, but also in school-aged children and adolescents (e.g., Pruessner et al., 1997; Shirtcliff & Essex, 2008). Children of the treatment groups were asked to collect saliva with salivettes (Sarstedt) on three consecutive days at pre-test and at two consecutive days at post-test. Sampling was to occur at the following five points of time: immediately after awakening, 30 minutes, 45 minutes and 60 minutes after awakening as well as at eight p.m. In order to avoid contamination of saliva, the children were instructed not to brush their teeth before saliva sampling. Furthermore, eating, and drinking beverages other than water were not allowed 60 minutes before saliva sampling. Participants reported their individual awakening times and the exact sampling times in a paper diary to check whether children followed these procedures. Multiple assessment days were necessary as diurnal cortisol secretion on a particular day has been shown to be influenced more by state factors than by trait-like influences (Almeida, Piazza, & Stawski, 2009; Hellhammer et al., 2007; Stalder, Evans, Hucklebridge, & Clow, 2010). For practical reasons, saliva cortisol samples could be collected only in the two training groups. Two indices representing HPA axis activity were calculated: The diurnal cortisol slope and the CAR. The diurnal slope represents the difference between the cortisol value at awakening and the cortisol value in the evening, divided by the mean number of waking hours (cf. Adam & Kumari, 2009). The CAR was calculated as a simple difference score: i.e., peak value (highest value of the following measurement points: 30, 45, 60 minutes after awakening) – awakening value (cf. Adam & Kumari, 2009). A steeper decline of the diurnal cortisol slope is typically associated with better psychosocial and physical health (Adam & Kumari, 2009), so that improved stress regulation would be indexed by an increased diurnal slope. Alterations in the CAR, which combines features of a reactivity index (response to awakening) with aspects of circadian regulation, are generally thought to occur in anticipation of demands of the upcoming day and thus depend on the daily burden (Fries, Dettenborn, & Kirschbaum, 2009; Stalder et al. 2016). Both heightened and blunted CARs have been found to be associated with psychosocial stress and poor health outcomes (Adam & Kumari, 2009.). Therefore, it is helpful to interpret the CAR in combination with further measures of self-regulation.

In addition, diurnal sAA levels, serving as a proxy for sympathetic activity and dysregulation of the ANS, were determined in the saliva samples as a second indicator of physiological stress regulation. SAA is one of the most important salivary enzymes. It is responsible primarily for the enzymatic digestion of carbohydrates (Granger, Kivlighan, El-Sheikh, Gordis, & Stroud, 2007) but is also involved in mucosal immunity by inhibiting bacterial growth in the oral cavity (Scannapieco, 1994). Diurnal secretory activity of sAA is characterized by a pronounced decrease during the first hour after awakening, followed by a steady increase during the rest of the day (Nater, Rohleder, Schlotz, Ehlert, & Kirschbaum, 2007). Daily sAA profiles have shown associations with chronic stress and stress reactivity, independent of free cortisol levels, such that increased stress levels correlate with higher overall sAA levels (ibid.). The diurnal sAA slope was determined analogously to the cortisol diurnal slope (cf. Adam & Kumari, 2009; please see above). The sAA awakening response was calculated as a simple difference score: value at 30 minutes after awakening – awakening value.

School-related outcomes

Verbal learning and memory were assessed by means of the VLMT (Verbaler Lern- und Merkfähigkeitstest, Test of verbal learning and memory; Helmstaedter, Lendt, & Lux, 2001). The test consists of a learning list and an interference list with 15 semantically unrelated words each, as well as a recognition list. The recognition list comprises all words from the learning and the interference list plus 20 additional words, ten of which are semantically and ten phonologically related to words from the learning or interference lists. VLMT can be applied with children and adults, starting from the age of six years. It is administered in individual sessions, with an auditory presentation of the material. During the acquisition phase, the learning list is presented five times in a row, with free recall after each round. This is followed by a single presentation and recall of the interference list. Next, the learning list is to be recalled without additional presentation. After a 30-minute interval, the recognition list is presented to the participants. After hearing each word they indicate whether it is old or new. Three parameters can be derived: data acquisition, consolidation in long-term memory, and recognition. All three parameters should improve if there is an increase in verbal memory between repeated assessments. The VLMT was administered in the mindfulness and the concentration training groups. Because the school was not able to allocate an alternative time slot, the relatively time consuming test sessions would have had to occur during regular class time (please see below, *Procedure*). Therefore the VLMT was not assessed in the passive control group.

Moreover, we measured mathematical competency with the help of RZD 2-6 (Rechenfertigkeits- und Zahlendiagnostikum; Test of arithmetic skills; Jacobs & Petermann, 2005). This test can be used with students from grade two to six and is conducted in individual sessions. RZD 2-6 comprises 18 subtests with increasing difficulty. Since the test aims at detecting students poor in arithmetic, we confined ourselves to two of the more difficult subtests which furthermore did not require high verbal skills. First, participants were to insert a missing operator or number in an otherwise complete equation (assessing flexibility in applying arithmetic rules). Second, participants were presented with two equations, one of which was already solved. They were asked to indicate whether the completed equation helped in solving the other one (assessment of arithmetic rule comprehension). The authors report internal consistency coefficients between .89 and .95, dependent on age groups and subtests involved.

Table 1 gives an overview of the concepts under investigation, of how the respective abilities are assumed to profit from mindfulness training and MCT, and of their operationalization in the present study.

Procedure

Sixteen participants were randomly assigned to the mindfulness intervention group (divided into two subgroups of eight students) and eight participants were assigned to the concentration training group. We decided to train two groups of eight pupils in mindfulness because in school settings this intervention is less established and less standardized than Marburg Concentration Training and may require a larger group size to reveal systematic effects, even if the methods of mindfulness training for adults have been carefully developed over the course of several decades and it has received relatively much scientific attention. Randomization was implemented by having each child from one class draw a lot that assigned them to one of the experimental conditions (mindfulness vs. concentration training). The mindfulness intervention group consisted of eight boys and eight girls, in the concentration training group there was one boy and seven girls. The passive control group with no intervention consisted of ten participants from the other (parallel) class, it comprised seven boys and three girls.

All pre-tests were run at the beginning of the school year. RZD 2-6 was administered at the experimental lab of the Language and Cognition Unit at the Psychology Department of the University of Duisburg-Essen. VLMT, IVE, and the Stress Regulation Strategies subscale from SSKJ 3-8 were administered in class during

Table 1. Overview of concepts under investigation, hypothesized impact of mindfulness training and MCT, and operationalization in the present study

Concept	Assumed to be trained by		Operationalization in present study
	Mindfulness training (formal meditation and informal practices)	**MCT (verbal self-instruction, relaxation)**	
Executive Functioning	Improved attention regulation in terms of sustained attention, attention switching and cognitive inhibition	Internalization of executive control through verbal self-instruction	Impulsivity (IVE)
Stress Regulation	Early perception and acceptance of emotions and stress without reflexively reacting to them	Promoting rational error treatment through verbal self-instruction, improved stress reduction through relaxation exercises based on autogenous training	Coping: Subjective stress regulation strategies (SSKJ 3-8; search for social support, problem-focused coping, constructive-palliative coping, destructive anger-related coping, avoidance-oriented coping) Physiological level in terms of HPA axis activity: diurnal cortisol profiles (awakening response, diurnal slope) Physiological level in terms of ANS activity: diurnal sAA profiles (awakening response, diurnal increase)
School-related Outcomes	Indirect enhancement of school-related outcomes by training abilities that are crucial to self-regulated learning	More direct training of learning strategies than in mindfulness training, although transfer is necessary to apply the strategies to actual school tasks	Verbal learning and memory (VLMT; acquisition, consolidation, recognition) Arithmetic (RZD 2-6; flexibility in applying arithmetic rules, arithmetic rule comprehension)

regular school time. The self-report questionnaires – same order for all participants – were filled out during the 30-minute break following the acquisition phase of VLMT. Saliva samples were collected at home. Interventions were commenced immediately after completion of pre-tests and lasted over the whole term; as a result, interventions comprised 25 training sessions spread over 18 weeks (interrupted by a two-week holiday towards the end of December). The mindfulness and concentration trainings were conducted twice a week, once for 60 minutes, once for 90 minutes, resulting in roughly 150 minutes of treatment each week. Trainings always took place within the frame of a regular school day. A team of at least two tutors instructed each group. Both the composition of the tutor teams and the assignment of teams to intervention groups were changed repeatedly to avoid examiner effects. Post-tests were conducted within two weeks after the end of the interventions.

Statistical analysis

First, we analyzed whether baseline differences could be observed between the two treatment groups and the passive control group with regard to the various outcome measures. One-way ANOVAs were conducted for dependent measures that were collected in all three groups (mindfulness, concentration training and passive control group), and independent t-tests were carried out for dependent measures that were collected in the two intervention groups only. Furthermore, we compared the groups with respect to differences in potential confounders such as age and sex. Also, Levene tests were applied that tested for homogeneity of variances at baseline. In order to approximate normal distribution, root mean square transformations were performed on the physiological indicators (CAR and diurnal slope) derived from cortisol and sAA values before statistical analysis.

Results revealed a baseline difference for IVE impulsivity, $F(2, 31) = 3.41$, $p = .046$. According to LSD post hoc tests, the passive control group was more impulsive than the mindfulness training group, $p = .014$, but no more impulsive than the concentration training group, $p = .51$. At baseline, groups also differed regarding the SSKJ subscale constructive-palliative coping, $F(2, 31) = 5.93$, $p = .007$. LSD post hoc tests revealed that the concentration training group scored lower than both the mindfulness training group, $p = .004$, and the passive control group, $p = .004$. There were no baseline differences for the remaining dependent measures (p's > .11) and for age ($p > .09$). Sex did not differ between both intervention groups, $p = .074$, it did however differ when all 3 groups were compared, $\chi^2(2) = 6.00$, $p = .050$. There were no main effects of age or sex, nor interactions of time with age or of time with sex for physiological measures (p's > .095). Levene-Tests at baseline were insignificant (p's > .093) for all measures except sAA awakening response, $p = .048$, so that analysis of variance seemed a reasonable strategy for analyses.

Hence, in subsequent mixed factorial ANOVAs the within subjects factor time and the between subjects factor group were included in all analyses. For dependent measures that were collected in all three groups sex was added as an additional between subjects factor to control for potential confounding effects. To correct for multiple comparisons, the Benjamini-Hochberg procedure (Hochberg and Benjamini, 1990) was applied (false discovery rate $q = .25$) in case of at least one significant main effect or interaction in the following subgroups of dependent measures: subjective stress regulation (six subscales), physiological stress regulation (four parameters), school-related outcomes in terms of VLMT (three subscales; results for the RZD 2-6 are not included due to low reliability, as elucidated below). No correction was applied for executive function, since this construct was operationalized via a single scale only.

Significance level was set as $p < .05$. Significant interactions, and, for exploratory reasons only, marginally significant interactions, where $.05 < p < .10$, were followed up with pairwise t-tests. Effect sizes are reported for significant pairwise comparisons.

All participants underwent both pre- and posttests, meaning that there was no drop out. Yet one participant from the mindfulness training group did not provide useable saliva samples at posttest, so that this participant had to be excluded from analyses of the saliva-based indicators of cortisol and sAA. In addition, there were missing data for the SSKJ only. A total of 12 missing values were imputed with the individual mean on the respective subscale at the corresponding time point. A maximum of one value per time point and participant was imputed.

Descriptive statistics and reliability coefficients for dependent measures are displayed in Table 2, Table 3 shows bivariate correlations for dependent measures and age. Datasets are available from the authors upon request.

Table 2. Descriptive statistics and internal consistency of dependent variables by measures, treatment groups, and times of testing. T1: pre-test; T2: post-test

Measure	Condition	T1		T2	
		M (SD)	*Cronbach's α*	*M (SD)*	*Cronbach's α*
IVE - impulsivity	Mindfulness training	3.56 (2.22)	.712	5.88 (2.99)	.712
	Concentration training	4.38 (2.50)		7.00 (4.54)	
	No intervention	6.50 (3.75)		7.40 (3.20)	
SSKJ 3-8 - search for social support	Mindfulness training	33.63 (8.21)	.796	32.75 (9.52)	.806
	Concentration training	33.75 (10.53)		30.75 (7.78)	
	No intervention	34.90 (9.42)		36.10 (9.68)	
SSKJ 3-8 - problem-focused coping	Mindfulness training	48.19 (6.92)	.713	48.56 (7.92)	.864
	Concentration training	42.38 (4.69)		45.63 (11.35)	
	No intervention	47.90 (7.19)		43.00 (12.39)	
SSKJ 3-8 - constructive-palliative coping	Mindfulness training	35.00 (7.23)	.863	37.44 (10.18)	.864
	Concentration training	24.00 (6.23)		30.50 (8.43)	
	No intervention	35.90 (10.62)		32.80 (10.60)	
SSKJ 3-8 - destructive anger-related coping	Mindfulness training	16.88 (6.62)	.828	19.06 (7.51)	.891
	Concentration training	22.88 (11.08)		24.75 (15.16)	
	No intervention	18.70 (6.00)		19.40 (7.23)	

Measure	Condition	T1		T2	
		M (SD)	*Cronbach's α*	*M (SD)*	*Cronbach's α*
SSKJ 3-8 - avoidance oriented coping	Mindfulness training	24.94 (5.56)	.587	25.88 (6.34)	.770
	Concentration training	23.38 (4.17)		20.50 (6.89)	
	No intervention	27.00 (7.33)		24.78 (7.95)	
VLMT - acquisition	Mindfulness training	50.75 (8.48)	N/A	62.13 (6.10)	N/A
	Concentration training	48.25 (4.71)		60.75 (9.62)	
VLMT - consolidation	Mindfulness training	1.06 (1.81)	N/A	0.13 (1.36)	N/A
	Concentration training	.38 (1.41)		1.13 (1.81)	
VLMT - recognition	Mindfulness training	13.25 (2.54)	N/A	13.94 (1.69)	N/A
	Concentration training	14.00 (0.93)		13.63 (3.11)	
RZD 2-6 - flexibility in applying arithmetic rules	Mindfulness training	2.87 (0.24)	.478	2.92 (0.18)	.507
	Concentration training	2.94 (0.12)		2.89 (0.17)	
	No intervention	2.96 (0.14)		3.00 (0.00)	
RZD 2-6 - arithmetic rule comprehension	Mindfulness training	6.13 (1.03)	.302	6.75 (0.58)	.015
	Concentration training	6.50 (0.93)		6.38 (1.60)	
	No intervention	6.20 (1.32)		7.00 (0.47)	
CAR	Mindfulness training	0.52 (0.66)	N/A	0.69 (0.85)	N/A
	Concentration training	0.57 (0.65)		0.97 (0.87)	
Cortisol diurnal slope	Mindfulness training	0.12 (0.04)	N/A	0.16 (0.03)	N/A
	Concentration training	0.13 (0.06)		0.16 (0.03)	
sAA awakening response	Mindfulness training	0.59 (1.52)	N/A	-0.48 (3.21)	N/A
	Concentration training	0.08 (3.56)		-1.45 (2.44)	
sAA diurnal increase	Mindfulness training	0.00 (0.15)	N/A	-0.12 (0.21)	N/A
	Concentration training	0.00 (0.15)		-0.02 (0.14)	

Results

Executive function in terms of impulsivity

Executive function was investigated in terms of the IVE impulsivity score. There was a marginally significant main effect of time suggesting a general increase of impulsivity over time, $F(1, 28) = 3.69$, $p = .065$, which was qualified by an interaction of time with sex, $F(1, 28) = 9.90$, $p = .004$, with males insignificantly increasing impulsivity from $M = 5.75$ at pretest to $M = 6.38$ at posttest, $t(15)= -0.89$, $p = .39$, and females significantly increasing impulsivity from $M = 3.61$ at pretest to $M = 6.89$ at posttest, $t(17)= -5.22$, $p < .0001$, $d = -0.83$; the remaining effects, among them the interaction of group with time, did not reach significance (*p*'s > .15).

Subjective stress regulation

The SSKJ 3-8 subscale Stress Regulation Strategies served as subjective measure of stress regulation in terms of coping strategies. The analysis did not reveal any significant main effects or interactions for search for social support, *p*'s > .26, destructive anger-related coping, *p*'s > .31, and avoidance-oriented coping, *p*'s> .21. For problem-focused coping there was a marginally significant interaction of group with sex, $F(2, 28) = 2.71$, $p = .084$. However, due to the imbalanced distribution of boys and girls in the three groups, this tendency will not be further interpreted. The remaining main effects and interactions failed to reach significance, *p*'s > .53. Regarding constructive-palliative coping, the analysis revealed a marginally significant interaction of group with time, $F(2, 28) = 2.88$, $p = .073$. There was a significant increase in the concentration group only, $t(7) = -2.61$, $p =.04$, but not in the mindfulness training and passive control group, *p*'s > .21 (other *p*'s > .39).

Physiological stress regulation

CAR and diurnal slope were the parameters derived to assess HPA axis activity. The ANOVA failed to reveal any main effects or interactions for CAR, *p*'s > .10. With respect to the diurnal slope, the analyses yielded

Table 3. Bivariate correlations of dependent measures and age

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26
1 Age																										
2 t1 IVE Imp	-.061																									
3 t2 IVE Imp	-.029	**.585**																								
4 t1 SSKJ Social	-.047	.088	.023																							
5 t2 SSKJ Social	-.280	.024	-.137	**.841**																						
6 t1 SSKJ Probl	-.058	*-.179*	*-.425*	.235	.214																					
7 t2 SSKJ Probl	.109	**-.596**	**-.723**	.091	.114	**.438**																				
8 t1 SSKJ Constr	.004	*.373*	.193	.130	.082	.307	-.324																			
9 t2 SSKJ Constr	.142	.087	-.061	.040	.046	.126	-.179	.649																		
10 t1 SSKJ Destr	.019	*.368*	**.569**	.315	.264	*-.424*	-.299	-.160	-.187																	
11 t2 SSKJ Destr	.100	.273	**.666**	.143	.076	*-.427*	*-.433*	-.048	-.005	**.841**																
12 t1 SSKJ Avoid	.130	**.448**	.215	.083	.043	-.062	-.248	*.386*	.173	.180	.149															
13 t2 SSKJ Avoid	.229	.254	.277	*.346*	.224	.041	-.123	*.375*	**.452**	.317	*.370*	**.485**														
14 t1 VLMT Acq	.008	.142	-.294	.055	.236	.021	.122	.184	.389.	-.080	-.271	-.124	.023													
15 t2 VLMT Acq	.111	.194	-.167	.306	.175	.003	.024	.265	.385	-.028	-.180	.033	.174	**.596**												
16 t1 VLMT Cons	-.124	-.232	-.315	-.030	.068	.172	.044	.358	-.014	-.226	-.189	.039	-.227	-.352	-.299											
17 t2 VLMT Cons	-.074	.204	.010	.344	.211	-.061	-.137	.033	.102	.144	.098	-.102	.118	-.211	.141	.262										
18 t1 VLMT Rec	-.109	.229	-.006	.023	.000	-.204	.098	*-.454*	-.252	.029	-.088	-.302	-.191	*.409*	.323	**-.565**	-.097									
19 t2 VLMT Rec	.024	.011	-.388	*.414*	.311	.152	*.437*	-.080	-.040	-.343	*-.501*	-.098	-.157	.303	**.524**	-.149	.112	**.562**								
20 t1 CAR	.128	-.006	.296	.351	.135	-.390	-.142	-.148	*-.454*	.287	.272	.029	.077	-.253	-.033	-.005	.052	.054	-.013							
21 t2 CAR	.253	-.109	-.028	.168	.069	-.062	.249	-.166	-.286	-.005	-.118	.077	.124	-.117	.028	-.116	-.149	.113	.239	*.475*						
22 t1 Cort Slope	-.150	-.230	*-.451*	.135	.271	.126	.351	-.241	-.303	-.271	*-.484*	-.163	*-.454*	.056	-.033	.198	.053	.019	*.475*	-.169	.193					
23 t2 Cort Slope	.013	-.087	.074	.105	.204	.121	-.160	.117	.024	-.030	.105	-.213	-.119	-.062	-.405	.243	.166	-.233	-.166	-.140	**-.575**	.209				
24 t1 sAA AWR	.139	.297	*.492*	-.077	-.316	-.120	-.337	.224	-.143	.142	.238	.356	.395	-.226	.051	-.195	.055	-.014	-.146	*.464*	.320	-.313	-.233			
25 t2 sAA AWR	-.260	.390	.126	.322	.280	.258	-.245	.294	.273.	.033	.091	.076	.323	.017	-.050	-.183	.124	.013	.024	-.088	-.190	-.079	.239	.282		
26 t1 sAA Inc	.081	-.129	-.248	.262	.167	.100	.122	.165	.292	-.056	-.004	-.171	-.016	.002	-.044	.236	.114	-.188	-.049	.120	-.339	-.044	*.486*	-.355	.221	
27 t2 sAA Inc	.052	-.296	.003	-.254	-.261	-.173	-.056	-.190	.038	-.090	-.006	*-.469*	-.309	.178	.101	.019	-.003	-.195	-.091	-.053	-.208	-.230	.066	-.313	**-.645**	.122

t1 pre-test; *t2* post-test; *IVE Imp* Inventory for Assessing Impulsivity, Risk Behavior and Empathy in 9- to 14-year-old children, impulsivity scale; *SSKJ* Inventory for Assessing Stress and Coping in Childhood and Adolescence, *Social* search for social support scale, *Probl* problem-focused coping scale, *Avoid* avoidance-oriented coping scale, *Constr* constructive-palliative emotion regulation scale, *Destr* destructive anger-related self-regulation scale; *CAR* Cortisol Awakening Response; *Cort Slope* Cortisol diurnal slope; *sAA AWR* salivary α-amylase awakening response, *Inc* diurnal increase; *VLMT* Test of verbal learning and memory, *Acq* Acquisition component, *Cons* Consolidation component, *Rec* Recognition component; bold script indicates $p \leq .01$; italic script indicates $p \leq .05$

a main effect of time, $F(1, 21) = 9.41$, $p = .006$, $d = 0.93$, in the form of a general increase between pre- and post-test across both groups (cf. Figure 2). Significance persisted after correction for multiple comparisons. The remaining main effects and interactions did not reach significance (p's > .47).

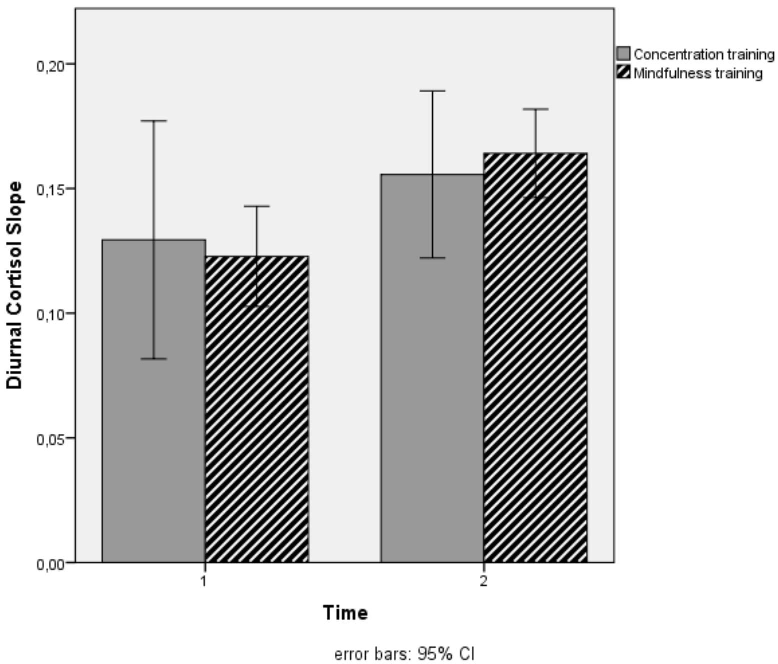

Figure 2. Development of diurnal cortisol slope from pre- to post-test for both intervention groups

SAA awakening response and diurnal slope were the parameters derived to assess the activity of the sympathetic nervous system. There was a marginal main effect of time for sAA awakening response in terms of a general decrease, $F(1, 21) = 3.28$, $p = .084$, but no significant main effects or interactions, p's > .43. There were no significant main effects or interactions for the diurnal slope either, p's > .15.

School-related outcomes

School-related outcomes were examined in terms of verbal memory (VLMT) and arithmetic skills (RZD 2-6). With regard to the acquisition indicator of VLMT, analyses revealed a main effect of time $F(1, 22) = 67.17$, $p < .0001$, $d = 2.42$ (other p's > .50) that remained significant after correction for multiple comparison and indicated a general improvement across both groups between pre- and post-test. As for the consolidation component of VLMT, the ANOVA revealed a significant interaction of time with group, $F(1, 22) = 4.49$, $p = .046$, which persisted after correction for multiple comparisons (other p's > .78). The mindfulness training group tended to improve performance between pre- and post-test, $t(15) = 1.83$, $p = .09$, whereas the concentration training group showed constant performance, $t(7) = -1.66$, $p = .14$. Concerning the recognition component of VLMT, there were no significant main effects or interactions (p's > .23).

As to the RZD 2-6, reliability in the current sample ranged clearly below the values reported in the manual (cf. Table 2). Since these outcomes do not suggest reliable assessment of mathematical competency by means of the RZD 2-6 in the children participating in this trial, interpreting these test scores does not seem warranted. Hence, the results are not reported here, but are available from the authors upon request.

Mediation analyses

Mediations were calculated to test whether a potential relationship between training of regulatory abilities (via mindfulness training or MCT) and school-related outcomes was mediated by regulatory abilities. Analyses were carried out for all indicators of regulatory and school-related abilities, even if there was no direct association between predictor and outcome, since a direct effect is no longer considered a necessary condition of an indirect effect (e.g., Hayes, 2009). Mediation models with corresponding regression coefficients are shown in Table 4. Because all 95% confidence intervals of the indirect effect of training on any observed school-related outcome through any assessed regulatory ability contained zero, there was no evidence that the effect of the training programs on school-related outcomes was mediated by regulatory abilities.

Table 4. Models of training of regulatory abilities (via mindfulness training or Marburg Concentration training) as predictor of school-related outcomes, mediated by regulatory abilities. For mediator and outcome variables change scores, i.e., the difference of posttest – pretest each, were used. The confidence interval for the indirect effect is a bootstrapped CI based on 5000 samples.

Mediator	Outcome	*a*[1]	*b*[2]	Direct effect[3]	Indirect effect[4]
IVE Imp	VLMT Acq	*b* = -2.13, *p* = .29	*b* = 0.30, *p* = .36	*b* = -0.49, *p* = .87	*b* = -0.63, 95% CI [-2.36, 1.49]
SSKJ Social		*b* = 2.13, *p* = .31	*b* = -0.90, *p* = .001	*b* = 0.80, *p* = .74	*b* = -1.92, 95% CI [-6.48, 1.64]
SSKJ Probl		*b* = -2.88, *p* = .46	*b* = -0.09, *p* = .61	*b* = -1.37, *p* = .65	*b* = 0.25, 95% CI [-0.67, 2.46]
SSKJ Constr		*b* = -4.06, *p* = .23	*b* = -0.13, *p* = .49	*b* = -1.67, *p* = .59	*b* = 0.54, 95% CI [-1.56, 4.52]
SSKJ Destr		*b* = 0.31, *p* = .88	*b* = 0.20, *p* = .52	*b* = -1.19, *p* = .69	*b* = 0.06, 95% CI [-1.58, 2.63]
SSKJ Avoid		*b* = 3.81, *p* = .21	*b* = 0.06, *p* = .79	*b* = -1.35, *p* = .67	*b* = 0.22, 95% CI [-3.11, 2.14]
CAR		*b* = -0.24, *p* = .49	*b* = -0.21, *p* = .92	*b* = -1.28, *p* = .69	*b* = 0.05, 95% CI [-1.77, 1.95]
Cort Slope		*b* = 0.02, *p* = .48	*b* = -20.75, *p* = .49	*b* = -0.90, *p* = .77	*b* = -0.33, 95% CI [-1.59, 2.08]
sAA AWR		*b* = 0.46, *p* = .75	*b* = -0.61, *p* = .19	*b* = -.0.95, *p* = .75	*b* = -0.28, 95% CI [-3.57, 1.49]
sAA Inc		*b* = -0.10, *p* = .33	*b* = -1.62, *p* = .82	*b* = -1.40, *p* = .66	*b* = 0.16, 95% CI [-1.04, 1.52]
IVE Imp	VLMT Con	*b* = -2.13, *p* = .29	*b* = 0.11, *p* = .23	*b* = -1.46, *p* = .08	*b* = -0.23, 95% CI [-0.70, 0.41]
SSKJ Social		*b* = 2.13, *p* = .31	*b* = -0.11, *p* = .18	*b* = -1.45, *p* = .08	*b* = -0.24, 95% CI [-0.84, 0.28]
SSKJ Probl		*b* = -2.88, *p* = .46	*b* = -0.02, *p* = .74	*b* = -1.73, *p* = .05	*b* = 0.04, 95% CI [-0.43, 0.52]
SSKJ Constr		*b* = -4.06, *p* = .23	*b* = -1.69, *p* = .05	*b* = -1.32, *p* = .11	*b* = -0.36, 95% CI [-1.16, 0.37]
SSKJ Destr		*b* = 0.31, *p* = .88	*b* = 0.00, *p* = .97	*b* = -1.69, *p* = .05	*b* = 0.00, 95% CI [-0.27, 0.56]
SSKJ Avoid		*b* = 3.81, *p* = .21	*b* = 0.15, *p* = .007	*b* = 2.25, *p* = .005	*b* = 0.56, 95% CI [-0.25, 1.64]
CAR		*b* = -0.24, *p* = .49	*b* = -0.55, *p* = .30	*b* = -1.68, *p* = .05	*b* = 0.13, 95% CI [-0.34, 0.74]
Cort Slope		*b* = 0.02, *p* = .48	*b* = 4.24, *p* = .60	*b* = -1.62, *p* = .06	*b* = 0.07, 95% CI [-0.23, 0.90]
sAA AWR		*b* = 0.46, *p* = .75	*b* = 0.06, *p* = .63	*b* = -1.58, *p* = .07	*b* = 0.03, 95% CI [-0.70, 0.29]
sAA Inc		*b* = -0.10, *p* = .33	*b* = -0.77, *p* = .67	*b* = -1.63, *p* = .07	*b* = 0.08, 95% CI [-0.65, 0.47]
IVE Imp	VLMT Rec	*b* = -2.13, *p* = .29	*b* = -0.05, *p* = .62	*b* = 0.96, *p* = .30	*b* = 0.10, 95% CI [-0.36, 0.96]
SSKJ Social		*b* = 2.13, *p* = .31	*b* = -0.09, *p* = .30	*b* = 1.26, *p* = .17	*b* = -0.20, 95% CI [-0.86, 0.31]
SSKJ Probl		*b* = -2.88, *p* = .46	*b* = 0.03, *p* = .54	*b* = 1.15, *p* = .21	*b* = -0.09, 95% CI [-0.68, 0.73]
SSKJ Constr		*b* = -4.06, *p* = .23	*b* = -0.02, *p* = .67	*b* = 0.96, *p* = .31	*b* = 0.10, 95% CI [-1.08, 0.64]
SSKJ Destr		*b* = 0.31, *p* = .88	*b* = -0.13, *p* = .15	*b* = 1.10, *p* = .21	*b* = -0.04, 95% CI [-0.60, 0.83]
SSKJ Avoid		*b* = 3.81, *p* = .21	*b* = -0.06, *p* = .35	*b* = 1.30, *p* = .17	*b* = -0.23, 95% CI [-1.20, 0.14]
CAR		*b* = -0.24, *p* = .49	*b* = 0.67, *p* = .26	*b* = 1.27, *p* = .18	*b* = -0.16, 95% CI [-0.83, 0.46]
Cort Slope		*b* = 0.02, *p* = .48	*b* = -18.46, *p* = .03	*b* = 1.40, *p* = .11	*b* = -0.30, 95% CI [-0.99, 0.86]
sAA AWR		*b* = 0.46, *p* = .75	*b* = 0.06, *p* = .66	*b* = 1.08, *p* = .25	*b* = 0.03, 95% CI [-0.48, 0.53]
sAA Inc		*b* = -0.10, *p* = .33	*b* = -2.93, *p* = .14	*b* = 0.82, *p* = .37	*b* = 0.29, 95% CI [-0.23, 1.08]

[1]path from predictor to mediator, [2]path from mediator to outcome, [3]direct effect (*c*') of predictor on outcome, [4]indirect effect of predictor on outcome through predictor (*ab*); *IVE Imp* Inventory for Assessing Impulsivity, Risk Behavior and Empathy in 9- to 14-year-old children, impulsivity scale; *SSKJ* Inventory for Assessing Stress and Coping in Childhood and Adolescence, *Social* search for social support scale, *Probl* problem-focused coping scale, *Constr* constructive-palliative emotion regulation scale, *Destr* destructive anger-related self-regulation scale, *Avoid* avoidance-oriented coping scale; *CAR* Cortisol Awakening Response; *Cort Slope* Cortisol diurnal slope; *sAA AWR* salivary α-amylase awakening response, *Inc* diurnal increase; *VLMT* Test of verbal learning and memory, *Acq* Acquisition component, *Cons* Consolidation component, *Rec* Recognition component

Discussion

The present research examined regulatory abilities in terms of self- and stress regulation as adaptive processes that operate synergistically. Regulatory abilities during childhood have proven to benefit a range of developmental outcomes, including social and intellectual competencies, health and academic success (Blair & Razza, 2007; Clausen, 1995; Kochanska, 1997; Moffitt et al., 2011; Padilla-Walker & Christensen, 2011; Spinrad et al., 2006; Tangney et al., 2004). Preadolescence has been identified as a crucial period for the development of self-regulation, i.e., as a life phase where the training of regulatory abilities appears to be particularly effective and important (Kaunhoven & Dorjee, 2017).

The present study investigated the effects of mindfulness training on preadolescents' regulatory abilities, examining executive functioning and stress regulation as well as school-related outcomes, using a multi-method approach with two alternative treatment groups and a passive control group.

Dispositional impulsivity as a trait-like inverse measure of executive functioning tended to rise in all groups, with a significant increase for girls compared with boys. This finding is unexpected, since, first, impulsivity shows a linear decline from childhood to adulthood (Shulman et al., 2016), and second, we hypothesized that both mindfulness training and concentration training as alternative treatment would lead to reductions in impulsivity. The present result suggests that contextual aspects such as the challenge of coping with a new school environment (the intervention took place during the first half-year of secondary school) had a greater influence on subjective judgements than our interventions, and that girls were particularly affected by these circumstances. Alternatively, our sample may have been too young to display a reduction in impulsivity – the maturation of impulse control has been found to be protracted and to continue into the early twenties, such that impulsivity decreases even after the age of 18 (overview: Shulman et al., 2016). Still, neither of the two treatment groups seemed to benefit from the intervention in terms of, e.g., accelerated reduction of impulsivity. For mindfulness training, this could go back to the well-known response-shift bias as previously documented (Sauer et al., 2013): Members of the mindfulness training group may have developed a better awareness of their own impulsivity, which possibly enhanced behavioral impulse control, but resulted in an increased impulsivity score in a self-report measure. Tentative support for this interpretation is provided by advantages for mindfulness training compared to MCT in some cognitive tests reported in Wimmer et al. (2016). However, to test this assumption directly, future studies are encouraged that assess impulsivity using both self-report and objective operationalizations.

With respect to stress regulation strategies as assessed with the help of SSKJ 3-8 only a marginal interaction effect of time with group with respect to constructive-palliative coping was observed. A follow-up t-test showed a significant increase in constructive-palliative coping only in the concentration group. One can tentatively speculate that relaxation exercises included in the concentration training may have been beneficial for the ability to use constructive-palliative coping strategies. Besides this, stress regulation strategies were not influenced by mindfulness or concentration training. This finding contradicts Frank et al. (2017) as well as the meta-analyses mentioned above, which described mindfulness-related benefits for emotional/behavioral regulation and socioemotional outcomes, respectively. The present results may again be due to the novelty of secondary school, which entailed a considerable emotional and intellectual challenge for the students. Potential treatment-related benefits may have competed with context-based obstacles to improvement of coping strategies, leading ultimately to null findings.

Interestingly, both training groups showed a steeper cortisol diurnal slope suggesting an improved regulation of the endocrine stress system, even though the students appeared to be challenged by the new school context as reflected by a rather rigid use of coping strategies. Furthermore, a marginal effect of time was also found with respect to the salivary alpha amylase awakening response, in terms of a more pronounced decrease in both groups. However, these effects cannot be traced back to causal effects of the trainings, as physiological measures were not assessed in the passive control group.

So far, studies investigating the effects of mindfulness training on diurnal cortisol and salivary alpha amylase levels in adults have rendered quite inconsistent results (Daubenmier et al., 2011; Flook, Goldberg, Pinger, Bonus, & Davidson, 2013; Malarkey, Jarjoura, & Klatt, 2013; Rosenkranz et al., 2013). These inconsistencies may partly be attributable to considerable differences in sampling schedules as well as assessment indicators. Our results, however, are in line with a recent meta-analysis on the effects of mindfulness-based interventions on salivary cortisol in healthy adults (Sanada et al., 2016) which reports moderate beneficial effects (Hedges's g equals 0.41).

Findings on the impact of mindfulness-based interventions on physiological stress regulation in children and adolescents are still few, so that reliable conclusions cannot be drawn. However, Schonert-Reichl et al. (2015), for example, found a potentially beneficial effect of mindfulness-based interventions on cortisol secretion also in youth, as the diurnal cortisol slope of children who received a 12-week mindfulness-based social emotional learning program changed little from pre- to post-test, whereas the slope deteriorated (i.e. changed from a steeper to a flatter pattern) in the control group, which received a social responsibility program. Furthermore, considering that cortisol has consistently been shown to relate to health outcomes, the beneficial effect observed in the mindfulness training group is also in line with Klingbeil et al.'s (2017) finding of physical health benefits in adolescents.

Finally, results on alterations in diurnal sAA levels, especially in children, are even more limited. Thus, further studies are warranted to follow up on the marginally steeper decline in sAA levels after awakening in both intervention groups. However drawing on results from adult populations, the observed tendency is in line with findings from Katz, Greenberg, Jennings, and Klein (2016) where perceived stress was associated with a less pronounced sAA awakening response.

Interestingly, the improvement in objective, psychobiological measures was not mirrored in the self-report data, which suggests that both methods capture different aspects in the assessment of self-regulatory effects. This corresponds well with the dissociation between subjective stress and physiological stress reactions, which has been observed repeatedly in acute stress test paradigms (Campbell & Ehlert, 2012; Schlotz et al., 2008). This dissociation has been explained with different temporal dynamics of both components of the stress response as well as the influence of personality characteristics, such as emotional reactivity and expressiveness.

A heterogeneous pattern of results emerged for the school-related outcomes. Both training groups showed no changes regarding the recognition of verbal material, but an enhanced acquisition of verbal memory. Additionally, the mindfulness training group tended to improve in the consolidation of verbal memory, while the performance of the concentration training group remained constant. This seems to indicate a slight advantage of mindfulness training, especially considering the fact that learning-relevant outcomes of mindfulness training may be more difficult to transfer to school-related tests than the principles of MCT. However, the difference between groups is small and therefore this result should be interpreted with caution.

The hypothesis that potential effects of the trainings on school-related outcomes would be mediated by improvements in regulatory abilities was not supported by the present data. There were indeed significant associations first, of both trainings with steeper diurnal cortisol slopes as an indicator of enhanced regulatory abilities, second, of both trainings with enhanced learning of verbal material via VLMT acquisition, and third, of mindfulness training with improved consolidation of verbal learning via VLMT consolidation (although this was only a tendency). Yet mediation analyses did not reveal significant indirect effects of the trainings on school-related outcomes through regulatory abilities. Besides the interpretation that mediation did not occur, this null finding could also be related to the power of the current pilot study that may have been too low to detect mediating effects.

The present study can be seen as advancing existing research in the following ways: First, a relatively extensive and intensive training protocol comprising two sessions per week over a period of four months was implemented to enable the detection of longer-term effects of mindfulness training. Second, the study applied multiple methods and combined self-report questionnaires with a well-controlled assessment schedule of two different physiological indicators and tests of objective performance. This clearly expands existing questionnaire-based research and offers a differential perspective on the outcomes of self-regulation training. Our results indeed show a complex pattern as the differential measures not always yielded converging evidence, a fact that confirms the incremental value of a multi-method approach.

The generalizability of our findings is however limited by sample size as well as by the fact that participants of the passive control group could not be assigned at random. Yet, the baseline measures do not indicate a systematic difference of the passive control group. Another important limitation results from the fact that not all measures could be collected in the passive control group. Thus, the time effects found for the diurnal cortisol slope and the acquisition component of the VLMT do not necessarily reflect specific training effects. Improved stress-regulation could, for instance, go back to effects of pubertal maturation: The transition between childhood and adolescence is a time of increased plasticity in the HPA axis (Flannery et al., 2017) which in principle could be mirrored by changes in diurnal cortisol cycles over four to five months. Yet such maturational effects would probably not produce a uniform time effect for both groups as found in the present study, but would generate greater inter-individual variability. The improvement in VLMT acquisition could be due to a repetition effect, such that, at posttest, participants were already familiar with the procedure with the consequence of heightened performance without any impact of mindfulness or concentration training.

Furthermore, the alternative treatment, MCT, was hypothesized to have effects on the same variables as mindfulness training. This means that MCT did not just act as a classic active control group controlling for group climate and general cognitive stimulation, i.e., treatment-unspecific but -related effects, but instead would actually have had to be treated as non-inferiority control group. Non-inferiority trials are usually conducted to determine whether a new treatment is no worse than a reference treatment. This means that an ideal non-inferiority control treatment has empirically proven to impact on the dependent variables of interest (e.g., Piaggio, Elbourne, Altman, Pocock, Evans, & Consort Group, 2006). Also, non-inferiority trials come along with specific methodological issues. For instance, a predefined margin of non-inferiority has to be set and the type 1 and type 2 errors must be reversed, resulting in the need for larger samples than other trial types (ibid.). Although the present study, as in a typical non-inferiority trial, included a control condition hypothesized to influence the same outcome variables as the experimental condition, it did not meet all the requirements of non-inferiority trials: First, even though there is, as outlined above, some evidence concerning the efficacy of MCT for improving EF as one component of regulatory abilities, there is thus far no empirical evidence regarding stress regulation and school-related outcomes. Hence, the existing empirical evidence on MCT does not fully satisfy the standards of non-inferiority trials. Second, the pilot character of our study entailed a relatively small sample size implying low power for “normal” testing already. Therefore, the methodological approach required for non-inferiority trials did not appear to be viable. As a consequence, MCT could not be treated as a non-inferiority control group.

It would also be interesting to investigate differential effects of mindfulness training and MCT in the future, i.e. to look at outcome variables where the effects of both approaches diverge. For example, whilst comparable effects on the outcomes of this study were predicted, there is reason to assume that both trainings differ regarding the mechanisms of action and certain side effects. On the one hand, decentering has been postulated as a mechanism underlying the effects of mindfulness (e.g., Brown, Bravo, Roos, & Pearson, 2015; Sauer & Baer 2010), but not MCT. On the other hand, one could speculate that the relaxation exercises used in MCT promote mental imagery, yet an effect of mindfulness training in this regard seems rather unlikely.

Despite these limitations, the following conclusions can be drawn on the effects of mindfulness training on preadolescents’ regulatory abilities and school-related outcomes:

Executive function in terms of self-reported dispositional impulsivity did not benefit from mindfulness training. In both treatment groups physiological stress regulation was more functional at post-test. Subjective stress regulation did not improve as a result of mindfulness training. Regarding school-related outcomes, the results indicate a slight superiority of mindfulness training over concentration training. This result is surprising in the sense that Marburg Concentration Training addresses learning skills directly, whereas mindfulness training does not. Interestingly, improvements of the mindfulness training group emerged only in physiological measures and in objective performance tests, but were not mirrored in self-report instruments. This could go back to a response-shift bias (as explained above), which is considered a result of enhanced meta-cognitive awareness and a specific consequence of mindfulness training. Alternatively, the null findings in several dependent measures could indicate that the time of our intervention period, i.e. immediately after transition to secondary school, is not ideal for fostering regulatory abilities. Coping with a new school environment seems to entail such an emotional and intellectual challenge for the students, that there may not have been much room for improvements and potential benefits of mindfulness training. Thus, it would be interesting to see whether mindfulness training immediately before the transition to secondary school yields better results.

To sum up, the present research can be considered a promising avenue for uncovering differential effects of mindfulness training and MCT, since different methods of measurement yielded partly converging and partly diverging evidence. This encourages the application of comparable multi-method approaches in large-scale RCTs with both active and passive control conditions.

Conflict of interest statement: The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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