MIND, BRAIN, AND EDUCATION

Neurodevelopmental Effects of a Mindfulness and Kindness Curriculum on Executive Functions in Preschool Children—A Randomized, Active-Controlled Study

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ABSTRACT— This study aimed to explore the effect of a mindfulness-based curriculum designed especially for preschoolers on facets of executive functions. Fifty-one preschoolers were randomly assigned to either a mindfulness and kindness curriculum (MC) or an active control dialogic reading program (DR). A battery of behavioral and neurophysiological tests was used to tap into facets of executive control (inhibition, shifting). Electroencephalography data were acquired during the attentional network task (ANT). Relative to DR, children in the MC group exhibited a reduced difference in the N200 Event related potentials (ERP) amplitudes for the congruent versus incongruent conditions during the ANT paradigm representing inhibition and shifting abilities. On the behavioral tasks, both groups improved on executive functions (EF) but on different facets; MC group showed increased inhibition and the DR group demonstrated significantly greater shifting abilities. The results highlight the sensitivity of electrophysiological data to detect subtle cognitive changes. The understanding of how mindfulness-based interventions in preschoolers affect facets of executive functions can enable further refinement and maximization of the benefits of these interventions for this age group.

INTRODUCTION

The Development of Executive Functions

Executive functions (EF) are a wide range of daily skills, including sustained attention, keeping short- (working memory) and long-term goals and information in mind while being able to manipulate them, refraining from responding immediately, resisting distractions, tolerating frustration, considering the consequences of different behaviors, reflecting on past experiences, and planning for the future (Zelazo, Blair, & Willoughby, 2016). Theoretically, the definition of EF was narrowed to inhibition, shifting/switching, and updating abilities (Miyake et al., 2000) and together with orienting and alerting attention abilities, they all form the Attention Network Model suggested by Posner and Peterson (Posner & Petersen, 1990) (see also Sumantry & Stewart, 2021) for the integration of both models). EF abilities have been the focus of increasing developmental research as they are believed to underlie performance and learning (Anderson, 2002) and are considered fundamental for the regulation of

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behavior, learning (Kaunhoven, Dorjee, & Reviews, 2017; Zelazo & Lyons, 2012), and social–emotional competencies (Griffin, McCardle, & Freund, 2016). Extensive research has shown that increased EF skills in early childhood predict a wide variety of imperative outcomes, including better school readiness (Checa, Rodríguez-Bailón, & Rueda, 2008; Posner & Rothbart, 2014; Razza, Bergen-Cico, Raymond, & Studies, 2015; Rueda, Checa, & Combita, 2012; Steinmayr, Ziegler, Träuble, & Differences, 2010), school performance as well as greater social–emotional well-being in adolescence (e.g., higher socioeconomic status (Mischel, Shoda, & Rodriguez, 1989) and fewer substance dependence problems and criminal convictions in adulthood (Moffitt, Arseneault, Belsky, et al., 2011). Therefore, understanding how to support the development of EF skills is an important goal for developmental research.

EF abilities emerge early in development, with a rapid burst in EF capacities during preschool years (Diamond, 2002; Welsh, Pennington, & Groisser, 1991). For example, the amplitude of the N200 event-related potential component, a prominent marker of EF (Buss, Dennis, Brooker, & Sippel, 2011; Dennis & Chen, 2007; Stieben, Lewis, Granic, et al., 2007), has been found to decrease negativity during development, reflecting a developmental increase in neural efficiency related to EF (Chapman, Woltering, Lamm, & Lewis, 2010; Espinet, Anderson, & Zelazo, 2012; Lamm, Zelazo, & Lewis, 2006; Lewis, Granic, & Lamm, 2006). The N200 component is elicited by neural generators in the dorsal, caudal anterior cingulate cortex approximately 200–400 ms after stimulus onset (Fincham, VanVeen, Carter, Stenger, & Anderson, 2002; Lewis et al., 2006). In adults, it is usually measured during tasks such as the Go/No-Go task, Stroop task, and the attention network task (ANT), targeting shifting/switching and inhibition (Espinet et al., 2012; Jha, Krompinger, & Baime, 2007; Lewis et al., 2006; Lewis & Todd, 2007). When successful discrimination of a pre-potent response occurs, or when inhibiting a response is required in case of a rule shifting, for example, a greater N200 amplitude is elicited (Bokura, Yamaguchi, & Kobayashi, 2001; Dennis & Chen, 2007; Falkenstein, Hoormann, & Hohnsbein, 1999; Lewis et al., 2006; Lewis & Stieben, 2004). In children, Espinet et al. showed less negative N200 amplitudes in three-to-five-year-old children performing the card sorting task, which showed an increased ability to solve conflicts and adapt to new rules, compared to children who showed difficulty in the task (Espinet et al., 2012). Another study administered the ANT task to children and measured the differences between N200 amplitudes for the congruent versus incongruent conditions, reflecting the children's EF abilities, specifically inhibition, and shifting (Rueda et al., 2004; Rueda et al., 2012; Rueda, Posner, Rothbart, & Davis-Stober, 2004; Rueda, Rothbart, McCandliss, Saccomanno, & Posner, 2005). In this task, children who showed better EF abilities (greater accuracy and reaction time) demonstrated a smaller difference in N200 amplitudes for the congruent versus incongruent conditions (Rueda et al., 2005). Such neurodevelopmental changes are mirrored by a gradual increase in functional connectivity and in long-distance structural connections as developmental stages progress. These are especially evident in neural circuits associated with EF, such as the prefrontal cortex (Zelazo, Carlson, & Kesek, 2008), anterior cingulate cortex (Zelazo, 2015), and neural networks, such as the cingulo-opercular and frontoparietal networks (see Farah & Horowitz-Kraus, 2019).

Large individual differences in EF development exist as a result of genetic predispositions (Greene, Braet, Johnson, & Bellgrove, 2008), but also because of maturational changes occurring during childhood strongly shaped by experience (Blair & Diamond, 2008; Evans & Kim, 2013). This significant impact of childhood experience on EF development suggests that active practicing of EF skills during this crucial developmental window can ignite a cascade of beneficial consequences, such as better school readiness, greater school engagement, positive school experiences, and positive relations with teachers and peers (Zelazo, Forston, Masten, & Carlson, 2018; Zelazo & Lyons, 2012). Studies indicate that neural circuits supporting the components of the attentional networks model and, more specifically, EF, are plastic and modifiable (Zelazo & Carlson, 2012), and even more so in preschool years (Rueda et al., 2012). These neural circuits were thought to be cultivated by relatively brief interventions, having various levels of difficulties, that challenge children to engage their developing EF skills (for a review, see Diamond & Lee, 2011). For example, Rueda et al. tested preschoolers who underwent a ten-session computerized attention training program and compared them to non-trained preschoolers (Rueda et al., 2012). N200 latencies decreased in the trained preschoolers, indicating increased efficiency in EF processes following training. The promising results regarding the effectiveness of interventions at an early age on components of the attentional networks model in general and on EF in particular (Anderson, 2002), have led to a search for efficient interventions for preschoolers (Diamond & Lee, 2011). Recently, various mindfulness practices have been increasingly attracting interest (Geronimi, Arellano, & Woodruff-Borden, 2020; Mak, Whittingham, Cunnington, & Boyd, 2018) as means to cultivate a wide range of emotional, prosocial, and cognitive skills in adults (Hölzel et al., 2011; Sumantry & Stewart, 2021) and children (Diamond & Lee, 2011; Flook, Smalley, Kitil, et al., 2010; Kaunhoven et al., 2017; Zelazo & Lyons, 2012) and have been recently integrated into several schools/preschool curriculums (Diamond, 2012). Although the exact mechanisms behind the potential benefits of mindfulness practices in adults and children are not fully understood, it is thought that improved attentional skills may be a key factor contributing to the positive effects observed (Sumantry & Stewart, 2021). Further understanding what aspects of EF processes important for development (Checa et al., 2008; Griffin et al., 2016; Kaunhoven et al., 2017; Posner & Rothbart, 2014; Razza et al., 2015; Rueda et al., 2012; Steinmayr et al., 2010; Zelazo & Lyons, 2012), in addition to attention processes, are affected by mindfulness training in children is critical to maximize effects and refine programs.

Mindfulness and EF

Mindfulness is often used as an umbrella term for a large group of practices, mostly involving cultivating attention to both external and internal bodily sensations and mental contents, with certain attitudes and intentions, and frequently coupled with prosocial qualities such as kindness, caring and gratitude (Levit-Binnun, Arbel, & Dorjee, 2021). At the core, mindfulness practices involve focusing one's attention on the present moment in a purposeful and non-judgmental way, to become more aware of one's thoughts, feelings, and surroundings (Kabat-Zinn, 2003). This self-regulation of attention involves adopting a curious and accepting attitude toward one's experiences and paying attention to them in a purposeful and non-judgmental manner (Bishop et al., 2004). During mindfulness practices, individuals repeatedly notice when attention has wandered and intentionally bring it back to the chosen object of focus. Such voluntary shifting of attention (a facet of EF) enables them to become more attuned to their own thoughts, feelings, and actions, as well as the thoughts, feelings, and actions of others. This may lead to an increase in kindness and compassion towards others as individuals become more aware of the impact their words and actions have on others.

Recently, a growing body of literature is suggesting that the positive effects of mindfulness practices on well-being and mental health may be mediated by their effects on attention regulation and EF (Bishop et al., 2004). Multiple studies, mostly in adults, investigated the effects of mindfulness practices on various tasks that tap into attention and EF (Baer, 2003; Chambers, Lo, & Allen, 2008; Grossman, Niemann, Schmidt, & Walach, 2004; Heeren, Van Broeck, & Philippot, 2009; Ortner, Kilner, & Zelazo, 2007; Tang, Ma, Wang, et al., 2007; Tang, Yang, Leve, & Harold, 2012; Zeidan, Johnson, Diamond, David, & Goolkasian, 2010). These studies were reviewed (Kechter, Amaro, & Black, 2019), using the Posner and Petersen (1990) three-attention networks model (alerting (or vigilance), orienting, and executive control/function). (Posner & Petersen, 1990). They concluded that mindfulness meditation benefited executive control, as well as the other two networks of alerting and orienting. Gallant (2016) conducted a comprehensive systematic review focusing on EF, using the Miyake et al. (2000) model of EF (Miyake et al., 2000) (comprising sub-facets of inhibition, shifting, and updating), and concluded that there was sufficient evidence that mindfulness meditators were better at inhibition of distractors than controls, while results for shifting and updating were mixed. A more recent meta-analysis (Sumantry & Stewart, 2021) coded the outcomes of multiple mindfulness studies according to both the Posner & Peterson and Miyake models. The meta-analytical findings concluded that mindfulness improved both attention (alerting) and EF in adults.

The promising findings in adults have motivated educators and education researchers to develop and test the effectiveness of mindfulness training in children. To date, most studies focused on school children, with accumulating indications that mindfulness training can also nurture a wide range of EF skills in pre-adolescents and adolescent youth (e.g., Felver, Celis-de Hoyos, Tezanos, & Singh, 2016; Harnett & Dawe, 2012; Meiklejohn, Phillips, Freedman, et al., 2012; Napoli, Krech, & Holley, 2005; Renshaw & Cook, 2017; Schonert-Reichl et al., 2015; Sheinman, Hadar, Gafni, & Milman, 2018; Tang et al., 2012; Vickery & Dorjee, 2016). For example, Felver et al. showed enhanced performance on the ANT in 9–12-year-old children following an 8-week mindfulness intervention (Felver, Tipsord, Morris, Racer, & Dishion, 2017). Pre-adolescents aged 9–11 years showed greater improvement in executive attention, including inhibitory control and cognitive flexibility on other tasks measuring facets of EF (the Flanker and Hearts and Flowers tasks), following a twelve-session mindfulness training versus a social responsibility curriculum training (Schonert-Reichl et al., 2015). Taken together, these studies suggest that mindfulness-based interventions can affect EF and attention abilities in school-aged children. However, much less is known regarding the effects of these interventions on younger kids.

The Effect of Mindfulness Programs on Executive Functions in Early Childhood

As the most rapid development of EF occurs during preschool years (Kuhl, 2010), mindfulness training may be especially beneficial at this age. Despite this, only a handful of studies have examined the effects of mindfulness training on preschoolers' EF skills, suggesting improvements in EF, social competence, school readiness, and future vocabulary and reading abilities (Cohen, Harvey, Shields, et al., 2018; Flook, Goldberg, Pinger, & Davidson, 2015; Lemberger-Truelove, Carbonneau, Atencio, Zieher, & Palacios, 2018; Lemberger-Truelove, Carbonneau, Zieher, & Atencio, 2019; Lim & Qu, 2017; Moreno-Gómez & Cejudo, 2019; Poehlmann-Tynan, Vigna, Weymouth, et al., 2016; Razza et al., 2015; Thierry, Bryant, Nobles, & Norris, 2016; Viglas, Perlman, & Studies, 2018; Wood, Roach, Kearney, & Zabek, 2018; Zelazo et al., 2018). For example, Flook et al. demonstrated how a 12-week mindfulness-based Kindness Curriculum compared to a wait-list control using teacher reports and behavioral assessments showed improved EF in the mindfulness group (Flook et al., 2015). Poehlmann-Tynan et al. further used the same mindfulness-based Kindness Curriculum in a dialogic reading (DR) intervention in a small sample of disadvantaged preschoolers (Poehlmann-Tynan et al., 2016). They found that while there was no difference in compassion and empathy between the mindfulness combined with DR and DR-only groups, preschoolers in the mindfulness combined with DR exhibited greater improvement in attention and regulation measured behaviorally. Training on a mindfulness-based social–emotional learning program for preschoolers (spanning 144 fifteen-minute sessions) versus a wait-list control showed improvement in various neuropsychological variables, including attention abilities in the mindfulness group (Moreno-Gómez & Cejudo, 2019). On the other hand, 6-week mindfulness with a reflection training program for preschoolers compared to an active control group of literacy training and a non-training condition showed no difference in EF following the mindfulness-reflection and literacy training (Zelazo et al., 2018). There was, however, a significant improvement in the mindfulness-reflection group compared to the non-training group, which was even more pronounced 4 weeks after training. In contrast, such a difference was not found between the preschoolers that attended the literacy and the no-training groups (Zelazo et al., 2018). Interestingly, in most of these studies, the cultivation of mindfulness skills was coupled with the cultivation of social–emotional skills such as kindness and gratitude. This is in line with the emerging understanding of the functional dependency of the development of social interactions and EF and recent suggestions that higher-order cognitive development might be facilitated, at least in part, by targeting the improvement of social skills and social interactions with caregivers and peers (Moriguchi, 2014; Perry, Braren, Rincón-Cortés, et al., 2019).

Overall, these results suggest that mindfulness-based curricula can be implemented in preschool classes and may be beneficial for EF development during preschool years (Cohen et al., 2018; Flook et al., 2015; Lemberger-Truelove et al., 2019; Lim & Qu, 2017; Moreno-Gómez & Cejudo, 2019; Poehlmann-Tynan et al., 2016; Razza et al., 2015; Thierry et al., 2016; Viglas et al., 2018; Wood et al., 2018; Zelazo et al., 2018). In addition, these studies suggest that mindfulness-based programs that also put emphasis on the cultivation of prosocial capabilities may have advantages over other EF interventions, such as literacy or DR programs in regard to EF improvement (Poehlmann-Tynan et al., 2016; Zelazo et al., 2018). These promising findings motivate further inquiry into the mechanisms of mindfulness-based interventions for preschoolers using additional methods, such as neurophysiological measures. Neurophysiological assessments are especially needed, as self-report measures and behavioral assessments alone do not always detect EF changes (Kaunhoven et al., 2017). For example, in Rueda et al., differences were found in ERP indexes but not in the behavioral measures during the ANT between preschoolers who underwent the EF training and those that had not, demonstrating that EF training in children is feasible (Rueda et al., 2012).

To better understand the effects of mindfulness training on neurodevelopment and its mechanisms (Kaunhoven et al., 2017), we conducted a study using a combination of behavioral tests and neurophysiological measures. Specifically, the study focused on the inhibitory and shifting facets of EF, which are the abilities most frequently tested in young children (preschoolers to kindergartners). The third component of EF, updating, is a more complex skill that involves maintaining and modifying new rules in working memory and is generally thought to develop later in life (Amso, Haas, McShane, & Badre, 2014; Voigt, Mahy, Ellis, et al., 2014). To this end, neurophysiological markers (ERPs), specifically the difference between N200 amplitudes for congruent versus incongruent conditions associated with EF training (following Rueda, Bruce, et al., 2004; Rueda et al., 2005; Rueda, Posner, et al., 2004), were combined with behavioral assessments of these two EF facets. This marker was chosen because of its high sensitivity to mechanistic processes, especially in young children (Perry et al., 2019) .

The study involved an 8-week mindfulness-based curriculum specifically designed for preschoolers, in which mindfulness-based practices were coupled with prosocial skills such as kindness and gratitude. Four-to-six year old preschoolers were taught to cultivate their ability to focus, shift and regulate their attention, in a curious and kind manner, to various aspects of their and other's experience, including their body, breath, senses, movement, feelings, thoughts, sensations (Flook et al., 2015; Teper, Segal, & Inzlicht, 2013; Zelazo & Müller, 2002).

An active control group that received a dialogic reading intervention (Arnold & Whitehurst, 1994) (DR) allowed differentiating the EF effects on preschoolers specific to mindfulness training coupled with social skills training. Hence, the current study aims to fill out the gap in knowledge by addressing the following questions: (1) What is the specific effect of mindfulness and kindness curriculum (MC) training on EF (inhibition, shifting) in preschool children? and; (2) What is the neurobiological signature underlying MC training in children, focusing on EF (i.e., inhibition and shifting as can be assessed using the N200 from the ANT)?

METHODS

Participants

Fifty-one preschool children participated in the current study (19 females and 32 males) with ages ranging from four to six years (average age = 4.9, SD = 0.69). This group was randomly assigned into two groups: (1) the MC group ($N = 22$, average age = 5, SD = 8, and 10 females) and (2) the active control DR group ($N = 29$, average age = 4.89, SD = 8.6, and 9 females). Children in the two groups did not differ in age (MC: mean age = 61.26 months and SD = 7.86; DR: mean age = 59.16, and SD = 8.57) ($t = 0.835$, $p = .409$). Inclusion criteria included healthy children aged 4–6 years old. Children were excluded from this study in case of neurological, developmental (such as autism), or psychiatric disorders. All parents had at least a bachelor's degree (>15 years of education) and were from a middle-class socioeconomic background. All recruited families were from the country's northern region, and the primary language at home was Hebrew.

Study Procedure

The overall duration of the program was 4 months and included the pre-intervention behavioral/cognitive data collection, the training period (2 months), and behavioral/cognitive and EEG data collection (one-month post-training). Of note, the measures reported here are part of a more extended battery of behavioral/cognitive measures, which were administered, in part, to ensure replication of previous results reported elsewhere (Twait, Farah, Shamir, & Horowitz-Kraus, 2019a) and were not included in the current paper. As for the intervention, both groups were exposed to the training materials for 8 weeks, three times a week, during 30-min meetings, totaling 24 sessions.

All sessions took place in daycare facilities in the north of Israel. Behavioral measures were collected at the daycare facilities before and after the intervention. Electrophysiological data were collected after the intervention at the institution. The study was approved by the institutional ethics committee. All parents signed written informed consent. Children were compensated for their participation with a gift.

Mindfulness and Kindness Curriculum (MC) Intervention Group

The intervention group received a mindfulness-based program designed specifically for preschool-age children and aimed at fostering mindful attention, self-regulation, and prosocial skills. The program's curriculum was inspired by the Kindness Curriculum (developed by the Center for Healthy Minds, University of Wisconsin, WI, USA) (Flook et al., 2015) with practices and activities adapted from the leading local mindfulness program for children, "Sfat Hakeshev" ("Mindful Language"), which has been integrated into Israeli schools since 1999 (Semple, Droutman, & Reid, 2017; Sheinman et al., 2018). An experienced mindfulness instructor led the adaptation of the program with over 20 years of personal mindfulness practice and over 12 years of experience working with the "Mindful Language" and other mindfulness-based programs for children. This instructor also administered the program to the preschoolers. Importantly, she was not part of the research team or daycare center team.

The mindfulness-based curriculum included learning and practice sessions focusing on three main modules: (1) Directing attention in a curious, kind, and nonjudgmental manner to the present moment: body, breath, senses, and movement; (2) Directing attention in a curious, kind nonjudgmental manner inwards: feelings, thoughts, sensations, and imagination; and (3) Directing attention in a curious, kind nonjudgmental manner toward others. In all modules, there was an emphasis on the development of a kind, caring, and accepting attitude toward self and others.

In each module, there were several themes. For example, in the first module, one theme was directing attention to the body; another was directing attention to breathing; a third theme was directing attention to the senses, and the fourth was directing attention to body movement. Each theme always spanned two sessions. In the first session, an experiential mindfulness-based activity related to the theme (e.g., focusing on breathing) of the lesson was administered, and children worked in their personal space on a personal yoga mat while lying down, sitting, or standing; in the second session, a short story related to the theme of the meeting was read to the children, followed by a discussion focused on contemplation of the story and how it relates to oneself and others. The instructor tried to minimize discourse with the children while reading the book, assisting the children in practicing patience, peacefulness, and awareness of themselves and others' personal space. Indeed, these qualities were practiced during each session as core guiding principles and were acquired gradually. During the discourses that followed the reading, the children were encouraged to speak and listen to each other with an open mind to practice acceptance and kindness. See Table 1 for session-by-session main themes and corresponding experiential understandings.

An Active Control Group (Dialogic Reading; DR)

Children in the control group were read to using the DR fundamental reading technique. This technique includes interactions between the child and the adult around a book while reading together (Van Kleeck, 2003). The program was designed to actively involve the children in the story during the reading session. The interaction around the book included the reader reading aloud while tracing the letters

Table 1
The Intervention Topics of the MC Program

Topic	Main experiential understanding that was addressed
Personal space	Me in my space
Attention	I pay attention
My inner world	I listen to myself
This moment	I am here and now
Concentration and stability	I am strong and stable
Safe and quiet place	I am safe and calm
Self-efficacy	Yes I can
Feelings	I look inwards with curiosity
Emotions	I have feelings
Emotional regulation	I have me
Thoughts	I have thoughts
Change	Everything changes all the time
Hearing	I hear voices and sounds
Touching	I feel and touch
Taste and smell	I taste and smell
Sight	I see
Mindful walking—activation of all senses	I am curious and attentive to what is around me
Freedom and liberation	I can give
Acceptance	I am what I am
Love	I love myself as I am
Gratitude	I am grateful for what I am what I have
Grace and giving	I love to give
Listening to a friend	I want to listen to you
I am part of the world	My heart loves

with her finger, pausing, and asking the children questions related to vocabulary, previous words, events, or pictures mentioned in the story, as well as inference questions. The reader (a person from the research team that was also the reader in Twait, Farah, Shamir, & Horowitz-Kraus, 2019b) also moderated the discussion with the children around the story's content, asking questions about the story, and expanding the children's answers to encourage active participation. The DR intervention was chosen as the control group for this study as it also includes storytelling and active conversations with the participants in a group setting (similar to the MC intervention); however, the questions and discussions are focused on the details in the book (the images, the letters, the vocabulary), without the specific content associated with the practice sessions of the MC (per Table 1). Hence, a comparison to this group will result in specific outcomes for the content and practices of the MC curriculum and not for the setting, conversations, and reading exposure.

Behavioral Measures

General nonverbal abilities were measured using the matrix task from the Wechsler Preschool and Primary Scale of Intelligence (WPSSI; Wechsler, 1949), and verbal abilities were measured using the vocabulary task from the WPPSI.

Executive functions abilities were assessed using a combination of tests. Inhibition was assessed using the "Sky Search" Subtest (TEA-CH) battery (Manly, Robertson, Anderson, & Nimmo-Smith, 1999) and using the Walk–Do not Walk subtest from the TEA-CH battery, and shifting was assessed animals/colors task (Ziv, 2017) (i.e., the children's version of the Stroop task). As stated above, we focused on inhibition and shifting, as they are more commonly tested in young children (preschoolers-kindergarten), whereas updating and maintaining a new rule in working memory is considered a more complex ability that develops later in life (Amso et al., 2014; Voigt et al., 2014).

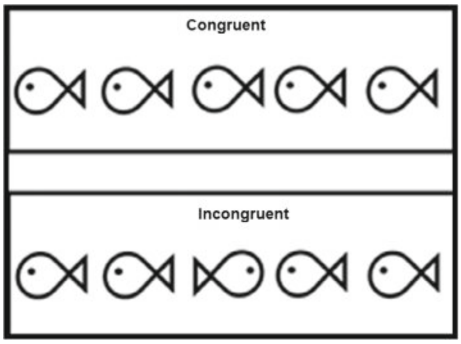

Fig. 1. The attention network test (ANT). A description of the children's version of the ANT paradigm following Rueda (Rueda, Bruce, et al., 2004). Children were instructed to respond to the middle fish and ignore the other four. The visual cues change along the task. Incongruent and congruent conditions were contrasted in the proposed analysis.

Electrophysiological Task

The Attention Network Test (ANT)

In the ANT, participants were presented with five horizontally displayed fish, where the middle fish was either facing the same (congruent condition) or the opposite direction (incongruent condition) compared to the other four fish (see Figure 1). Each trial began with a central fixation cross presented for a random variable duration of between 500 and 1,500 ms, followed by a horizontal row of five fish. The fish were displayed on the screen for 1,000 ms, followed by another fixation cross presented for 500–1,500 ms. Congruent and incongruent trials were presented 25 times each (overall, 50 trials) in a random manner. Children were instructed to push the left or right keys on a response pad as fast as they could, corresponding to the direction the middle fish was facing. Participants were able to respond during a 2000-ms response window, after which a new trial was initiated. Behavioral data (Reaction Times, RT and accuracy, ACC) were recorded as well.

Electrophysiological (EEG) Recording

EEG data was recorded via 64 electrodes mounted on a custom-made cap (Bio-Logic Ltd., Claix, France), according to the international 10/20 system and sampled at a rate of 2048 Hz with an analog band-pass filter of 0.1–70 Hz and a 12-bit A/D converter and stored for offline analysis. All electrode impedances were maintained at or below 5 kΩ. The EEGs were recorded during the ANT and obtained post-intervention only to maximize each child's cooperation (see also Twait et al., 2019b).

Data Analyses

Behavioral Data Analysis

Two-way independent t-tests between the two intervention groups were conducted to rule out baseline differences in EF for the behavioral measures noted above.

To determine the effect of interventions on inhibition and shifting abilities, several 2 × 2 (Test [Test 1, Test 2], Group [MC, DR]) Repeated Measures Analysis of Variance (RM-ANOVA) tests were conducted for the behavioral measures with several post hoc within/between-group effects. A correction for multiple comparisons was performed using a Bonferroni correction.

Electrophysiological Data Analysis

Event-Related Potential Analysis: Preprocessing of the EEG Data

An eye-movement correction was carried out by the ICA algorithm implemented in Brain Vision Analyzer software (version 1.05, Brain Vision Products, Munich, Germany), and filtered with a 30-Hz filter. The average reference was used on all electrodes. ERP epochs were time-locked separately to congruent and incongruent stimuli. Stimulus-related epochs started 100 ms before and ended 1,000 ms after stimulus onset. Both types of epochs were averaged separately for correct and incorrect trials. All epochs were subsequently inspected visually to ensure that they were free of residual artifacts. Only epochs for correct responses were analyzed. In addition, artifact rejection conditions were defined by: (a) Maximal gradient of 40 μV/ms; (b) maximal allowed absolute difference of 100 μV in a 100-ms interval; (c) minimal allowed amplitude of −70 μV and maximally allowed amplitude of 70 μV; (d) minimal allowed absolute difference of 0.5 μV in a 100-ms interval.

The baseline correction for the N200 stimulus-locked component was −100 to 0 ms prestimulus. Peak N200 amplitudes were measured as the largest negative peak 150–250 ms poststimulus onset and were detected by the Fz Cz and FCz electrodes following (Rueda et al., 2005). N200 amplitudes for congruent and incongruent conditions were averaged separately. Only epochs for correct responses were analyzed.

EEG Data Statistical Analyses

Attention Network Task (ANT)

Behavioral data (accuracy and reaction time [RT]). To assess the effect of the intervention on ANT performance, a $Delta_{RT}$ (i.e., the difference in RT for incongruent vs. congruent conditions) was calculated for each participant by subtracting the RT in the congruent trials from the RT in the incongruent trials. The $Delta_{ACC}$ was also calculated by subtracting accuracy (ACC) rates for congruent trials from the accuracy of incongruent trials.

Electrophysiological data. To assess the effect of interventions on inhibition and switching using the electrophysiological data, a 2 × 2 Group by Condition (MC, DR) × (Congruent, Incongruent) RM-ANOVA was conducted for the N200 component (amplitude and latency), separately for each electrode (Fz, Cz, and FCz). To test the effect of intervention within each group, the difference between congruency conditions was calculated by subtracting the N200 amplitudes and latencies in the congruent condition from the N200 amplitudes and latencies in the incongruent condition for each participant ($Delta_{N200}$ = Incongruent N200 amplitude minus congruent N200 amplitude). $Delta_{N200}$ differences between the groups were compared using two-way independent t-tests.

RESULTS

Participants

Fifty-one preschool children completed the behavioral tasks pre- and postinterventions (19 females and 32 males). Three participants withdrew from the EEG component of the study, one child refused to perform the EEG, another child left the preschool, and two participants did not have both conditions (congruent, incongruent), resulting in a final sample of 44 participants who had a full dataset of both EEG and behavioral datasets (29 boys, 15 girls); the MC group had $N = 19$ (females 7) children, and the control DR group had $N = 25$ (females 8) children.

Behavioral Data

Baseline Abilities

Children in the MC and DR intervention groups showed similar baseline abilities (see columns A and C in Table 2).

The Effect of MC versus DR Interventions

RM ANOVA revealed a main effect of Test for orienting and alerting attention abilities and for EF measures pointing at greater results for Test 2 than Test 1 in both training groups. No significant Group × Test interactions were found. Post hoc t-tests showed that following the intervention, children

Table 2
Behavioral Measures per Group and Task Following the MC versus the DR Interventions

	MC group		*DR group*				
Measures	*Test 1 (A)* *M (SD)*	*Test 2 (B)* *M (SD)*	*Test 1 (C)* *M (SD)*	*Test 2 (D)* *M (SD)*	*T (p)*	*Contrast*	*F test*
Inhibition, Sky Search, Score for time per correct target (TEA-CH; Manly et al., 1999)	6.363 (3.958)	8.409 (3.333)	5.857 (3.363)	7.071 (3.495)	−2.931 (0.008) −2.1(0.45) 0.282 (0.779) 1.371 (0.177)	B > A D > C A > C B > D	Test F (1, 48) = 13.155 $p = .001$, $\eta^2 = 0.215$ Group F (1, 48) = 1.049 $p = .311$, $\eta^2 = 0.021$ Group × test F (1, 48) = 0.855 $p = .360$, $\eta^2 = 0.018$
Inhibition, Sky Search, Scale score (TEA-CH; Manly et al., 1999)	6.590 (4.521)	8.909 (3.878)	6 (3.925)	7.5 (4.290)	−2.609 (0.016) −1.873 (0.72) 0.259 (0.797) 1.202 (0.235)	B > A D > C A > C B > D	Test F (1, 48) = 10.145 $p = .003$, $\eta^2 = 0.174$ Group F (1, 48) = 0.959 $p = .323$, $\eta^2 = 0.020$ Group × test F (1, 48) = 0.466 $p = .498$, $\eta^2 = 0.010$
Inhibition, Walk Do not Walk, Number of correct items (TEA-CH; Manly et al., 1999)	3.800 (1.196)	4.200 (1.281)	2.814 (1.468)	3.185 (1.569)	−1.453 (0.163) −1.17 (0.252) 1.711 (0.094) 1.659 (0.104)	B > A D > C A > C B > D	Test F (1, 45) = 3.096 $p = .085$, $\eta^2 = 0.064$ Group F (1, 45) = 8.016 $p = .007$, $\eta^2 = 0.151$ Group × test F (1, 45) = 0.005 $p = .946$, $\eta^2 = 1.151$
Shifting, Sum of animals and colors, Sum of total score—Colors (Switching inhibition task; Ziv, 2017)	24.950 (4.406)	26.700 (2.754)	23.259 (6.785)	25.814 (2.815)	−1.769 (0.93) −2.264 (0.032) 0.837 (0.407) 1.01 (0.317)	B > A D > C A > C B > D	Test F (1, 45) = 7.568 $p = .009$, $\eta^2 = 0.144$ Group F (1, 45) = 1.337 $p = .254$, $\eta^2 = 0.006$ Group × test F (1, 45) = 0.265 $p = .609$, $\eta^2 = 0.029$

Table 2
Continued

Measures	*MC group*		*DR group*				
	Test 1 (A) *M (SD)*	*Test 2 (B)* *M (SD)*	*Test 1 (C)* *M (SD)*	*Test 2 (D)* *M (SD)*	*T (p)*	*Contrast*	*F test*
Shifting,	24.190 (5.065)	26.142 (2.815)	23.037 (7.987)	26 (3.293)	−1.654 (0.114)	B > A	Test
Sum of total score—Animals (Switching inhibition; Ziv, 2017)					−2.172 (0.039) 0.456 (0.650) −0.112 (0.911)	D > C A > C B > D	F (1, 46) = 6.939 p = .011, η^2 = 0.131 Group F (1, 46) = 0.274 p = .603, η^2 = 0.006 Group × test F (1, 46) = 0.293 p = .591, η^2 = 0.006

Note. All tests mentioned above are normalized for age, except for the animals/colors sifting task (raw scores are given). M = mean; SD = standard deviation; TEA-CH = test of everyday attention for children; Test 1 = prior to intervention; Test 2 = after the intervention.

in the MC group showed a significant increase in the inhibition facet of EF from Test 1 to Test 2. The DR group demonstrated a significant increase in the shifting facet of EF from Test 1 to Test 2 following the intervention. See Table 2 for these results.

ANT Results

Reaction Time and Accuracy

T-test analyses suggested no significant differences were found between the congruent and incongruent conditions in reaction time ($Delta_{RT}$) and accuracy ($Delta_{ACC}$) between intervention groups. See Table 3 for the data.

Electrophysiological Results

N200 amplitude

The RM-ANOVA (Group [MC/DR] and Condition [Congruent/Incongruent]) revealed a significant Group × Condition interaction in the Cz electrode: (F [1, 42] = 6.488, p = .015, η^2 = 0.131) and a trend for the FCz electrode: (F [1, 42] = 3.943, p = .053, η^2 = 0.006); higher $Delta_{N200}$ was observed in the MC versus the DR groups (i.e., a smaller difference between the N200 amplitudes for the congruent and incongruent conditions for the MC group). No interaction effect was found for the Fz electrode (F [1, 41] = 1.079, p = .305, η^2 = 0.026). No main effects of Group or Condition were found for the examined electrodes. See Table 3 and Figures 2 and 3 for the data.

N200 latency

The two-way mixed design repeated measures ANOVA (Group [MC/DR], Condition [Congruent/Incongruent]) revealed no significant Group × Condition interaction for Fz electrode: (F [1, 41] = 0.404, p = .529, η^2 = 0.010); Cz electrode: (F [1, 42] = 0.478, p = .493, η^2 = 0.011); and FCz electrode: (F [1, 42] = 0.890, p = .351; η^2 = 0.051), or a main effects of Group, or Condition for the latency data. See Table 4 and Figures 2 and 3 for the data.

DISCUSSION

The current study aimed to identify the specific neurophysiological and behavioral changes related to EF in 4–6-year-old children following MC compared to an active DR control group. Relative to the DR group, children in the MC group showed a decreased gap between the N200 amplitudes for congruent versus incongruent conditions during the ANT, representing better inhibition and shifting abilities (i.e., they were better in shifting their attention to the incongruent rule and inhibiting themselves not to respond as they have in the previous step).

Table 3
Comparisons of Reaction Time and Accuracy Results between the MC and the DR Groups Following the Intervention (Test 2).

Condition	*MC group Congruent (A) M (SD)*	*MC group Incongruent (B) M (SD)*	*DR group Congruent (C) M (SD)*	*DR group Incongruent (D) M (SD)*	*Contrast*	*T (p)*
Reaction time (RT), in msec	964.484 (137.489)	984.589 (232.271)	926.582 (172.046)	1,004.060 (234.854)	B > A D > C A > C D > B	0.787 (0.435) 0.997 (0.786)
Accuracy (ACC), in percentages	84.6 (13.0)	77.0 (18.8)	82.4 (11.2)	76.4 (17.9)	A > B C > D A > C B > D	0.609 (0.546) 0.103 (0.919)

Note. M = mean; SD = standard deviation.

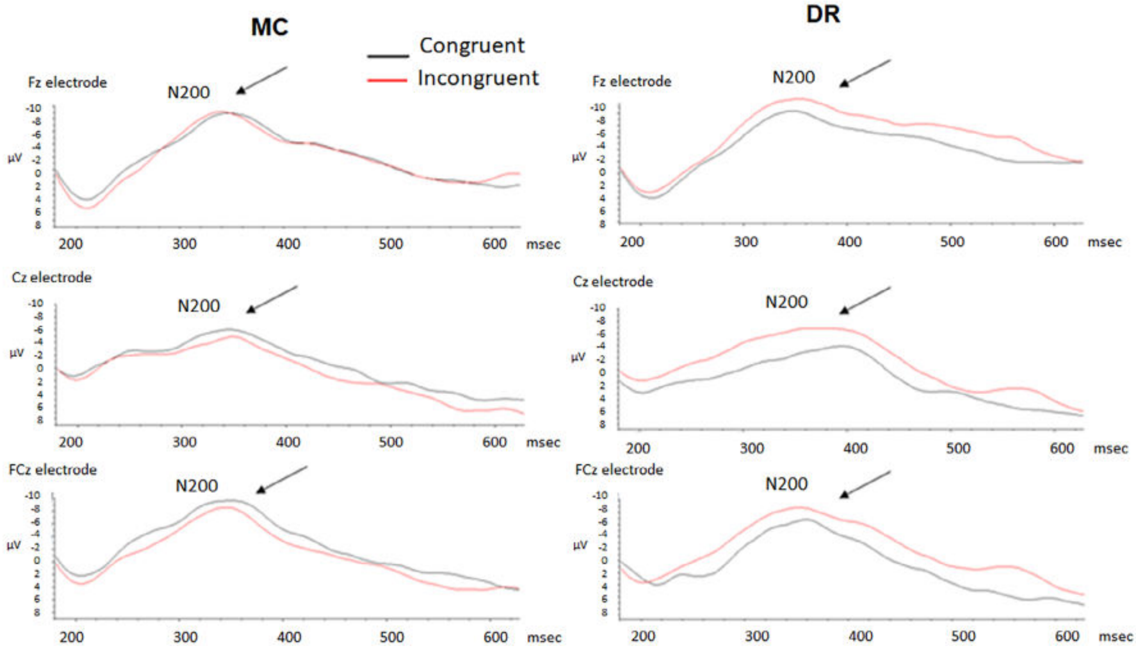

Fig. 2. N200 for the incongruent and incongruent conditions for the MC versus DR groups. Time-locked grand average of the N200 component waveforms for both congruency conditions at the midline of the Fz, Cz, and FCz electrodes for both MC (left panels) and the DR (right panels) groups. The congruent condition is in gray and the incongruent condition is in red. The Z-axis corresponds to the time (milliseconds) and the Y-axis corresponds to the amplitude size (µV).

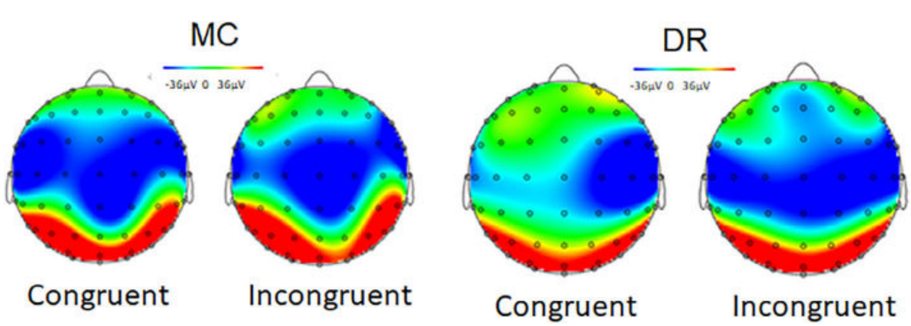

Fig. 3. Topographic maps for the congruent and incongruent conditions. Topographic maps for the congruent and incongruent conditions in the MC (left) and the DR (right) groups. The cold colors signify a negative voltage; the hot colors signify a positive voltage (scale −36 to 36 microvolts). A clearer difference between conditions is observed for the DR group.

Table 4
N200 Amplitudes and Latencies for the Congruent and Incongruent Conditions Following the MC versus the DR Intervention (Test 2) as an Assessment for Shifting and Inhibition (EF)

	MC group		*DR group*				
N200 Amplitude (μV) Electrodes	*Congruent (A) M (SD)*	*Incongruent (B) M (SD)*	*Congruent (C) M (SD)*	*Incongruent (D) M (SD)*	*Contrast*	*T (p)*	*F test*
Fz	−11.25 (5.647)	−11.34 (8.445)	−10.65 (6.293)	−13.16 (6.523)	A > B	0.093 (0.958)	Group
					C > D	2.516 (0.112)	F (1, 41) = 0.127 p = .723, η^2 = 0.003
					C > A	0.600 (0.747)	Condition
					B > D	1.824 (0.429)	F (1, 41) = 1.251 p = .270, η^2 = 0.030
							Conditions × Group
							F (1, 41) = 1.079 p = .305, η^2 = 0.026
Cz	−8.72 (4.350)	−7.24 (5.449)	−6.25 (7.104)	−10.29 (5.532)	B > A	1.486 (0.369)	Group
					C > D	4.045 (0.007)	F (1, 42) = 0.043 p = .836, η^2 = 0.001
					C > A	2.477 (0.188)	Condition
					B > D	3.055 (0.075)	F (1, 42) = 1.388 p = .245, η^2 = 0.032
							Conditions × Group
							F (1, 42) = 6.488 p = .015, η^2 = 0.131
FCz	−11.75 (6.770)	−10.69 (7.126)	−9.49 (6.634)	−11.66 (6.385)	B > A	1.062 (0.391)	Group
					C > D	2.173 (0.049)	F (1, 42) = 0.120 p = .731, η^2 = 0.003
					C > A	2.264 (0.273)	Condition
					B > D	0.970 (0.637)	F (1, 42) = 0.468 p = .498, 0.011
							Conditions × Group
							F (1, 42) = 3.943 p = .053 η^2 = 0.006

Table 4
Continued

N200 Amplitude (μV) *Electrodes*	*MC group* *Congruent (A)* *M (SD)*	*MC group* *Incongruent (B)* *M (SD)*	*DR group* *Congruent (C)* *M (SD)*	*DR group* *Incongruent (D)* *M (SD)*	*Contrast*	*T (p)*	*F test*
N200 Latency (in ms)							
Fz	350 (38.661)	351.47 (42.661)	353.17 (31.185)	363.00 (35.465)	B > A D > C C > A D > B	1.474 (0.882) 9.833 (0.267) 3.167 (0.768) 11.526 (0.339)	Group F (1, 41) = 0.640 $p = .428$ $\eta^2 = 0.015$ Condition F (1, 41) = 0.793 $p = .395$, $\eta^2 = 0.018$ Condition × Group F (1, 41) = 0.404 $p = .529$, $\eta^2 = 0.010$
Cz	355.05 (32.286)	370.11 (42.439)	361.84 (40.718)	368 (46.826)	B > A D > C C > A B > D	15.053 (0.128) 6.160 (0.470) 6.787 (0.554) 2.105 (0.879)	Group F (1, 42) = 0.047 $p = .830$, $\eta^2 = 0.001$ Condition F (1, 42) = 2.718 $p = .107$, $\eta^2 = 0.061$ Condition × Group F (1, 42) = 0.478 $p = .493$, $\eta^2 = 0.011$
FCz	346 (25.974)	346.84 (48.695)	351.04 (35.806)	366.24 (42.045)	B > A D > C C > A D > B	0.842 (0.942) 15.200 (0.136) 5.040 (0.607) 19.398 (0.164)	Group F (1, 42) = 1.793 $p = .188$, $\eta^2 = 0.041$ Condition F (1, 42) = 1.111 $p = .298$, $\eta^2 = 0.026$ Condition × Group F (1, 42) = 0.890 $p = .351$, $\eta^2 = 0.051$

Note. M = mean; SD = Standard deviation.

Changes related to EF were also found in the behavioral data: the MC group was superior to the DR control group in inhibition following training. On the other hand, the MC group was not superior to the DR controls in the shifting component of EF. Rather, as per previous findings (Twait et al., 2019b), we found that the DR training positively affected shifting.

The Effect of MC Training on EF

Our results regarding a reduced difference in the ANT N200 amplitudes between the congruent and incongruent conditions in the MC group, though no significant interaction was found, are in line with developmental studies that demonstrated how such a reduced difference is associated with greater neural efficiency and maturation (Buss et al., 2011; Rueda et al., 2005; Rueda et al., 2012; Rueda, Posner, et al., 2004). The difference between the N200 amplitudes for congruent versus incongruent conditions was previously related to EF abilities (Espinet et al., 2012) as part of the attentional networks model (Petersen & Posner, 2012).

Interestingly, the MC group did not exhibit superior performance, as did the DR group, on the behavioral shifting task, although the EEG task did indicate an improvement in shifting. A possible explanation can be that the behavioral shifting task that was utilized in this study (the animals and colors shifting task; Ziv, 2017) is a Stroop-like task. Luck and Gold (Luck & Gold, 2008) differentiate between tasks in which attention is utilized to select between inputs (e.g., the ANT task) versus tasks that require selection and shifting between rules (Stroop-like tasks). During the MC intervention, inhibition of automatic processes is made, and the attention is shifted intentionally towards particular objects or stimuli and from external stimulation to internal processes, including monitoring thoughts and feelings and inhibiting them if needed. On the other hand, in the DR intervention, the attention is directed from one external stimulus to another (while focusing on the stimuli in the book). Thus, it is possible that a task that emphasizes shifting attention to select between rules is not optimal or sensitive enough to study improvement in shifting that was trained on embodied stimuli and not mental rules. Future studies should assess mindfulness-based training effects in preschoolers using behavioral shifting tasks that (also) directly assess shifting between inputs.

This study joins previous intervention mindfulness-based programs in older children and adults that have proven themselves successful in improving EF attention processes (Diamond & Lee, 2011; Flook et al., 2015; Zelazo & Lyons, 2011; Zelazo & Lyons, 2012). The results of the current study demonstrate that the effect of MC training on EF in preschoolers can also be detected neurobiologically. Strikingly, it seems like the EEG data was sensitive to the change also in shifting in addition to those in inhibition (which were revealed behaviorally). This supports previous claims regarding the importance of EEG measures to reveal subtle mechanistic cognitive signatures of learning in young populations (Berger, 2011).

This study adds to a growing body of evidence supporting the training of academic or social/emotional skills with EF principles embedded in them (Cecil, Brunst, & Horowitz-Kraus, 2021; Cirino et al., 2019; Flook et al., 2015; Horowitz-Kraus & Holland, 2015; Peng & Goodrich, 2020). It might be that during childhood, when EF abilities are not yet fully matured, training academic or social/emotional skills while engaging in additional EF skills have the potential of improving EF skills with a transfer to additional abilities, which may explain the reported academic success in children trained in mindfulness. An additional follow-up study in the current study cohort might reveal the differential outcomes of mindfulness-based curriculums on academic skills and the relation to the level of EF changes following training.

Study Limitations

One limitation of this study was the lack of EEG data collected prior to the interventions (i.e., at Test 1). Additional limitations were the relatively small sample size of the participants and small variability in socioeconomic status and parents' education, which did not allow controlling for age and ethnic/racial identification. With that said, however, statistical analysis of behavioral data before interventions did not show any significant differences in group performance preceding both interventions, strengthening the argument of the effect of the MC training shown in the electrophysiological data. In addition, the results of the current study using EEG did not allow for further research on the exact location of the neurobiological impact of MC training. The use of fMRI could shed more light on the cognitive development of neurobiological markers in children in terms of activation of specific brain regions related to perceptual conflict resolution in preschool children following MC training. In addition, the study focused mainly on the facets of EF most studied in young children. To test the full attentional networks model, additional tests, including orienting and alerting attention abilities, are needed as well as adding a measure to test forms of updating to characterize the complete EF aspect. In addition, after correcting for multiple comparisons, the change in shifting following intervention in the behavioral results section was not significant, which may reflect the need to use other tasks more sensitive to shifting/switching abilities, such as the Wisconsin card sorting task, to determine the changes in shifting in this active control group. In addition, here, the MC group focused on both mindfulness and kindness training, and future studies should examine the differential effect of each of the components separately (mindfulness vs. prosocial skills) on facets of EF. Last, although the described program is based on many years of "hands-on" experience of mindfulness experts working with children, work that has been studied previously (Semple et al., 2017; Sheinman et al., 2018), it has been organized as a curriculum for the first time for this study. Although the developed curriculum was greatly inspired by the Kindness Curriculum (Flook et al., 2015), and was taught by an experienced facilitator, its fidelity, as measured by the treatment fidelity tool for mindfulness interventions (Kechter et al., 2019), has yet to be established.

Conclusions

To the best of our knowledge, this was the first study that attempted to examine neurophysiological mechanisms of MC training in preschoolers. As childhood is a critical period in the development of EF skills, curricula that are based on practices such as mindfulness can influence the shaping of brain development in ages as young as preschool. Integrating the behavioral and neurophysiological measures can give greater insight into the underlying mechanisms and effects of mindfulness-based programs during the crucial developmental window in early childhood and help in developing such programs to promote optimal EF development early in life. Together with previous studies, these results offer an optimistic view of interventions regarding EF development and propose mindfulness-based training as a promising way to shape and impact childhood experiences by improving EF skills.

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Conflict of interest

The authors have stated explicitly that there are no conflicts of interest in connection with this article.

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