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The Effect of Mindfulness-Based Interventions on Children's Self-Regulation

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The Effect of Mindfulness-Based Interventions on Children's Self-Regulation

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Originality statement

I declare that this doctoral dissertation was composed by myself, that the work contained herein is my own, and contributors (co-authors) are explicitly highlighted for each study wihin the dissertation and also in the acknowledgements. All contributros (co-authors) have agreed on including our collaborative publications (or manuscript). Due references have been provided on all supporting literature and resources. This work has not been submitted to any other degree or processional qualification, however, parts of this work have been published in the *International Journal of Behavioral Development*, the *Brain Sciences*, and the *Educational and Developmental Psychologist*.

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Introduction

In longitudinal studies, high self-regulation in childhood has been generally predicted better social and school functioning (Moffitt et al., 2011; Tánczos et al., 2014), while low self-regulation has been related to later substance use, externalizing behavior problems, depression, and anxiety (Coskunpinar et al., 2013; Coyne et al., 2018; Kuhn et al., 2017; Morris et al., 2010). Mindfulness-based interventions (MBIs) have been reported to be one of the most effective techniques to foster children's self-regulatory skills including executive functions (Dunning et al., 2018; Takacs & Kassai, 2020, Zoogman et al., 2015). The controlling of attentional processes has been often trained during mindfulness and proposed to facilitate self-regulation by strengthening executive control processes required for prioritizing and achieving one's goals and providing an optimal strategy to restore optimal external and internal conditions (Beckmann & Kellmann, 2004; Papies & Aarts, 2016). However, there is still a lot of contradictory results about the efficacy of mindfulness-based interventions on different aspects of self-regulation (i.e., executive functions, attention, emotion regulation), and a lack of research regarding the moderators of their efficacy (e.g., socio-cognitive characteristics of children, age, at-risk status, type of MBIs, components of programs). Moreover, a novel approach in MBIs, namely mindfulness training with EEG-feedback (or neurofeedback), has been commenced to gain interest in intervention research, however, its feasibility and efficacy with children has not yet been investigated thoroughly.

The current doctoral project aimed to extend prior research by assessing some open questions regarding the efficacy and moderators of mindfulness-based interventions on outcomes related to children's self-regulation. Secondly, the current dissertation intended to analyze the content of evidence-based MBIs for children in different developmental stages, and provide a practical age-appropriate guideline with recommendations for those who aim to practice mindfulness with children. Lastly, our goal was to investigate whether there is potential in inexpensive portable brain-sensing devices which provide EEG-feedback to support the learning process and effects of mindfulness meditation among children. In order to accomplish these research goals, a meta-analysis, a content analysis, and a pilot feasibility study were conducted.

First of all, in the meta-analysis we investigated the effects of mindfulness-based interventions on inattentive and hyperactive-impulsive behavior among 3-to-12 years old children (Vekety, Logemann & Takacs, 2021). The limitations of previous meta-analyses (Cairncross et al., 2016; Chimiklis et al., 2018) were adressed by our rigorous inclusion criteria of solely (cluster-) randomized controlled trial studies and moderators of intervention efficacy were assessed. With the beneficial effects of mindfulness-based interventions for children's behavior in mind, in the second study a content analysis was conducted in which we deconstructed evidence-based mindfulness programs to identified the core practices of mindfulness with children in two different developmental stages: early and middle childhood (Vekety, Kassai & Takacs, under review) in order to advise practical implementation of such programs. Finally, as an attempt to test an innovative technology-based mindfulness approach in an educational context, in the last pilot study of the doctoral project a mindfulness program with a portable brain-sensing device providing EEG-based feedback was adopted for elementary school children (Vekety, Logemann & Takacs, under review). The feasibility of this novel method within an educational context and its efficacy on children's executive functions and attention were explored.

In Chapter 1 the key concepts of the dissertation are discussed from different scientific perspectives including self-regulation and behavior problems, mindfulness and mindfulness-based interventions for children. In Chapters 2-4, the studies of the doctoral research are reported in details. In the final Chapter a general summary and discussion of the results of the studies are presented including interpretation of the theoretical and practical relevance of the findings with reference to the existing literature taking into account the limitations of the studies. The current doctoral project involved important theoretical and practical aspects for education and psychology as well, which will be thoroughly explicated within the common background of the doctoral project and the overview of the studies.

Studies of the Doctoral Research

STUDY 1: The effect of mindfulness-based interventions on inattentive and hyperactive-impulsive behavior among children - A meta-analysis

STUDY 2: How to practice mindfulness with children? A content analysis of evidence-based interventions from a developmental perspective

STUDY 3: Feasibility and effects of mindfulness meditation training with a brain-sensing device on executive functions and brain activity correlates in children

CHAPTER 1

Background

Self-Regulation

Since the 1980s a large number of publications on self-regulation appeared in the fields of social, personality, cognitive, educational, clinical, developmental and health psychology (Hofmann et al., 2012; Molnár, 2009). All these fields recognized the critical role of self-regulation in human adaptation, however, each area covers specific aspects of self-regulation using their own terminology (see Table 1). From the 2000s researchers have attempted to reduce this fragmentation and increase coherence in the different fields to promote a further understanding of the phenomena involving self-regulation (Boekaerts et al., 2000). Nowadays, self-regulation is generally interpreted as an umbrella concept, gathering well-known constructs such as executive functions, emotion regulation, behavioral regulation, cognitive control, delay of gratification, persistence, attention, executive control, effortful control, and self-control (Baumeister et al., 2004; Diamond & Aspinwall, 2003; King et al., 2018; Norman & Shallice, 1986; Rueda et al., 2005). Due to its multidimensional nature, self-regulation is still a difficult construct to define theoretically, and operationalize empirically. For this reason, the present subsection aims to introduce self-regulation by gathering its influential representations and models from different fields to present a comprehensive picture.

One of the earliest work that studied self-regulation comprehensively belongs to the developmental psychologist Claire B. Kopp (1982), who gathered the antecendents of self-regulation from the prenatal period and the possible mediators of its development (i.e., neuropsychological maturation, caregiver sensitivity, quality of mother-child relationship, cognitive processes). Kopp (1982) defined self-regulation as a complex ability to comply with request, adapt to situational demands, modulate intensity, frequency, and duration of verbal and motor acts in social and educational situations, to delay gratification, and to be aware of the socially approved behaviors. This social-cognitive developmental perspective highlights that self-regulation represents an important aspect of socialization (Kopp, 1982). Rothbart and Posner (1985) mainly agreed with this model, but pointed out that self-regulation involves inborn, automatic mechanisms and also voluntary mechanisms that develop through social interactions and the acquisition of culture. Their research proved that infants enter the world with innate, biologically-based temperamental characterisctics, such as self-regulation that can be defined as behavioral patterns of approach/avoidance, attentional orienting and selecting, which can modulate reactivity. Reactivity was defined as the arousability of motor activity, affect, autonomic, and neuroendocrine response, more specifically the speed, intensity, and duration of emotional, attentional, and motor reactions (Rothbart et al., 2004). According to Rothbart's model (1989) reactivity can be assessed through parameters of threshold of reaction, latency, intensity, and recovery time. Building on this model, neuroscience has identified automatic reactions evoked by stimulus as bottom-up self-regulatory processes that are generated in the amygdala (Chambers et al., 2009). In contrast, goal-directed voluntary processes evoked by cognitions (or knowledge) have been recognized as top-down self-regulation and integrated in the frontal lobe and the parietal cortex with many subcortical connections (Banfield et al., 2004; Cieslik et al., 2015; Luria, 1973; Posner & Raichle, 1994; Siegel, 1999; Shomstein, 2012; van Veen & Carter, 2002). Findings from neuroscience have complemented Rothbart's model: top-down self-regulation, that is knowledge driven, was proved to modulate bottom-up reactivity (or arousability) generated by salient stimuli (Connor et al., 2004; Gross, 1998). For instance, top-down self-regulatory strategies, such as cognitive reappraisal, can modify an emotion's impact in the brain region of the amygdala indirectly by activating the prefrontal brain regions with the reinterpretation of emotional stimuli (Gross, 1998). Importantly, emotions can be generated both by bottom-up and top-down processes, and cognitive reappraisal. Cognitive reappraisal is an often-used technique in psychological therapies such as the Cognitive-Behavioral Therapy (CBT) (Beck et al., 1979), and has proved to be more efficient moderating top-down generated emotions (McRae et al., 2012). Cognitions and behavior can also be influenced by bottom-up and top-down processes, but the top-down regulatory strategy of cognitive reappraisal can effectively modulate both (Long & Hayes, 2014). Additionally, it has been proved that top-down and bottom-up processes represent overlapping organizational principles, and in most situations and tasks they interact to optimize self-regulatory performance (Egeth & Yantis, 1997).

Parallel to the research from the social-cognitive developmental and neuropsychological perspectives, cognitive neuroscience has focused its attention on top-down voluntary control responsible for planning and execution of behavior (Banfield et al., 2004; Posner & Raichle, 1994). In one of the earliest cognitive models by Baddley and Hitch (1974), working memory was proposed to compose of three component: (i) the visuospatial sketchpad, (ii) the phonological puffer, and (iii) the central executive. While the role of the first two components was to store and update modality sepcific information, the central executive was reponsible for coordinating between the two other components and long-term memory. Later, Baddley and

Hitch (1994) updated their model regarding the role of the central executive, influenced by Norman and Shallice's (1986) Attention to Action model, which describes three sub-components of cognitive control that manage interactions and activities. The action schemata sub-component performs automatic skills, well-learned behaviors, and routinized cognitive processes, which all have an associated degree of activation that can be affected by incoming information. The contention scheduling sub-component solves conflicts among competing routinized activities based on their degree of activation. These schemas often activate each other automatically, but they can also be triggered by environmental stimuli. The last sub-component, the supervisory attentional system (SAS), continuously monitors and activates when higher-order cognitive mechamisms are required for adaptive behavior. Cooper and Shallice (2006) described five different situations in which the activation of automatic schemas is not optimal and the SAS presumable activates: (1) in situations where planning and decision making are required, (2) in situations where troubleshooting is required, (3) in unusual situations where a novel, untrained response is required, (4) in dangerous or technically difficult situations, and (5) in situations where strongly fixed, usual responses should be overwritten or when one should resist temptation. In the same decade, the concept of executive functions (EFs) has emerged among cognitive neuroscientists describing the goal-directed cognitive processes involved in monitoring and organizing the behavior (Denckla, 1989; Lezak, 1983). The concept of executive functions has become popular, because research found that EFs are essential for success in school and work situations, as well as everyday living (Jurado & Roselli, 2007). Diamond’s (2006, 2013) well-known comprehensive model includes three basic components of EFs, namely inhibition, working memory and cognitive flexibility, and so-called higher order executive functions that reflect the complex manifestations of the three core EFs.

Inhibition, the first core component of EFs has been described as being able to override automatic responses to a stong predisposition or external lure by controlling one’s attention, behavior, thoughts and/or emotions (Diamond, 2013; Miyake et al., 2000). Besides being called inhibition, this has been termed attentional control or attentional inhibition, endogenous, top-down, goal-driven, voluntary, volitional, selective, focused, or executive attention (Posner & DiGirolamo, 1998; Theeuwes, 2010). Inhibitory control mechanisms have been widely known in cognitive psychology to be involved in attention, memory, and language processes (Dagenbach & Carr, 1994 cited in Rueda et al., 2005). Voluntary control of inhibition begins to develop rapidly from the first year of life, with the maturation of the frontal lobe and the increasing number of connections between neurons (Diamond et al., 2007). In the course of development, behaviors that reflect inhibition are mostly based on socio-cultural learning, and later it gradually shifts to be guided by the child's own internalized rules and values, which is called self-control (Bronson, 2000; Hay, 2001; Luria, 1973).

The second core component of EFs in Diamond's model (2013) is working memory that operates as a mental information storage and manipulator. Working memory has been proposed to be necessary for making sense of language, translating instructions into action plans, updating plans with new information, seeing relations between items or ideas, and recalling memories for plans (Diamond, 2013). The updating function of working memory has been demonstrated even in 12 months old infants, however, mental manipulation is far slower to develop (Diamond, 1985; Davidson et al., 2006). Working memory has a limited capacity that shows individual variation, however, adults can memorize and operate withan average of four to seven units (Cowan, 2001; Cowan, 2010; Miller, 1956).

The third core component of executive functions according to Diamond (2006, 2013) is cognitive flexibility (or shifting) that enables the individual to change perspectives. More specifically, cognitive flexibility requires a complex process in which previous perspectives must first be consciously inhibited and then a new, different perspective must be brought into working memory. From another aspect, cognitive flexibility also means that we can think creatively (divergently) and change strategy when solving a problem (Diamond, 2013). Additionally, cognitive flexibility has been also associated with the ability known as mentalization, or theory of mind, which allows us to consider the views, thoughts, and states of others when interpreting their behavior, beliefs, and desires (Chan et al., 2008). As findings from developmental cognitive psychology proposed, cognitive flexibility builds on the other two components (inhibition and working memory), thus it appears later in development (Garon, Bryson & Smith, 2008)

Between the ages of 3-to-5 years, there is a significant increase in preschoolers' working memory, inhibition, and cognitive flexibility performance, which occur parallel to the changes in self- and social understanding (De Luca & Leventer, 2008; Diamond, 2013). This increased development provides a solid basis for more complex higher-order executive functions, such as planning, problem-solving, reasoning, and fluid intelligence, which develop later (Senn et al., 2004). Early theories thought executive functions were stable and static skills, however, neuroscience has shown that the brain network associated with executive functions is flexible and can be developed through learning and practice, not only in childhood but also in adulthood (Bryck & Fisher, 2012; Zelazo & Carlson, 2012).

Executive functions have also been categorizeded as “cool” or cognitively mediated (emotion free) behavioral regulation skills (e.g., attention, cognitive control, problem-solving) or “hot” emotion and motivation related skills (Zelazo & Carlson, 2012). This perspective is connected to models known as Dual System Models which include two operating systems (Hofmann et al., 2009). The “hot” subcortical system is reflexive and responsive to the actual environment, especially to stimuli with emotions, high novelty, or reward value (Inzlicht et al., 2021). Meanwhile, the “cold” system is influenced by long-term goals, carefully and effortfully planned actions, and impulse control which flexibly adapts the person to the environment (Meeus et al., 2021). Self-control dilemmas are often caused by the conflict of these two systems, such as the tension between long-term rewards or instant gratifications (e.g., waiting for two marshmallows or eat one now), where the more strongly activated “winner” system determines the behavior (Hofmann et al.,, 2009).

As Table 1 summarizes, self-regulation has been analyzed as a multidimensional construct that represents a variety of voluntary and automatic skills, processes, and individual characteristics involved in controlling and directing functions, states, and inner processes which help humans to successfully adapt to their environment (Rueda et al., 2005). According to the theory of Baumeister and colleagues (2004) the prioritization of goals is influenced by motivation and willpower, which can highlight a goal compared to others. The representations and models suggest that self-regulation has a crucial role from birth to help us to adapt to our environement and recover from stress through selecting and implementing an optimal strategy to restore the state of homeostasis (Beckmann & Kellmann, 2004). From a pedagogical aspect, high self-regulation has been claimed to be an important characteristic among effective learners (Molnár, 2002). Highly self-regulated learners have been stated to be more persistent, motivated, interested, and achieve more academically (Molnár, 2002). Many research suggests that poor self-regulation s a root cause of most of the social and personal problems of people from Western societies, such as addiction, criminality, procrastination, debts, or many psychological disorders (Baumeister et al., 2004; Coskunpinar et al., 2013; Coyne et al., 2018; Kuhn et al., 2017; Morris et al., 2010). In the following subsections, causes and consequences of deficient early self-regulation will be discussed, with a specific focus on attention, impulse control, and attention-deficit/hyperactive disorder (ADHD). Although there are several developmental deficits related to self-regulation (e.g., eating disorder, obsessive-compulsive disorder), we chose to focus on ADHD because of its high prevalence in childhood (Balazs & Kereszteny, 2014; Newman & Wallace, 1993; Scahill & Schwab-Stone, 2000).

Table 1

Models and Representations of Self-Regulation

Publication (first author, year)	Models and representations of self-regulation
Mischel et al., 1970	Delay of gratification and attention
Kanfer et al., 1972	Self-control theory for behavior therapy
Baddley et al., 1974	Three component working memory model, central executive as a component
Kopp, 1982	Antecendents of self-regulation: control and system organization, compliance, impulse control
Lezak, 1983	Executive functions: how behavior is organized
Rothbart et al., 1985	Self-regulation is a temperament characteristic that has affective, behavioral, and motivational aspects
Norman et al., 1986	Attention to Action model: three components of cognitive control, two automatic and one voluntary component (SAS)
Zimmerman et al., 1986	Self-regulated learning theory
Denckla, 1989	Executive functions and executive dysfunction among atypically developing children
Posner et al., 1990	Three component attention model: sustained, orienting, and executive attention
Baumeister et al., 1994	The Strength Model of self-control, ego depletion, motivation, and willpower
Barkley, 1997	Behavioral inhibition, sustained attention, self-control, executive functions in Attention-Deficit Hyperactivity Disorder (ADHD)
Siegel, 1999	Window of Tolerance model: optimal physiological arousal for effective emotion regulation
Miyake et al., 2000	Executive function model: updating working memory, shifting attention, inhibiting automatic responses
Diamond, 2006	Executive function model: inhibition, working memory, cognitive flexibility

Hoffman et al., 2009	Dual System Model: „hot” and „cold” self-regulation	

Self-Regulation Problems in Childhood

Research in the previous decades has revealed that teachers reported 15 to 50% percent of children having difficulties in behaviors requiring self-regulation, such as paying attention, remembering instructions, completing tasks independently, transitioning between tasks, or controlling automatic responses (i.e., raising their hand before participating or taking turns) (Koch, 2016; McClelland et al., 2000; Rimm-Kaufman et al., 2000). This might be problematic as self-regulatory efforts have been demonstrated to be essential in situations of dysregulation, such as conflicts, over-reactions, and tantrums (Howard et al., 2020). When these episodes of dysregulations are unaddressed, they can undermine a child’s relationships with peers and effective communications with adults (Miller et al., 2010). Behaviors related to self-regulation lay a foundation for individual learning, contribute to overall classroom functioning, and the quality of relationships with the teacher (Ponitz et al., 2007; Fowler et al., 2008).

Difficulties of self-regulation can occur in a children’s life due to various genetic (or intrinsic) and environmental (or extrinsic) factors (Eaves et al., 1997; Fox & Calkins, 2003). Genetic and biological factors of weak self-regulation are accompanied by a developmental susceptibility to weak EFs, attention, and inhibitory/impulse control problems (Blair & Diamond, 2008). Psychosocial environmental factors like (but not limited to) household chaos (Razza et al.n, 2012), poverty (Blair, 2010; Howse et al., 2003), parental psychological problems (Banerjee et al., 2007), divorce of the parents (Weaver & Schofield, 2015), insecure attachment (Siegel, 1999), early overexposure to electronic media (Cheng et al., 2010), family stress (Becker & McCloskey, 2002), sleep problems (Gregory & O’Connor, 2002; Sadeh et al., 2002), attachment problems (Hofer, 1995), stressful life events, and trauma (Attar et al., 1994) are all risk factors for self-regulation problems. Ford and Balustein (2013) revealed that childhood trauma and maltreatment induces involuntary self-protective survival-oriented biological changes in the brain’s three key areas: (i) the motivation and reward system related to dopamine hormone; (ii) distress tolerance related to serotonine and adrenaline hormones; and (iii) executive functions. These biological changes often persist after such stressful experience despite being no longer functional.

Compared to adults, children have underdeveloped self-regulatory abilities and coping skills, since their brain is still maturing, which makes them more vulnerable to stress (Blair, 2010). In addition, Hackman and colleagues (2010) stated that brain development occurs within a socioeconomic context and childhood socioeconomic status (SES) influences neural development. Therefore, children from lower socioeconomic backgrounds are at increased risk of experiencing stress and showing higher rates of attention problems and impulsive behavior (National Institute of Child Health and Human Development Early Child Care Research Network, 2005). A possible explanation for this relation might be the bidirectional model by Blair and Ursache (2011), stating that self-regulation and stress physiology interact in a feedback loop in response to envionmental cues. In line with this model, Beckmann and Kellmann (2004) proposed that self-regulation plays an important role in the optimal recovery from stress, by distancing oneself from a stressor, and supporting the orientation on a new activity. On the contrary, persistent or severe dysregulation can promote the perseverance of stress and increases the risk of developing behavioral and mental health problems (Beckmann & Kellmann, 2004; Hyde et al., 2012; Zhou et al., 2007). Prevention and intervention programs that aid self-regulation can be essential for the optimal development of children (Diamond, 2007, 2011). As Kuhn and colleagues (2018) found, developed top-down (or knowledge driven) processes might buffer the risks presented by biologically based deficient bottom-up self-regulation. These findings highlight the importance of those self-regulatory processes that are voluntary and can be developed through learning from the early years.

In the next subsection, attention, impulse control and ADHD, one of the most common disorders of self-regulation in childhood, will be thoroughly discussed.

Attention, Impulse Control and Attention-Deficit/Hyperactive Disorder (ADHD)

According to developmental psychology, the neuro-physiological mechanisms responsible for attention and impulse control have been observed to be the first signs of a more complex and later developing self-regulation (Berger et al., 2007; Kopp, 1982).

The three-component attention model presumes neuroanatomically different but interrelated brain networks in the background of attention processes (Posner & Petersen, 1990; Rothbart & Posner, 2015). The model differentiates three types of attention: (1) sustained attention, (2) orienting attention, and (3) executive attention. *Sustained attention* is considered as a bottom-up process, which has a role in reaching and maintaining alertness. According to Kopp (1982), initial forms of this attention process can be observed when infants start to show clearly defined cycles of wakefulness that are relatively similar to the social definitions of day and night. From childhood, this state of alertness (or wakefulness) helps to determine the response speed on any trial of cognitive tasks (Rothbart & Posner, 2015). *Orienting attention* directs the focus to external stimuli and helps to choose the relevant information that is connected to the individual's goal. Early in the development, an infant's attentional orienting appears to act as a distress or arousal regulator, by turning the eye away from stimulation as a self-soothing activity (Harman et al., 1997; Kopp, 1982). Finally, *executive attention* appears when we face cognitive conflicts that require the inhibition of automatic responses and goal-directed behavior. This type of attention is also responsible for concentration, selective processes of attention, and is considered to be the neurobiological basis of top-down self-regulation (Tiego et al., 2020). From top-down processes of attention, orienting attention develops first and rapidly in early childhood, then in primary school executive attention begins to mature intensively. According to Welch (2001) functions associated with the executive attention network overlap with the more general domain of executive function in childhood, which involves inhibition, working memory, cognitive flexibility, planning, and problem-solving. Correspondingly, research has established that poor executive attention has been associated with a larger impact of impulses on self-regulatory behavior (Hofmann et al., 2008).

The other early form of self-regulation, namely impulse control is often referred as impulsivity as a trait-level personality characteristic, a dimension of temperament, and also as a cognitive style (Pulkkinen, 1996). Impulses can be automatic motoric, cognitive, social-emotional, and motivational responses. According to Pulkkinen (1996), impulse control is an attempt to inhibit or modify these impulsive responses on the basis of situational demands, information, memory, or cognitive reappraisal. When impulse control fails, it manifests in the behavior as an inadequate reflection to the environment, error-prone information processing (Barkley, 1997). As it can be seen, impulsivity is well-known to be measured as a behavior or personality trait, but its failures have its roots mostly in inhibitory control (Thorell & Wahlstedt, 2006).

Although attention and impulse control are still developing through the lifespan, there are some age-appropriate behavioral expectations for children to regulate their own actions (Washington State Early Department of Early Learning, 2012). In the first years, children typically have difficulties with activities requiring sitting and listening, because their attention span is relatively short. From the age of 4-5 years, a child should be able to pay attention for 2 to 10 minutes on a task chosen by an adult (e.g., pick up toys, dress up), and 10 to 15 minutes on a novel and interesting task. At this age, a child should be able to resist impulses, wait longer to respond in structured settings and choose an appropriate behavior with little adult direction. Parallel to the maturation of the nervous system, one can expect children to sustain attention in an effortful manner for longer periods, as well as to ignore distractions which simultaneously appear in their environment (Washington State Early Department of Early Learning, 2012).

These behavioral expectations help experts to identify children who lagged behind in self-regulation development.

Persistent patterns of inattention and hyperactivity-impulsivity are the core characteristics of ADHD, the most commonly diagnosed neurodevelopmental disorder in childhood that interferes with functioning across multiple settings (American Psychiatric Association, 2000). According to the Diagnostic and Statistical Manual of Mental Health Disorders (DSM-V), inattentive behavior can be described by behaviors such as failure to listen when spoken to, or completely carry out instructions, along with difficulties of sustaining attention, organization, and on-task behavior (Kofler, Rapport & Alderson, 2008). Hyperactivity-impulsivity is generally described with behaviors such as an inability to sit still, excessive verbalization and activity, failure to inhibit responses and control behavior, and a tendency to interrupt others. These behavioral problems typically arise before the age of 7 years and stay relatively persistent over the development (American Psychiatric Association, 2000). Correspondingly, three presentations of the disorder have been noted in the DSM-V: the predominantly inattentive type, the hyperactive-impulsive type, and the most common combined type (Epstein & Loren, 2013). Although 5-10% of the children population is estimated to be affected by ADHD, it is well-known in clinical practice that a substantially higher number of children and adolescents present subthreshold symptoms (Balazs & Kereszteny, 2014).

Evidence suggests, that ADHD has both genetic and environmental underpinnings. The heritability estimates of the disorder vary between 75 to 90% (Rietveld et al., 2004). Genetic studies have found the dopamine D4 receptor gene (DRD4) and the dopamine neurotransmitter transporter gene (DAT1) to be associated with the prevalence of ADHD (Cook et al., 1995; LaHoste et al., 1996). Environmental risk factors of ADHD are overlapping with factors mentioned in the previous subsection of self-regulation problems, therefore these are not detailed here (Banerjee et al., 2007).

An influential theory investigating the root cause of ADHD claims that ADHD is a disorder of inhibitory control, which underlies a broader deficit in EFs (Barkley, 1997). This theory state that the ability of internal control (or self-control) does not develop typically in children with ADHD. According to Barkley (1997), there is a link between inhibitory control and four executive neuropsychological functions, namely: (a) working memory, (b) self-regulation of affect-motivation arousal, (c) internalization of speech, and (d) behavioral analysis and synthesis. Barkley's model also predicts some ADHD specific characteristics such as decreased empathy, decreased emotion regulation during goal-directed behavior, and increased emotional reactivity in provoking situations. Some of Barkley's predictions were proved to be true, but later Nigg (2000) estimated that only 35-50% of children with the combined type of ADHD have an inhibitory control deficit. Thus, the inhibitory control deficit might not be the only primary core deficit which causes the symptoms of the disorder.

According to another theory by Diamond (2005), the core deficit in the inattentive type of ADHD might be working memory and not inhibition. Those children with the inattentive type of ADHD easily get bored (also called an under-arousal state or hypoarousal), thus their problem might be more motivational rather than cognitive. Complementary to the previous models, motivational theories of ADHD claim that children with ADHD have an aversion to delay periods, which are likely to be filled by fidgeting and other off-task behavior (Sonuga-Barke, 2003). As neuroscience has demonstrated, pathologies of the brain's frontal areas related to inhibition, executive attention, and alertness are extensively common in ADHD (Berger & Posner, 2000). According to Logemann and colleagues (2010) specific anomalies can be found on electroencephalographic (EEG) measures of brain activity among ADHD patients. In particular, clinical studies observed an increased slow wave theta (4-7 Hz), less alpha (8-12 Hz) and decreased fast wave beta (12-22 Hz) activity (Clarke et al., 1998 in Logemann et al., 2010).

Although pharmacological treatments for children with ADHD are effective in the short-term, they often involve unpleasant side effects (Barkley et al., 1990). Side effects, such as increase in physiological and affective symptoms and a lack of weight gain were reported by parents of children taking psychostimulant medication for ADHD (Schachar et al., 1997). Additionally, Zylowska and colleagues (2008) stated that many patients with ADHD do not respond to pharmacological treatment, and also there are others who seek for additional treatments to alleviate their symptoms. Previous research suggested that non-pharmacological alternative treatments improving self-regulation and self-management, such as mindfulness-based interventions (MBIs), MBCT, or CBT, might be of high relevance for those with ADHD symptoms (Zylowska et al., 2008). However, there are no rigorous meta-analysis that observed the effect of MBIs on ADHD symptoms among children. In the following subsections, it will be discussed how mindfulness could potentially improve self-regulation problems, such as ADHD, with associated skills and mechanism throughly disscussed throught which mindfulness may exerts its benefits.

Mindfulness to Improve Self-Regulation

Mindfulness has been primarily defined as the act of bringing awareness to the experience of the present moment with a non-judgmental attitude (Kabat-Zinn, 2003). Later, mindfulness has also been interpreted as an enduring personality trait characterized as a susceptibility to be open to new experiences, attentive to distinctions, sensitive to context, aware of multiple perspectives, and oriented in the present (Brown & Ryan, 2003; Pirson et al., 2018). Moreover, cognitive theories have described mindfulness as a „special" attentional state (Bishop et al., 2004), and as a „set of neurocognitive-behavioral skills" that cultivate the regulation of attention and executive functions (Flook et al., 2015; Schonert-Reichl et al., 2015).

Zelazo and Lyons (2012) stated, that a non-judgmental attitude towards the exploration of the here-and-now, concentration, redirection of one's attention when it has wandered, and non-reactivity to thoughts and emotions are essential mindfulness-related skills, and MBIs are thought to enhance such skills. Based on previous research, attention (Lutz et al., 2008), emotion regulation (Broderick & Jennings, 2012; Galla et al., 2020), self-reflection and meta-cognition (Chambers et al., 2008; Jennings et al., 2012), empathy and compassion (Cheang et al., 2019) have also been considered as mindfulness-related skills and are often cultivated in mindfulness-based programs.

Moreover, mindfulness has been showed to decrease trauma-related negative symptoms, such as intrusive thoughts, and higher mindfulness has been associated with higher resilience (also known as flexible adaptation to changes) (Ortiz & Sibinga, 2017).However, it is important to note, that traumatized children are recommended to get special trauma-focused interventions with the presence of a clinical psychologist or trauma-focused expert. The reason behind this is that mindfulness practice can have possible risks, such as the loss of sense of being in control, self-judgemental thoughts, or getting owerwhelmed from the practice when experiencing stress (Kaufmann et al., 2021).

Mindfulness-Based Interventions

The concept of mindfulness has been rooted in ancient Buddhist philosophy and Vipassana meditation practice, and in the last several decades clinical and educational practitioners have begun to adopt the concept of mindfulness in the promotion of mental and physical health (Cullen, 2011). In 1979, Jon Kabat-Zinn developed the Mindfulness-Based Stress Reduction Program (MBSR) which was the first therapeutic intervention incorporating mindfulness meditation (MM) and yoga in its core practice targetting to treat those people from the Western society who suffer from acute or chronic stress (e.g., related to illness, pain, work). During the 2000s, mindfulness has been added to Cognitive Behavior Therapy (CBT) (Beck, 1976 in Beck, 1993), because research findings revealed positive effects of mindfulness on both bottom-up and top-down self-regulation (Kabat-Zinn et al., 1992; Teasdale et al., 1995;

Zelazo & Lyons, 2012). Unlike in CBT, there is little emphasis in Mindfulness-Based Cognitive Therapy (MBCT) on changing the content of thoughts, rather it is focusing on raising awareness to the arising thoughts and changing our relationship to thoughts (Teasdale et al., 2000). MBCT mainly aimed to help to prevent the relapse from depression and anxiety (Teasdale et al., 1995).

The evolution of mindfulness-based programs continued at a faster pace from the 2000s. Due to the positive findings of mindfulness programs on adult's self-regulation and mental health (Bartlett et al., 2019; Carpenter et al., 2019; Ebert & Sedlmeier, 2012), many practitioners and researchers have suggested that mindfulness practices could be beneficial for children in educational settings (Langer, 1993; Napoli, 2004). MBIs in education and mindfulness-related skills could thus be of significance because how children regulate their attention during learning, master mindful learning, or deal with stress and difficult emotions can influence the level of risk for maladaptive developmental trajectories (Compas et al., 2001). As mindfulness-related skills can be developed through intentional practice and socialization (Roeser & Eccles, 2015), MBIs in education have been claimed to have a high ecological validity for being able to reach a lot of children from different socio-economic backgrounds and promoting their optimal functioning, many times with the involvement of their teachers (Janz et al., 2019; Meiklejohn et al., 2012) or their parents (Lo et al., 2019, 2020). Based on previous research, mindfulness-based interventions seem to be promising cost-effective avenues to practice mindfulness-related skills in education, and increase physical, social-emotional, and mental health, while reducing self-regulation problems in children and youth (Carsley et al., 2018; Klingbeil et al., 2017; Takacs & Kassai, 2019; Zenner et al., 2014). However, it is important to highlight that children with psychological problems or trauma require special mindfulness inteventions with trained teachers to avoid any negative effects.

Mindfulness-based interventions (MBIs) have been used as an umbrella term including a wide variety of programs, that are based on the theory and practice of mindfulness, adopted to different stages of development. In the past ten years several programs have been developed and investigated with children, such as the Still Quiet Place (Saltzman, 2014), Paws b (.b Foundation, 2015), MindUP (Hawn Foundation, 2011), Kindness Curriculum (Flook et al., 2015), Mindful Awareness Practices (Flook et al., 2010), Inner Kids (Kaiser-Greenland, 2016), and the YogaKids (Bergen-Cico et al., 2015). Consequently, there is substantial heterogeneity between MBIs for children and youth, relating to dosage, theoretical base, and types of practices used (Emerson et al., 2020). Yet, there is no well-grounded consensus about the minimum number of mindfulness sessions that yields sustainable effects, neither from the content or core practices of MBIs. Acute effects on children's anxiety, attention, and executive functions could be observed in some studies even after one short mindfulness exercise (Bigelow et al., 2021; Carsley & Heath, 2018), while enduring changes in emotion regulation might only occur after long-term and/or more intensive programs (Tarrasch, 2018). Additionally, regarding the components used in MBIs, there is a lack of developmental perspective which summarizes age-appropriate recommendations for those who practice mindfulness with children. On the other hand, in the last couple of decades developmental experts shared a consensus in some basic principles regrading MBIs with children. As Jennings and colleagues (2012) stated an efficient age-appropriate mindfulness program should depend on the phase of development of intentional attention control and inhibition, as well as meta-cognition (to think about one's thoughts). Being aware of these developmental trajectories, experts recommend to begin mindfulness practice with a focus on sensory awareness experiences or mindful movements with the body (Jennings et al., 2012). As Hooker and Fodor (2008) reported in their review, directing a child's attention to what they can experience in the external environment is a non-abstract and attention-grabbing task for younger children rather than the observation of inner experience. Other basic principles regarding mindfulness practices targeting children were described in previous studies: (a) optimizing the duration of sustained practice sessions (e.g., sitting meditation), (b) using a wide variety of different practices and techniques, (c) implementing more movement-based activity, (d) incorporating multiple sensory modalities into activities, (e) relying on metaphors to communicate difficult concepts, (f) using humor and fantasy, (g) repeating the key aspects of mindfulness, (f) allow children to explore and try out new things (Felver et al., 2013; Hooker & Fodor, 2008; Jennings et al., 2012; Zelazo & Lyons, 2012). By applying these principles, mindfulness practices can be adopted for children in different developmental stages by adjusting the difficulty, language, and content of the program for their attentional and socio-cognitive characteristics.

Lastly, we find it important to mention two other psychological techniques that can be used to reduce stress and improve self-regulation among youth, namely autogenic training and relaxation. In the following paragraph, the similarities and differences are summarised between these three techniques.

Similarities and differences of mindfulness, autogenic training, and relaxation. The similarities of mindfulness, autogenic training, and relaxation are demonstrated with the following examples: (i) all can help to calm down and relieve stress; (ii) all can have a somatosensory, bodily focus; (iii) all are altered states of consciousness; (iv) accpeting present experiences is key in all three techniques. One of the main differences between the three techniques is that mindfulness trainings can be very complex with strong cognitive behavioral components, while autogenci training and relaxation mainly have a somatosensory bodily focus with the addition of symbol therapy components (Szőnyi, 2015). There is some evidence that mindfulness might help cognitive regulation more than relaxation, because Jain and colleagues (2007) found that mindfulness reduced rumination of negative thoughts more than relaxation. Another difference, is that mindfulness can be defined as a state and a skill as well, and mindfulness can be transformed to daily activities also (e.g., mindful eating, walking, washing the dishes). However, the similarities and differences in their mechanisms and effects have not been studied in previous literature.

Mechanisms of Mindfulness

The study of Jha and colleagues (2007) suggested, that mindfulness training improves attention-related behavioral responses by enhancing the functioning of specific subcomponents of attention. Correspondingly, the theory of Lutz and colleagues (2008) described three different types of attention trained through mindfulness programs which contribute to the development of different mindfulness-related skills. The first type is focused attention on an intentionally chosen object (e.g., breath, sounds) which promotes the ability to focus and calm the body and mind. The second type of attention is an open and receptive awareness to present internal or external experiences, which builds the skill of non-judgmental self-reflection to mental and sensory phenomena. The third type of attention in mindfulness-based interventions involves the monitoring of thoughts and emotions of oneself and others with kind acceptance, which promotes prosocial skills such as empathy and compassion.

MBSR, MBCT and many later mindfulness-based interventions have included regular, concentrated sitting and walking mindfulness meditation parctice in which one’s focuses attention on a particular stimulus (i.e., breathing, body sensations), during a particular period of time (Thompson & Waltz, 2007). This concentrated form of mindfulness meditation, called Focused Attention (FA) meditation, in which one centers attention on an intended object (i.e., the sensation of breathing or an external visual point) (Lutz et al., 2008; Tomasino & Fabbro, 2015). This form of meditation practice has been recommended for novel practicioners, and it has been shown to enable practitioners to develop selective and sustained attention, while eliminating task-unrelated thoughts and spontaneous mind-wandering (i.e., Default-Mode Network (DMN) activity) (Tang et al., 2012). The other MM style, called open-monitoring (OM), involves the non-reactive and non-judgemental monitoring of the present moment with all sensations, emotions, and cognitions. This form of MM requires more expertise and practice, and it seems to be associated with brain areas involved in monitoring attention and vigilance (Lutz et al., 2008). On the other hand, it is important to note that while some neural networks and psychological mechanisms are different in forms of MM, it has been proposed that mindfulness meditations share a common core neural network. This joint network enhances activity within the parasympathetic nervous system which induces calmness and relaxation, and also the regulation of attention, as well as metacognition (or decentering) (Ainsworth et al., 2013; Sperduti et al., 2012). Brewer and colleagues (2011) found that the main nodes of the DMN, which are associated with mind-wandering, self-referential processing, and unhappiness, were relatively deactivated in experienced meditators across all forms of MM.

Mindfulness-related skills and their improvement have been associated with neuropsychological mechanisms approached from electroencephalographic (EEG) neural oscillatory studies (Cahn & Polich, 2006; Lomas et al., 2015; Tomasino & Fabbro, 2015). Neural oscillations serve as key mechanisms in enabling communication between distant brain areas, with oscillations of different frequency corresponding to different brain network configurations and processes (Hipp et al., 2012). Accordingly, prior research has mainly reported alpha (8-12 Hz) and theta (4-8 Hz) oscillations as brain-activity correlates of mindful awareness, with an acute increase in amplitude during mindfulness practices and at resting state after a training (Aftanas & Goloseikin, 2003; Cahn & Polich, 2006; Kerr et al., 2013; Lomas et al., 2015). Alpha brain activity has been reported to play a role in attention regulation, inhibition, information processing, and filtering sensory input coming from our environment (Foxe & Snyder, 2011; Gruzelier, 2014; Kerr et al., 2013; Klimesch, 2012). Similar to alpha, theta oscillations have also been associated with inhibitory and memory consolidation processes, but they also signal a deep internally focused state connected to self-reflection (Gruzelier, 2014). In contrast, low beta brain activity has been associated with external attention in a wakeful state, while increased high beta activity (22-30 Hz) has been related to arousal and stress (Alonso et al., 2015; Ssang-Hee & Jung-Tae, 2010).

Based on these findings from neuropsychology and the recent development of brain-computer interfaces (BCIs), EEG-feedback protocols were composed to target mindfulness-related neuromodulation. This application of EEG-feedback is strikingly different from classical neurofeedback to reduce attention-deficit/hyperactivity disorder (ADHD) symptomatology. Generally, EEG-feedback protocols to reduce ADHD symptoms suppress theta activity and enhance low beta activity (12-20 Hz) (Logemann et al., 2010). In contrast, EEG-feedback protocols for mindfulness-related brain activity aim to reinforce activity in alpha and theta bands with positive feedback, while decrease high beta activity (Chow et al., 2017; Hawley et al., 2021; Hunkin et al., 2021; Kovacevic et al., 2015). Additionally, studies of mindfulness training and alpha-based neurofeedback training have found that both can lead to increases in alpha power and mindful awareness, and proposed alpha as a mediator of training effect on cognitive functioning (Bing-Canar et al., 2016; Chow et al., 2017; Grosselin et al., 2021; Hawley et al., 2021; Navarro-Gil et al., 2018; Polich et al., 2020; Sun et al., 2021; Yu et al., 2020). This improvement in regulating alpha waves exerts its positive influence in learning by allocating attentional resources more fully during early processing phases, and also by the neuromodulation of beta waves to slower alphas which process is responsible for memory consolidation (Moore et al., 2012; Yeh et al., 2021).

Novel Approaches: Mindfulness Practice With a Brain-Sensing Device and EEG-feedback

The number of studies investigating the effect of mindfulness training with EEG-feedback for adults has been constantly growing in this decade; showing positive effects of on attention and cognitive performance when compared to a control condition (Balconi et al., 2019a; Bhayee et al., 2016; Crivelli et al., 2019b; Hunkin et al., 2021), and a relaxed mindset with reduced stress and anxiety (Balconi et al., 2019b; Crivelli et al., 2019a; Hawley et al., 2021; Hunkin et al., 2021). However, evidence from other research regarding mindfulness with EEG-feedback have not shown a conclusive positive effect, thus it is still an open question whether such technological innovations can render any positive effects and support traditional mindfulness training (Acabchuk et al., 2021; McMahon et al., 2020; Polich et al., 2020).

In a prior study, Bhayee and colleagues (2016) randomly assigned adult participants to either a real-time mindfulness training with auditory EEG-feedback with the wearable Muse brain-sensing headband and mobile application (InteraXon Corp., 2015), for 6 weeks, or an active control group with the same amount of time, solving online math problems. Results revealed that participants in the intervention group had a significantly larger reduction in reaction time from pre- to post-test on the Stroop task than the active control group, which may suggest that the mindfulness group's inhibitory responses and attention became faster, thus more efficient. Likewise, Crivelli and colleagues (2019) implemented a 4-week intensive mindfulness training with auditory EEG-feedback, supported by the Muse brain-sensing device. Adult participants were were randomly allocated to either the neurofeedback-assisted mindfulness meditation group or the active control group. The mindfulness group demonstrated a relaxed mindset, improved electrophysiological markers of attention regulation (i.e., alpha/beta ratio at resting-state, event-related potentials during a Stroop-like task), and improved cognitive performance as measured by a complex reaction time task. Another prior study by Hunkin and colleagues (2021) has found that BCI-assisted mindfulness training with Muse headband resulted in increased state mindfulness and less mind-wandering when compared to a mindfulness (without feedback) group. Interestingly, they have also found that for some participants receiving feedback on mind-wandering during mindfulness practice heightened arousal and frustration, thus for them feedback was rather distracting and incongruent with their subjective experience. These studies with adults provide some initial support for the effect of mindfulness with EEG-feedback in improving aspects of attention and EFs; however, it is much less studied whether this novel approach is feasible and effective with children and from what age.

There have been only two empirical studies with children assessing preliminary effects of a mindfulness training with EEG-feedback, however these studies only used subjective reports by teachers. A study by Martinez and Zhao (2018) found that 3-minute of technology-supported mindfulness practice with the Muse headband once a week for 6 months resulted in less office discipline referrals among 13-14 years old students. The other empirical study from Antle and colleagues (2018) implemented a 24-session mindfulness training with an alpha and theta visual EEG-feedback protocol to reduce anxiety and increase mindful attention. Computer games were combined with visual feedback to create an age-appropriate environment for 5-to-11 years old children. According to their findings, this protocol successfully increased relaxation and mindful attention within-group from pre- to post-test in a classroom context reported by teachers and school counselors. Although these results are promising, no studies have been conducted yet assessing the effects of mindfulness with EEG-feedback on objective measures of executive functions and brain-activity correlates compared to a control condition. The current study extends prior research by assessing whether mindfulness supplemented with auditory EEG-feedback modulates plausible mindfulness-related electrophysiological correlates and translates to observable benefits in terms of objective measures of executive functions required for academic performance and self-regulated learning. Moreover, to the best of our knowledge, this is the first study that assessed whether a non-invasive brain-computer interface, can be used to enhance the effect of mindfulness on key processes important in a supportive and sustainable learning environment for elementary school children.

Summary of the Background

In summary, self-regulation is a multidimensional construct studied in education and psychology as well, given its importance in providing control processes which support children's successful adaptation in school, daily life, and interpersonal relationships. Poor self-regulation and executive functions (EFs), such as the inability to regulate attention, delay gratification, and flexibly switch between cognitions or behaviours to solve problems, have been associated with a host of short- and long-term problems across the lifespan, including school failure, drug abuse, and psychological disorders (Tang et al., 2012). However, previous research has demonstrated that EF skills can be enhanced and they are especially malleable in childhood, thus early interventions that address these skills are of enormous relevance (Diamond & Lee, 2011). As a prior meta-analysis investigating the effects of childhood interventions have pointed out, mindfulness was the most effective intervention to enhance EFs (Takacs & Kassai, 2019). The pedagogical relevance of mindfulness in schools also lies within the fact that research from the previous decades have revealed that teachers reported 15 to 50% percent of children having difficulties in behaviors requiring EFs, such as paying attention, remembering instructions, completing tasks independently, transitioning between tasks, or controlling automatic responses (i.e., raising their hand before participating or taking turns) (Koch, 2016; McClelland et al., 2000; Rimm-Kaufman et al., 2000).

Practicing conscious attention and other mindfulness-related skills, such as meta-cognition, decentering, acceptance, and orienting to the present moment, have been shown to aid both top-down and bottom-up self-regulation (Zelazo & Lyons, 2012). Therefore, it has been proposed that mindfulness-based interventions might decrease inattentive and hyperactive-impulsive behavior among children, however, previous meta-analyses did not provide rigorous methodological criteria for a conclusive evidence (Cairncross et al., 2016; Chimiklis et al., 2018). For this reason, the aim of Study 1 was to gather previous (cluster-) randomized controlled trials studies and reveal the efficacy of MBIs on inattentive and hyperactive-impulsive behavior among 3-12 years old children.

Despite that mindfulness received much attention in the recent decades, there has been a great heterogeneity among MBIs for children and a lack of clarity over the components and activities in programs for children in different developmental stages (Butterfield et al., 2020). Correspondingly, in Study 2, the content of mindfulness-based interventions for early and middle childhood have been analyzed, and a practical guideline from a developmental perspective was created for those who plan to practice mindfulness with children.

Given the fact that in some core practices of MBIs mindful attention can be difficult to master, especially for children, a novel approach called mindfulness with EEG-feedback (or neurofeedback-assisted mindfulness) on brain activity correlates of mindfulness have emerged from technological innovations for interventions. However, the feasibility of such a novel intervention has not been tested with children. As a result, in Study 3, we aimed to test the feasibility and effects of mindfulness training with EEG-feedback on children's self-regulation. In the following chapters, the results of these three studies will be demonstrated and discussed.

CHAPTER 2

STUDY 1:

The Effects of Mindfulness-Based Interventions on Inattentive and Hyperactive-Impulsive Behavior Among Children - A Meta-Analysis

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Abstract

Current research has reported the beneficial effects of mindfulness-based interventions (MBIs) on general domains of cognition and behavior among children. The present study is the first meta-analysis with controlled studies investigating the pre-post change effects of MBIs on two, widely experienced behaviors in childhood education, namely inattentiveness and hyperactivity-impulsivity. With a special developmental focus on the early years, a total of 21 studies with 3-to-12-year-old children were included in the meta-analysis. Results indicated that MBIs decreased children's overall inattentive and hyperactive-impulsive behavior with a small but significant effect size (k = 21, g^{+} = 0.38, p < .001). However, this overall positive effect was only significant when teachers rated children's behavior and non-significant when parents and children themselves were the informants. Additionally, MBIs showed a moderate effect in reducing inattentiveness and hyperactivity-impulsivity for children at-risk for such behavior. In conclusion, results indicate that MBIs which are relatively easily applied in educational practice, have the potential to decrease inattentive and hyperactive-impulsive behavior, and might contribute to children's overall better functioning at school.

Keywords: inattentiveness, inattention, impulsivity, hyperactivity, ADHD, mindfulness, mindfulness-based interventions, children, meta-analysis

Statement of the Problem

Behavior regulation problems, such as impulsive actions and deficient attention control, are often experienced among children in educational and clinical practice (Koch, 2016; Närhi et al., 2017; Schonert-Reichl et al., 2010). According to the survey of the Primary Sources, teachers reported an increased level of behavior problems, such as inattentiveness and hyperactivity-impulsivity across children (Scholastic and the Bill & Melinda Gates Foundation, 2012), which might have a cascading long-term effect on cognitive and social-emotional functioning from childhood to adulthood (Diamantopoulou et al., 2007; Moffitt et al., 2011). Consequently, it would be important to support practitioners by yielding evidence-based recommendations about whether MBIs could be used to support attention and impulse control from the early years, and decrease inattentive and hyperactive-impulsive behavior. As reported by previous meta-analyses, mindfulness-based interventions (MBIs) can be nurturing to a broad range of skills and domains (Dunning et al., 2018; Klingbeil et al., 2017; Maynard et al., 2017; Zenner et al., 2014; Zoogman et al., 2015). However, there is still substantial ambiguity pertaining to whether MBIs render specific behavioral effects. As the number of studies with MBIs has been growing, Klingbeil and colleagues (2017) have encouraged future studies on MBIs with more refined outcome domains, such as inattentiveness and hyperactivity-impulsivity. Such sub-domain analysis will yield evidence-based recommendations about whether MBIs could be used to alter these behaviors in childhood. In addition, it would be important to gain a more in-depth understanding of moderators that affect the efficacy of MBIs for changing these behaviors.

Aim of the Research

In the current study, we aimed to address previous methodological limitations in meta-analyses, and synthesize the available (cluster-)randomized controlled studies on the potential of mindfulness practices to reduce inattentive and hyperactive-impulsive behaviors in 3-to-12 years old children. The significance of this meta-analysis is also supported by the opinion of Sumner and colleagues (2018), who stated that the field of behavior change suffers from fragmentation and poor reporting, thus the rigorous systematic synthesis of evidence in behavior change interventions is needed. This meta-analysis would yield evidence-based recommendations about whether school-integrated MBIs could be used to alter these specific behaviors from early childhood. These would be important findings, given that pharmacological treatments for ADHD symptoms are not recommended at an early age, because they often involve unpleasant side effects (Barkley et al., 1990). In addition, it would be important to gain a more in-depth understanding of potential moderators of the efficacy of MBIs, such as environmental and/or developmental disadvantage of children, which are neglected areas in the previous systematic syntheses.

Hypotheses

1. In line with previous meta-analyses, we expected that mindfulness-based trainings have a small but significant effect on reducing behaviors of inattention and hyperactivity-impulsivity. That is, it was hypothesized that those children who participate in MBIs show a stronger reduction in both inattentive and hyperactive-impulsive behavior on pre-to-post-test change compared to the control groups.
2. We also hypothesized that samples at-risk for poor attention and impulse control benefit more from MBIs than non-at-risk samples. Consequently, a stronger positive effect of MBIs on inattention and hyperactivity-impulsivity was expected for samples with a diagnosis related to a neurodevelopmental disorder (e.g., ADHD) and samples with low socioeconomic status (SES). In addition, we assessed the effects of other potential moderators of the MBIs effectiveness, such as age, features of the intervention (e.g., length, leader, types of practices), and study quality.

Methods

Search Strategy

A systematic literature search was conducted to identify potential studies that investigated the effect of MBIs on children's inattentive and hyperactive-impulsive behavior (for the search string see Appendix 1). The comprehensive search was conducted in five electronic databases (PubMed, Scopus, Web of Science, Google Scholar, ProQuest) for journal articles and unpublished dissertations and theses. The search was conducted up until April 2020. Concurrently, using the snowball method, the reference lists of meta-analyses, review articles, and relevant studies on the efficacy of MBIs were also screened. The PRISMA flow diagram (see Appendix 2) demonstrates the process from identification until the inclusion of studies. Finally, 71 studies were assessed for eligibility based on the full-text articles, and 21 met all our inclusion criteria.

Inclusion and Exclusion Criteria

The included studies had to meet the following criteria:

- Study design: A randomized controlled or cluster-randomized (children were not randomly assigned to the conditions on an individual but on a group level (e.g., classroom)) design.
- Results of the intervention group were compared to a passive (no treatment) or an active control group (an activity that was not intended to decrease inattentive and/or hyperactive-impulsive behavior).
- Participants: The age of the sample did not exceed 12 years at the beginning of the study. That is because previous meta-analyses neglected the early ages of development, hence this study aimed to apply a special developmental focus on early and middle childhood.
- Intervention: The intervention program was primarily based on the concept of mindfulness (e.g., mindfulness meditation, mindfulness-based school curriculum, mindful yoga etc.), with mindfulness practices such as mindful breathing, mindful movements, enhancement of awareness or/and body scan as core elements of the program. Those studies that were explicitly described by the study's authors as "mindfulness" interventions were included in the meta-analysis.
- Studies that utilized mindfulness-based interventions to have an indirect effect on children through training solely the parents or the teachers were excluded from the meta-analysis.
- Studies including mindfulness as a sub-component in the intervention (e.g., DBT) were also excluded.
- Outcome measures: The study reported results on at least one outcome measure of inattentive and/or hyperactive-impulsive behavior, which was based on either self-report or the report of parents and/or teachers (e.g., the Hyperactivity subscale from the Strengths and Difficulties Questionnaire) on pre- and post-test. Questionnaires not differentiating between inattention and hyperactivity-impulsivity – but referring to both in the items - were also included as relevant outcome measures of overall attention and impulse control problems (e.g., BRIEF Global executive composite subscale).
- Language: The paper was written in English.

Operationalization of Variables and Coding Procedure

Studies that met inclusion criteria were coded by two independent coders. Statistical data for calculating the effect sizes and potential moderator variables were operationalized, and coded for each study: 1. sample characteristics (age, whether children were at-risk for attention problems and hyperactivity-impulsivity due to low SES or a neurodevelopmental disorder), 2.

study design (randomization on an individual-level (RCT) or a group-level (quasi-experimental), control condition (active or passive)), 3. characteristics of the MBIs (length of the intervention in hours and sessions, the instructor (teacher, expert, or both)), 4. type of outcome measure(s) (inattention, hyperactivity-impulsivity or an overall scale), and the informant/rater (children, parents or teachers), 5. statistics for calculating effect sizes (sample sizes, means and standard deviations on the pre- and the post-test) (see Table 1).

Some questionnaires and/or subscales were not apparently classifiable by the DSM-IV ADHD behavior symptomatology, which we used as a reference point for the categorization of the outcome measures (American Psychiatric Association, 2000). In those cases, we looked through the items of the scale to make a decision. For instance, the subscale of Emotion Regulation from the teacher-rated Social Competence Scale (Flook et al., 2015) was coded as an outcome measure of hyperactive-impulsive behavior based on the content of the items. After inspection of the items, the Youth Self-Regulation Inventory was categorized as a measure of overall inattentive and impulsive behavior.

Samples were considered at-risk for inattentive and hyperactive behavior in two cases: i) the presence of extant psychosocial stress factors in the children's environment (e.g., low income, household chaos, and disadvantaged living environment), or ii) the presence of a neurodevelopmental disorder (e.g., ADHD, learning disorders, ASD etc.). Any disagreements between the two coders were discussed until a consensus was reached. Inter-rater reliability (percentage of agreement) ranged from 80% (type of outcome measure) to 100% (sample size, diagnosis).

Table 1

The characteristic of the included studies

First author & year of publ.	Age range	Sample at-risk	Control	Intervention	Led by	Length	Outcome measures
Akbari, 2014	9-11 years	Yes, dyscalculia	Passive n = 15	Mindfulness-based curriculum n = 15	expert	10 sessions, 15 hours	SRQ-A(overall)
Bergen-Cico, 2015	11-12 years	No	Active: talk about mindfulness	Mindfulness & hatha yoga n = 72	teacher	48 sessions, 3 hours	ASRI (overall)
Britton, 2014	11-12 years	No	Active: history class n = 48	Mindfulness meditation training module n = 52	teacher	30 sessions, 3 hours	YSR (inattention)
Crescentini, 2016	7-8 years	No	Active: read & comment n = 16	Mindfulness-Oriented meditati program (MOM) n = 15	expert	24 sessions, 8 hours	1) CBCL (inattention) 2) CRS (inattention, hyperactivity) 3) CGI (hyperactivity)
Desmond, 2010	11-12 years	Yes, Low SES	Passive n = 25	Wellness works (from MAPs) n = 15	teacher	10 sessions, 6 hours	BRIEF (overall)
Flook, 2010	7-9 years	No	Active: reading n = 32	MAPs program n = 32	expert	16 sessions, 8 hours	BRIEF (overall)
Flook, 2015	M = 4.67 (SD = 0.27)	Yes, Low SES	Passive n = 37	Kindness Curriculum (KC) n = 29	expert	24 sessions, 10 hours	TSC (hyperactivity)

Table 1

Continued

First author & year of publ.	Age range	Sample at-risk	Control	Intervention	Led by	Length	Outcome measures
Janz, 2019	M = 6.5 (SD = 0.89)	No	Passive n = 36	CalmSpace n = 53	teacher	>120 sessior 40 hours	SDQ (overall)
Lo, 2019	5-7 years	Yes, Low SES	Passive n = 51	Family-based Mindfulness n = 51	expert	8 sessions 9 hours	CBCL (inattention)
Lo, 2020	5-7 years	Yes, ADHD	Passive n = 50	Family-based Mindfulness n = 50	expert	8 sessions 9 hours	1) CBCL (inattention) 2) SWAN (overall, inatte-ntion, hyperactivity)
Moreno-Gómez, 2020	5-6 years	No	Passive n = 38	Mindkinder n = 76	teacher + expert	144 sessions 36 hours	1) SPECI (overall) 2) BASC-2 (inattention)
Napoli, 2005	6-9 years	No	Passive n = 97	Attention Academy n = 97	expert	12 sessions, 9 hours	ACTeRS (inattention)
Razza, 2015	3-5 years	No	Passive n = 13	Mindfulness & hatha yoga n = 16	teacher	120 sessions 40 hours	CBQ (inattention, hyperactivity)
Sidhu, 2013	8-12 years	Yes, ADHD	Active: puzzle & Lego	Still Quiet Place program n = 15	expert	8 sessions, 6 hours	1) BASC-2 (inattention 2) CRS (inattention)
Thierry, 2016	4-5 years	Yes, Low SES	Passive n = 24	MindUp program n = 23	teacher	15 sessions, 6 hours	BRIEF (overall)

Table 1

Continued

First author & year of publ.	Age range	Sample at-risk	Control	Intervention	Led by	Length	Outcome measures
Torres, 2019	3-5 years	Yes, low SES	Passive n = 19	based on Kindness Curriculum & Mindful Games n = 23	teacher + expert	16 session 5 hours	BRIEF (overall)
Vickery, 2016	7-9 years	No	Passive n = 38	Paws b program n = 33	teacher	12 sessions, 6 hours	BRIEF (overall)
Viglas, 2015	4-6 years	Yes, Low SES	Passive n = 55	Mindful Schools program n = 72	expert	18 sessions, 6 hours	SDQ (hyperactivity)
Waldemar, 2016	10-12 years	No	Passive n = 58	Social-Emotional Learning (M-SEL) program n = 62	expert	12 sessions, 12 hours	1) SDQ (hyperactiv 2) SNAP-IV (overall
Willenbrink, 2018	8-12 years	Yes, Low SES	Passive n = 89	Growing Minds n = 100	expert	20 sessions, 7 hours	SSIS (overall)
Zelazo, 2018	3-5 years	Yes, Low SES	Active: literacy n=76	Mindfulness + Reflection n = 74	teacher	30 sessions, 12 hours	CBQ (inattention, hyperactivity)

SES = socioeconomic status, ADHD = attention deficit-hyperactivity disorder ; SRQ-A = Self-Regulation Questionnaire (Academic), ASRI = Adolescent Self-Re
ory, YSR = Youth Self-Report, CBCL = Child Behavior Checklist, CRS = Conners Rating Scale, BRIEF = Behavior Rating Inventory of Executive Function, TSC = T
ocial Competence Scale, IEC = Involuntary Engagement Coping Scale, ACTeRS =ADD-H Comprehensive Teacher Rating Scale, SCRS = Self-Control Rating Sca
dren's Behavior Questionnaire, BASC-2 =Behavior Assessment System for Children, SDQ =Strengths and Difficulties Questionnaire; SNAP-IV = Swenson, No

Meta-Analytical Procedures

The dependent variable in the present meta-analysis was the standardized average pre-to-post-test change difference between the intervention and control groups on inattentive and hyperactive-impulsive behavior outcome measures. The 3.3 Comprehensive Meta-Analysis software was used. In the analyses, effect sizes were standardized using the post-test standard deviations because none of the primary studies reported on the correlation between the pre- and post-test variables (Morris & DeShon, 2002). The difference in pre-post-test change was chosen as the dependent variable instead of the difference in posttest scores because cluster randomized trials were also included, which does not ensure equal groups.

In consideration of the relatively small sample sizes and different outcome measures in the primary studies, the standardized mean difference (Hedges' *g* estimate) was calculated to assess the difference between the intervention and the control condition. The Hedges' *g* formula was chosen because it corrects for small sample bias (Hedges, 1983). The average effect size and the corresponding 95% confidence interval were calculated using the random-effects model, which incorporates heterogeneity in meta-analyses (Borenstein et al., 2011). In our case, the positive effect size suggests less behavior problems in the intervention as compared to the control group. Cohen's (1988) interpretation of the effect sizes was obtained by our meta-analysis: a) "small" in magnitude around 0.20, b) "medium" around 0.50, and c) "large" around or above 0.80. Before calculating the average effect size, the independent effect sizes were screened for outlying values. A study with a standardized residual exceeding ± 3.29 was considered an outlier. We investigated the overall effect of MBIs on attention and impulse control problems, as well as the effects specifically on symptoms of 1. inattention and 2. hyperactivity-impulsivity.

The heterogeneity of the effect sizes was estimated using the *Q*-statistic and the I^2 estimate, which signifies the between-study variance caused by systematic differences across the studies beyond sampling error. Small I^2 values, until 25%, represent low variance. Moderate to large (above 50% and 75%) ratios of between-study variance (I^2) suggests substantial heterogeneity and the possibility that the observed heterogeneity may be explained by other factors on the study-level (Higgins et al., 2011).

Regarding the issue of publication bias, we applied several strategies. First of all, we aimed to include unpublished dissertations, theses, and research reports to avoid the tendency of journals to publish studies with significant results (Rosenthal, 1979). Secondly, we assessed the possibility of publication bias in the data set by examining the funnel plot with Egger's regression test (Egger et al., 1997). Additionally, a selected list of items was used from the

Cochrane Collaboration' Risk of Bias Tool and coded by one of the authors to assess the quality of the included studies (Higgins et al., 2011; Pascoe et al., 2017). Risk of bias was coded for the following five items: (i) sequence generation (whether the study described how they generated the allocation); (ii) allocation concealment (whether the study described the method they used to conceal the allocation sequence); (iii) blinding of informants who assessed children's behavior on the outcome measures (whether the informants were aware of the participants' condition); (iiii) missing outcome data (describes the completeness of main outcome data, including attrition and exclusion); (iiiii) selective reporting (of the outcome data in the study). Each study was rated for all categories, by giving 'minus' when the risk of bias was low, 'plus' indicating a high risk of bias, or 'question mark' if the risk of bias was unclear (see Table 4). Risk of bias was used as a moderator variable (RoB index) by calculating a discrete variable: each 'minus' was given a 1, each 'question mark' a value of 0, and each 'plus' a value of -1. With this change, individual studies could have a value between -5 and 5, with lower scores indicating a higher risk of bias.

Moderator variables were identified and coded across the studies regarding the characteristics of the samples, study design, interventions, and outcome measures. Moderator effects show the degree of the dependence between the effect sizes and the moderator variable (Hedges & Pigott, 2004). A series of retrospective statistical power analyses were performed for the subgroup effects, and the meta-regressions as suggested by Valentine and colleagues (2010). When tests for subgroup analysis are retrospectively found to have low power (less than approximately 80% as suggested by Cohen (1988), non-significant effects do not provide strong evidence for the rejection of a true effect. In most cases, power estimates showed low power for moderator variables (except publication and at-risk status), thus we decided to report only descriptive information instead of underpowered subgroup analysis ($Q_{between}$).

Results

Overall Effect of MBIs on Inattention and Hyperactivity-Impulsivity

A significant, small-sized positive effect of MBIs was found (see Table 2), which was a moderately heterogeneous effect, which is also visible on the forest plot. According to the I^2 statistics, approximately 44% of the variance was attributable to systematic rather than random error. The standardized residuals indicated that there were no outlier studies (see Figure 1).

Table 2

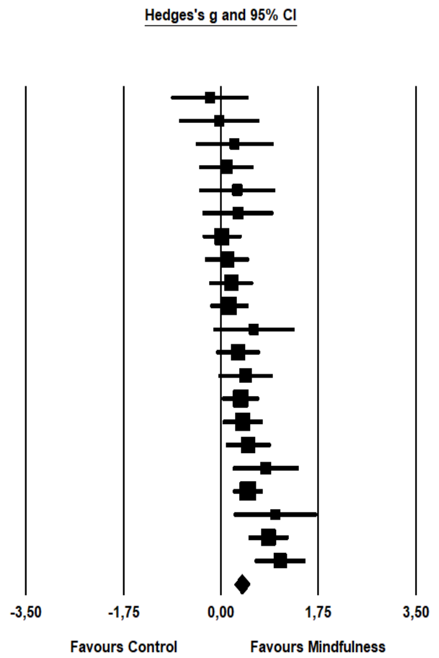
Average effects found overall and specifically for inattentive and hyperactive-impulsive behavior

	Intervention effects based on pre-post change					Heterogeneity		
	k	Mean effect size *(g^+)*	95% CI	*p*	SE	Q value	*p*	I^2
Overall effect	21	0.38	[0.25; 0.51]	<.001	0.07	35.89	.00	44%
Inattentiveness	9	0.22	[0.01; 0.42]	.03	0.10	16.28	.04	51%
Hyperactive-impulsive behavior	5	0.36	[0.15; 0.56]	<.001	0.11	1.36	.85	0%

Figure 1

Forest plot of the overall effect sizes of included studies

Study name		Statistics for each study						
		Hedges's g	Variance	Standard error	Lower limit	Upper limit	Z-Value	p-Value
Vickery (2016)	Combined	-0,195	0,125	0,354	-0,888	0,499	-0,550	0,582
Razza (2013)	Combined	-0,027	0,133	0,365	-0,742	0,688	-0,074	0,941
Crescentini (2016)	Combined	0,249	0,124	0,352	-0,441	0,938	0,706	0,480
Flook (2010)	Combined	0,097	0,061	0,247	-0,387	0,581	0,393	0,694
Torres (2019)	BRIEF - overall	0,296	0,119	0,346	-0,382	0,973	0,856	0,392
Desmond (2010)	BRIEF - overall	0,308	0,104	0,322	-0,323	0,939	0,956	0,339
Zelazo (2018)	Combined	0,023	0,030	0,174	-0,318	0,364	0,132	0,895
Britton (2014)	YSR - inattention	0,110	0,040	0,199	-0,279	0,500	0,555	0,579
Moreno-Gómez (2019)	Combined	0,186	0,039	0,198	-0,202	0,574	0,940	0,347
Waldemar (2016)	Combined	0,156	0,030	0,173	-0,184	0,495	0,898	0,369
Sidhu (2012)	Combined	0,594	0,138	0,371	-0,133	1,320	1,601	0,109
Lo (2019)	CBCL - inattention	0,309	0,039	0,198	-0,078	0,697	1,563	0,118
Flook (2015)	TSC -hyperactivity	0,444	0,062	0,248	-0,042	0,931	1,791	0,073
Bergen-Cico (2015)	ASRI - overall	0,357	0,028	0,167	0,029	0,684	2,134	0,033
Viglas (2015)	SDQ - overall	0,394	0,032	0,180	0,041	0,746	2,191	0,028
Lo (2020)	Combined	0,494	0,041	0,202	0,099	0,889	2,450	0,014
Thierry (2016)	Combined	0,809	0,090	0,299	0,222	1,395	2,702	0,007
Napoli (2005)	ACTeRS - inattention	0,488	0,018	0,134	0,226	0,750	3,652	0,000
Akbari (2014)	SRQ - overall	0,980	0,142	0,377	0,241	1,720	2,600	0,009
Willenbrink (2018)	Combined	0,853	0,033	0,181	0,498	1,209	4,706	0,000
Janz (2019)	SDQ - overall	1,064	0,053	0,230	0,612	1,515	4,619	0,000
		0,380	0,004	0,067	0,248	0,511	5,659	0,000



Specific Effects

Inattentive behavior effect size. There were nine studies assessing the specific effects of MBIs on inattentiveness. As shown in Table 2, a significant small positive effect of MBIs on inattentiveness was found. However, it should be noted that the 95% confidence interval was quite large so this estimate does not seem to be very precise. The effect was significant and moderately heterogeneous.

Hyperactive-impulsive behavior effect size. Five studies reported outcomes about the effect of MBIs specifically on hyperactive-impulsive behavior. As shown in Table 2, the effect of MBIs on hyperactive-impulsive behavior was significant, small-sized, positive and homogeneous.

Table 3

Subgroup analysis for the efficacy of mindfulness in reducing overall inattentive and impulsive behavior

	Intervention effects based on pre-post change						
	k	Mean effect size (g^+)	95% CI	*p*	SE	Q between	*p*
At-risk status							
At-risk children	11	0.47	[0.29; 0.64]	<.001	0.09	1.68	.19
Non-at-risk children	10	0.29	[0.10; 0.49]	.003	0.10		
Type of MBIs							
Mindful yoga	2	0.29	[-0.01; 0.59]	.05	0.15	-	
Complex programs	19	0.39	[0.25; 0.54]	<.001	0.07		
Leader of MBIs							
Teacher	9	0.35	[0.11; 0.59]	.005	0.12	-	
Expert	10	0.43	[0.26; 0.60]	<.001	0.09		
Informant of outcome measure							
Teacher	14	0.53	[0.15; 0.90]	.006	0.19		
Parent	6	0.17	[-0.17; 0.50]	.33	0.17	-	
Child	5	0.15	[-0.01; 0.72]	.62	0.29		
Study design							
RCTs	11	0.39	[0.26; 0.51]	<.001	0.06	-	

Quasi-experimental	10	0.36	[0.09; 0.64]	.009	0.14	
Control group						
Active	6	0.19	[0.02; 0.37]	.03	0.09	-
Passive	10	0.45	[0.29; 0.61]	<.001	0.08	

Moderator Analyses

Age. The meta-regression analysis indicated that the mean age of children did not moderate the efficacy of MBIs on overall inattention and hyperactivity-impulsivity significantly (coefficient = 0.02, SE = 0.02, CI 95% [-0.05; 0.05]).

At-risk status. Eleven studies (52%) included samples at-risk for attention or impulse control problems (see Table 1). MBIs had a significant medium-sized positive effect on overall attention and impulse control problems of at-risk children, and a small significant effect for non-at-risk samples (Table 3). When comparing the two samples, there were no significant differences in efficacy between the two groups. More specifically, the two study examining children with ADHD showed a significant medium-sized positive effect (k = 2, Hedges' g = 0.52, SE = 0.37, 95% CI [-0.13; 1.32], p = .004), while the one study including children with dyscalculia found a significant large positive effect (k = 1, Hedges' g = 0.98, SE = 0.37, 95% CI [0.24; 1.72], p = .009). Children from low SES background showed a significant, small reduction in inattentive and hyperactive-impulsive behavior (k = 8, g^+ = 0.42, SE = 0.11, 95% CI [0.21; 0.64], p < .001). Similarly, typically developing samples from probably middle and/or high SES showed a small but significant reduction regarding their inattentive and hyperactive-impulsive behavior from MBIs (k = 9, g^+ = 0.31, SE = 0.11, 95% CI [0.09; 0.53], p =.006).

Leader of intervention. Approximately half of the MBIs were implemented by an expert (52%), two MBIs by teachers and experts together (10%), and the rest were instructed by the teachers (38%). In studies where the teacher was the leader of the MBIs, a small, significant positive effect on impulsivity and inattentiveness was observed. Expert-led MBIs showed a somewhat larger significant positive overall effect (see Table 3).

Informants. MBIs showed a medium-sized, significant effect in reducing inattentiveness and impulsivity when teachers were asked to rate children's behavior (see Table 3). However, measures based on children's self-report and parental reports indicated non-significant effects (see Table 3). There was only one study which specifically stated using blind raters in respect to group assignment (Crescentini, Capurso, Furlan & Fabbro, 2016). The effect size found in this study was positive but not significant (Hedges' g = 0.23, SE = 0.35, 95% CI [-0.46; 0.92], p = .51).

Length of intervention. The overall duration of the trainings varied between 3 to 40 hours, including between 8 to 120 sessions, with a median of 6 hours and 10-12 sessions in total. Both total intervention time (coefficient = 0.004, SE = 0.01, 95% CI [-0.01; 0.02])) and number of training sessions (coefficient = 0.003, SE = 0.03, 95% CI [-0.003; 0.004]) had very small significant positive relationships with the effect size.

Study design. Eleven of the included studies (52%) utilized a quasi-experimental study design, while ten studies (48%) implemented individually randomized controlled design. In the overall efficacy of MBIs on inattention and hyperactivity-impulsivity, randomized controlled trials demonstrated a significant, small-sized positive effect similar to quasi-experimental studies (see Table 3)).

Control group. The average effect size in studies utilizing active controls indicated a small-sized significant positive effect size, however studies with passive control groups showed a medium, significant positive effect size (see Table 3).

Publication bias. As shown in Table 1, the included studies were published between 2005 and 2020 with a steady increase in the number of studies on MBIsfor children after 2010. A meta-regression analysis revealed that the year of publication had no significant relationship with the effect size (coefficient = 0.006, CI 95% [-0.03; 0.04]). Most of the studies (76%) were published in peer-reviewed journals, while there were three dissertations, one thesis and one unpublished research report. The average effect size found in published (k = 16, g^+ = 0.34, SE = 0.08, 95% CI [0.19; 0.49], p <.001) and unpublished reports (k = 5, g^+ = 0.54, SE = 0.12, 95% CI [0.30; 0.78], p <.001) were both significant, positive, and varied from small to medium; however, there was no difference between these average effect sizes (Q_{between} (1) = 2.05, p = .15), which further supports the absence of publication bias.

Risk of bias. Studies with the highest risk of bias (RoB index: -1) indicated a significant medium-sized positive effect (k = 2, g^+ = 0.54, SE = 0.12, 95% CI [0.31; 0.78], p <.001), while studies with the second highest risk of bias (RoB index: 0) showed a small-sized marginally significant positive effect (k = 7, g^+ = 0.17, SE = 0.09, 95% CI [-0.01; 0.35], p =.06). Studies with lower risk of bias demonstrated a significant, small-to-medium-sized positive effect (RoB index: 1) (k = 4, g^+ = 0.50, SE = 0.22, 95% CI [0.08; 0.93], p =.02), (RoB index: 2) (k = 3, g^+ = 0.71, SE = 0.25, 95% CI [0.23; 1.1], p =.004), (RoB index: 3) (k = 3, g^+ = 0.40, SE = 0.11, 95% CI [0.18; 0.62], p <.001). Included studies with the lowest risk of bias showed a non-significant effect (RoB index: 4) (k = 2, g^+ = 0.14, SE = 0.17, 95% CI [-0.20; 0.48], p =.41).

Table 4

Risk of bias assessment for the included studies

Study	Sequence generation	Allocation concealment	Blinding of outcome assessment	Missing outcome data	Selective outcome reporting
Akbari, 2014	?	-	?	?	?
Bergen-Cico, 2015	?	?	+	-	-
Britton, 2014	-	-	?	-	-
Crescentini, 2016	?	-	-	-	-
Desmond, 2010	+	?	?	?	-
Flook, 2010	?	?	+	-	-
Flook, 2015	?	?	+	?	-
Janz, 2019	-	?	+	-	-
Lo, 2019	-	-	+	-	-
Lo, 2020	-	-	+	-	-
Moreno-Gómez, 2020	?	?	+	-	?
Napoli, 2005	?	?	?	?	+
Razza, 2015	+	?	+	-	-
Sidhu, 2013	?	-	+	-	-
Thierry, 2016	+	?	+	-	?
Torres, 2019	-	?	+	-	-

Vickery, 2016	+	?	+	-	-
Viglas, 2015	?	-	?	-	-
Waldemar, 2016	+	?	+	-	-
Willenbrink, 2018	?	?	+	-	-
Zelazo, 2018	?	?	+	-	-

Discussion

This is the first meta-analysis of rigorously controlled pre-post-test studies of mindfulness-based interventions (MBIs) applied to improve children's inattention and hyperactive-impulsive behavior, which are two commonly experienced behavior problems in (pre-)school. By only synthesizing studies with control or comparison groups, the present study addressed limitations of previous meta-analyses including Cairncross et al. (2016) and Chimiklis et al. (2018). In general, children assigned to MBIs showed small to medium improvements in inattentive and hyperactive-impulsive behavior relative to children in the control groups. By observing these specific behavioral effects of MBIs, this meta-analysis provides a unique contribution to previous meta-analyses (e.g., Dunning et al., 2018; Klingbeil et al., 2017) that observed overall effects of MBIs on comprehensive cognitive and behavioral domains. Furthermore, this is the first meta-analysis that accounted for at-risk status (i.e., neurodevelopmental or socioeconomic risk of self-regulation impairment) as a potential moderator of efficacy of MBIs in reducing inattentive and hyperactive-impulsive behavior.

Including a total of 21 studies, meta-analytic results revealed that MBIs render a significant small positive effect on inattentive and hyperactive-impulsive behaviors. According to these findings, MBIs have a nurturing effect on attention and impulse control of children from 3-to-12 years of age. These benefits may be driven by both bottom-up (e.g., stress reactivity reduction) and top-down processes (e.g., enhancing executive function skills) of self-regulation, trained during mindfulness practices (Zelazo & Lyons, 2012). As Shapiro and colleagues (2006) assumed the first process of mindfulness practice is that it leads to a different perspective which results in positive changes regarding targeted outcomes, like better impulse control and less inattention.

Our results are in line with the results of previous meta-analyses, assessing the effect of MBIs on related domains including attention and behavior regulation, which showed small positive effects (Carsley et al., 2018; Dunning et al., 2018; Klingbeil et al., 2017; Maynard et al., 2017; Takacs et al., 2019; Zenner et al., 2014; Zoogman et al., 2015). The meta-analysis of Chimiklis and colleagues (2018) investigating the effect of MBIs, all kinds of yoga and meditation interventions on inattention and hyperactivity-impulsivity also indicated small to moderate positive effects of these interventions, although it is important to note, that most of their included studies implemented a single-subject design (73%) and were not RCTs (82%), unlike in the current meta-analysis. Cairncross and Miller (2016) reported moderate to large positive effects of MBIs on inattentiveness and hyperactivity-impulsivity, also with the majority of studies utilizing a single-subject design. The present study is the first meta-analysis with controlled studies investigating the effect of MBIs on inattentive and hyperactive-impulsive behavior in early and middle childhood with a pre-post change design.

The effect of MBIs on inattentive and hyperactive-impulse behavior was heterogeneous. As suggested by Borenstein and colleagues (2011), the characteristics of the included study designs were analyzed as moderators. Regarding study designs, results indicated similar small-sized significant positive effects within RCT's allocated on an individual level and quasi-experimental studies (allocated on a group level). Interestingly, Dunning and colleagues (2018) found that MBIs have a beneficial effect on negative behavior (e.g., aggression, hostility, etc.) and attention (not just inattentive behavior) among youth, but this effect disappeared in the case of negative behavior, and became tendency level in case of attention when they assessed the effects in studies that compared the effect to active control conditions. Our results demonstrated significant small positive effect sizes in studies using active control and medium-sized effects in studies using passive control groups, which tendency is relatively concurrent to the results of the meta-analysis by Dunning et al. (2018).

Moderator analyses about the individual characteristics of children revealed, that children at-risk for such behavior problems showed a medium-sized effect, while non-at-risk groups indicated a small-sized effect. However, findings revealed that this difference was non-significant, thus samples at-risk did not benefit significantly more from MBIs than non-at-risk samples. More specifically, studies with socioeconomically disadvantaged children showed a significant moderate-sized positive effect, while studies with typically developing children from middle and/or high SES showed a small positive average effect. In the two studies that tested MBIs with ADHD children, the effect was positive, medium-sized and significant. Another study including children with dyscalculia, in contrast, found a significant, large positive effect (Akbari et al., 2014). These are promising preliminary results, but further research is warranted regarding the potential of MBIs for children with neurodevelopmental disorders.

From other individual characteristics, the effect of children's age was also investigated, and showed a non-significant moderator effect regarding the efficacy of MBIs to decrease inattentiveness and hyperactive-impulsive behavior. This finding showed that MBIs could be efficiently implemented from an early age, such as 3 years, until elementary school. Given that this meta-analysis aimed to fill the gap in previous literature and put a special focus on investigating the efficacy of MBIs from an early age, this is an important finding.

Interestingly, the average effect of MBIs based on teachers' rating of children's behavior was significant, positive and moderate in size, while non-significant effects appeared when reports of parents and the children themselves were assessed. Similarly, Klingbeil and colleagues (2017) also showed a non-significant effect size regarding self-reports. Unlikely, Chimiklis and colleagues (2018) reported a significant effect of MBIs when rated by the parents, whereas this effect was heterogeneous and moderated by the length of the intervention and former ADHD diagnosis, with longer interventions and former ADHD diagnosis indicating a larger effect size. One explanation for the absence of parent- and self-perceived efficacy of MBIs could be that all MBIs from the selected studies were implemented in a (pre-) school setting, and teachers were mostly non-blind for group assessment. Additionally, in approximately half of the MBIs, the teachers were the ones giving children the intervention and reporting on their behavior, which might be a serious source of expectation bias. Furthermore, there might be a chance that MBIs in education provided by teachers are changing teachers' perceptions of children more than they are changing children's behaviors. Another possible explanation might be that hyperactivity-impulsivity and inattention can be more striking in the school environment, where high levels of sustained attention, regulation of behavior and delay of impulses are required. Also, teachers might also be more professional and objective in observing children's behavior than parents or the children themselves. This is supported by the longitudinal study of Verhulst and colleagues (1994) where teacher's reports about behavioral problems were more accurate predictors of poor outcomes in the future than parent's observations.

Results also indicate that MBIs can be similarly efficiently implemented by regular teachers as long as reducing inattentiveness and hyperactivity-impulsivity is concerned, however, experts showed a somewhat larger effect size comparing to teachers. These findings are in line with the findings of Maynard and colleagues (2016). Another meta-analysis by

Carsley and colleagues (2018) reported that MBIs facilitated by a teacher had a greater effect at post-test of mental health than those delivered by an outside facilitator, while regarding mindfulness outcomes an outside facilitator was more beneficial.

Implications

Due to their cost-effectiveness and feasibility, MBIs have gained a substantial amount of interest in the recent years. This meta-analysis reinforces the rationale for the implication of MBIs in an educational context even from the preschool years. Our findings indicated that teachers can effectively implement MBIs following some training, and decrease inattentiveness and hyperactivity-impulsivity in their groups. To our knowledge this is the first meta-analysis that investigated the moderating effect of the samples' risk status for behavior regulation problems regarding the efficacy of MBIs, and this finding has very important implications for the practical application of MBIs. According to the results, MBIs on a group level are beneficial for all children in school, but for those who are at-risk for attention and impulse control problems these benefits seem to be even somewhat larger. Similarly, Diamond and Lee (2011) also found that children with less developed self-control, such as children from low SES or with low EF skills or ADHD, gain the most from any intervention which train self-control. These findings might indicate that MBIs could potentially reduce the achievement gap between children, and support those who underperform because of attention or impulse control problems.

Another important finding about the implication of MBIs was that the length of the programs did not seem to have an effect on the efficacy of MBIs, which means that even a shorter intervention, such as 3-5 hours, can effectively decrease inattention and hyperactivity-impulsivity among 3-to-12 years old children.

Limitations and Future Directions

First of all, unfortunately statistical power was low for many of the subgroup-analyses and meta-regressions, except for at-risk status of the samples and publication status, thus a subgroup comparison was conducted only with these moderators. The analyses of other moderator variables (e.g., leader of intervention, length of MBIs, etc.) were limited to effect sizes.

Although this meta-analysis restricted selection criteria to the inclusion of solely controlled studies with pre-post assessment, the included studies still represent some risk of bias due to methodological issues (see Table 4) - for example (i) the lack of an active control group in some studies might have led to performance bias and non-specific treatment effects, (ii) two quasi-experimental studies allocated on a group level reported non-equal groups at pre-test, thus the risk of selection bias (Lo et al., 2020; Torres, 2019), while four quasi-experimental studies did not report baseline differences, and (iii) non-blind raters might be influenced by expectancy and detection bias (Higgins & Altman, 2008). It is important to note, that most studies with MBIs failed to report the blinding of outcome assessment.

Finally, although the central question of the present meta-analysis was to change behaviors of inattention and hyperactivity-impulsivity, interestingly, there was only two studies that implemented a mindfulness intervention with a diagnosed ADHD sample. Thus, it is questionable whether the present results can be generalized to children with an ADHD diagnosis. At the same time, the present meta-analysis highlights this gap in the literature, and encourages future mindfulness RCT investigations with ADHD samples.

Conclusions

Mindfulness-based interventions for children resulted in a small- to medium-sized significant decrease in inattention and hyperactivity-impulsivity depending on whether children were at-risk for such behavior problems due to neurodevelopmental or environmental disadvantage (e.g., ADHD, low SES), or non-at-risk. Importantly, the overall effect was significant and moderate when the informants were teachers, but when parents or the children themselves rated their own behavior, the effects were non-significant. Despite the limitations, these results provide additional empirical evidence for the inclusion of MBIs in the school curriculum and the consideration of mindfulness practices as a possible support for the development of attention and impulse control in early and middle childhood (both preschool and elementary school). This is further highlighted by the finding that MBIs arebeneficial for children at-risk for inattentive and hyperactive-impulsive behavior and non-at-risk children as well. Accordingly, MBIs added to the curriculum might serve as an early intervention to reduce the gap in attention and impulse control skills among disadvantaged and non-disadvantaged children. Overall, results highlight the potential of MBIs as classroom interventions, which can be relatively easily added to the curriculum, and can serve as a tool for educators to constructively reduce the widely reported attention and impulse control problems. In the future, further research is needed to investigate the effect of MBIs on other specific behaviors in childhood (e.g., subtypes of anxiety, compulsion, aggressive behavior). These findings would have an important practical relevance especially for interventions embedded in education to decrease behavior problems.

CHAPTER 3

STUDY 2:

How to Practice Mindfulness With Children? A Content Analysis of Evidence-Based Interventions From a Developmental Perspective

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Abstract

As the number of mindfulness-based interventions (MBIs) for children has been constantly growing, there is a benefit to be derived for a comprehensive study that gathers what mindfulness activities have been reported to be effective at particular developmental stages, and how these practices have been modified to make them age-appropriate. To address this problem, the content of twenty-six (cluster-) randomized controlled studies were analysed to identify any quantitative and qualitative differences.

The duration of MBIs varied greatly ranging from 4 to 25 weeks, 8 to 144 sessions, and 3 to 45 hours, with session duration from 3 to 90 minutes, which is an important factor to take into account. MBIs for early childhood were more likely to use mindful movement practice, psychoeducation, and story-based context. In case of other components, such as breathing awareness, working with thoughts and emotions, qualitative differences were found between early and middle childhood regarding how the activities were implemented in a developmentally appropriate way. Preliminary review results showed a positive impact of MBIs with specific components on attention, executive functions, metacognition, self-regulation, prosociality, and anxiety.

The present study offers practical implications and distinguishes differences in mindfulness activities for early and middle childhood. Important developmental considerations have been raised for future program developers and practitioners regarding of mindful movement and body practices, psychoeducation, and story-based elements in MBIs.

Keywords: mindfulness, children, development, content analysis, components, practice, MBIs

Statement of the Problem

In 2015 Roeser and Eccles addressed the question whether mindfulness programs can be modified in a developmentally appropriate and effective way for children. Since that time a series of meta-analyses has proved that mindfulness-based interventions (MBIs) are evidence-based avenues to increase children's mental health and self-regulatory skills, indicating that the adaptation was successful (Carsley et al., 2018; Dunning et al., 2018; Klingbeil et al., 2017; Takacs & Kassai, 2019; Zoogman et al., 2015; Vekety et al., 2021). However, there has been substantial variation in the evidence-based MBIs for children and a lack of clarity over individual mindfulness components across programs (Butterfield et al., 2020). Some MBIs have focused more on sitting meditation exercises (Britton et al., 2014), while others have incorporated a strong focus on children's social-emotional skills (Flook et al., 2015; Waldemar et al., 2016), and some MBIs have been predominantly based on mindful body exercises such as yoga (Razza et al., 2015). The present study aimed to identify which mindfulness activities and components in MBIs are appropriate for children in different developmental stages by analyzing the content of evidence-based MBIs. Furthermore, the current study provides a preliminary review about the impact of MBIs with specific components on different outcomes among children related to self-regulation (e.g., attention, emotional control, impulsivity, aggression). As practicing mindfulness during early and middle childhood may be a sensitive period, given that cognitive processes including self-regulation develop most remarkably over these developmental stages, it would be important to contribute to the anchoring of the theory and practice of mindfulness over these time periods (Dunning et al., 2018; Moreno, 2017).

Aim of the Study

The present content analysis aimed to investigate the components in mindfulness-based interventions for children with a special developmental focus on the differences in components and related activities for early and middle childhood. The meta-analysis of Zenner and colleagues (2014) investigated the components and activities of twenty-four MBIs with youth from 6 to 18 years. They identified the following eleven components in MBIs: (a) breathing awareness, (b) working with thoughts and emotions, (c) awareness of senses and practices of daily life, (d) body-scan, (e) mindful movements, (f) group discussion, (g) kindness practice, (h) psycho-education, (i) body practice (like yoga), (j) home practice, and (k) additional material. This meta-analysis demonstrated that MBIs for youth implemented a wide variety of components. However, they omitted investigation of the components and related activities in MBIs for children in early childhood, and also to differentiate between components and activities in different developmental stages. Moreover, previous studies have not yet explored how MBIs with specific components impact different outcomes, while this question is also of high practical relevance.

Research Questions

RQ1: Which components are implemented in evidence-based MBIs in early and middle childhood?

RQ2: Are there any qualitative and quantitative differences between the components and the corresponding activities in MBIs for early and middle childhood?

RQ3: What are the affected outcomes in the included studies of MBIs with specific components?

Methods

Sample of Mindfulness-Based Interventions

Studies which investigated the effect of MBIs were selected from two previous meta-analyses of ours that showed significant small to moderate effects of MBIs on self-regulation, more specifically executive functions ($g^+ = 0.46$), inattention ($g^+ = 0.22$), and hyperactive-impulsive behavior ($g^+ = 0.38$) among 3-to-12 years old children (Takacs & Kassai, 2019; Vekety et al., 2021). The twenty-six (cluster-) randomized controlled studies included in these meta-analyses provided strong evidence for the efficacy of these MBIs on children's self-regulation. As Rosenthal and DiMatteo (2001) stated, meta-analyses present the highest level of evidence. One reason behind this is that the methodology of meta-analyses requires researchers to be extremely thorough in the search for relevant studies. Accordingly, it was decided to subject these evidence-based mindfulness programs from our two meta-analysis for further investigations in the present content analysis, in order to investigate the best practices of teaching mindfulness in early and middle childhood. The first meta-analysis studying the effects of different types of interventions, including MBIs (*k* = 6), on children's executive functions, involved primary studies until 2017 (Takacs & Kassai, 2019). The second meta-analysis provided findings about the effects of MBI's (*k* = 21) on hyperactive and impulsive behavior in childhood, included studies until 2020 (Vekety et al., 2021). Both meta-analyses conducted a rigorous systematic search, inclusion and exclusion criteria to identify empirical studies about the effect of mindfulness-based interventions on executive functions and hyperactive-impulsive, inattentive behavior.

From the twenty-seven studies identified in the two meta-analytic studies, there were one study which was included in both meta-analysis (Viglas, 2015). Two included studies used the exact same mindfulness protocol (Flook et al., 2015; Poehlmann-Tynan et al., 2015). and another two studies implemented the same protocol of a family-based mindfulness program (Lo et al., 2019; Lo et al., 2020). Consequently, the content of these MBIs were analyzed as one.

Furthermore, there were two studies incorporating a mindful yoga training based on the YogaKids program (Bergen-Cico, Razza & Timmins, 2015; Razza, Bergen-Cico & Raymond, 2015), however, their protocols were not identical because they targeted quite different age groups (see Table 1), thus it was decided to treat the two programs as independent.

Moreover, the corresponding authors of the included studies were contacted through email for a more detailed description of the content of the MBIs applied in their studies. Six of the contacted authors replied and provided further information (Bergen-Cico et al., 2015; Flook et al., 2010, Flook et al., 2015; Poehlmann-Tynan et al. 2015; Vickery & Dorjee, 2016; Wimmer et al., 2016).

Stages of Analysis

As Figure 1 outlines, in the first stage of the research the main aim was to answer the first research question and identify the components in MBIs for children with a qualitative content analysis. This first analysis provided data about the components implemented in MBIs for children. In the second stage, a descriptive analysis was conducted to indicate the ratio of specific intervention components applied in the primary studies. To answer the second research question, a difference analysis was performed on the quantitative data to reveal any distinction between the frequency with which the components were used in programs in early and middle childhood MBIs. Additionally, a qualitative analysis was completed on the content derived from stage one, to separate qualitative differences between the components and activities in both developmental stages. In the third stage, a review was conducted about the empirical evidence on the outcomes of included MBIs with specific components identified in stage one. Lastly, the fourth step of the research was to integrate results from all analyses and draw conclusions.

Figure 1

The Stages of Analysis with Associated Research Questions

Type of Analysis		
	1. Qualitative: content analysis (RQ1)	4. Integration of results, drawing conclusions
	2. Quantitative: descriptive analysis, analysis of difference (RQ2) Qualitative: content analysis of components and activities (RQ2)	
	3. Preliminary review of empirical evidence on the outcomes of included MBIs with specific components (RQ3)	

Qualitative Analysis

As the first step of the content analysis, an external scheme about the components of MBIs by Zenner and colleagues (2014) was pilot tested. Two of the authors coded five of the included studies independently. The two coders were knowledgeable in mindfulness programs with 4-5 years of experience within this field. After the preliminary coding Zenner's scheme was revised. Two categories (i.e., mindful movements, body practices) were merged into one (i.e., mindful movements and body practices) because the coders could not clearly differentiate between them based on the content of the programs. Moreover, the coders identified two additional components in MBIs, namely playfulness and story-based context. The final category system incorporated ten core components of MBIs with children: (1) breathing awareness, (2) working with thoughts and emotions, (3) awareness of senses and practices of daily life, (4) body-scanning, (5) mindful movements and body practices, (6) kindness practice, 7) psycho-education, (8) group discussion, (9) home practice, (10) additional components (i.e., playfulness, story-based elements). Definitions for each component can be found in Table 1.

Table 1. Definition for each mindfulness program component

Component	Definition
Breathing awareness	paying attention to one's own breathing without effort to control it or change it
Working with thoughts and emotions	practices about emotion comprehension, expression, and regulation; and/or meta-cognition
Awareness of senses and	paying attention to sensory experiences in the present moment (e.g., seeing, hearing, touching, smelling, tasting); and/or practicing

practices of daily life	mindful attention during everyday activities (e.g., eating, brushing teeth)
Mindful movement and body practice	paying attention to one's own body movement (e.g., walking); and/or body practices like yoga, tai chi
Body scanning	paying attention to one's own body by focusing on the sensations or relaxation of one or more body parts, in steps from part to part
Kindness practice	practicing kindness and non-judgemental attitude towards ourselves and others; and/or activities aim to enhance prosocial skills (e.g., empathy, sharing)
Psychoeducation	structured and didactic information sharing about mindfulness and related skills (e.g. stress management) with children or their parents
Home practice	practicing mindfulness at home by involving the parents (and family) to some extent
Group discussion	group conversations led by the mindfulness teacher, involving the discussion and self-reflection related to mindfulness activities
Playfulness	game-like mindfulness activities characterized by fun and spontaneity (e.g., pretend play, puppet shows)
Story-based context	mindfulness activities embedded in a story; and/or reading a story related to an aspect of mindfulness (e.g., sharing)

Descriptive information gathered from the studies were recorded on a coding scheme: (i) age of the participants and their developmental stage, (ii) name of the MBIs, (iii) duration of the sessions and program, (iv) components and activities identified in the MBIs program description, (v) significant effects of the MBIs in primary studies. The categorization of developmental stages was based on the age range of the sample in the primary studies. Children until the age of 7 years were considered to belong to early childhood, while samples from 8 to 12 years were categorized as middle childhood (Best Start Resource Center, 2015).

The categorized content of the components and related activities in MBIs was highlighted in all studies and organized with QSR International's Nvivo 12 software (2018). To identify any qualitative differences between component-related activities, developmental stage related signs in the content were scanned, and similarities or differences were coded. However, in many cases the quantity of content was insufficient for further qualitative analysis because there were only a few words in the paper about the components and related activities (e.g., "awareness of self through sensory awareness", "kindly focus their attention on different body parts", "mindful movement to energize the mind-body"). Those cases contributed only to the quantitative analysis of RQ2, but not the qualitative analysis. The following number of the included studies could be subjected for the qualitative analysis based on the details provided: breathing awareness (k = 15), working with thoughts and emotions (k = 13), awareness of senses (k = 11), body scanning (k = 5), mindful movement and body practice (k = 11), kindness practice (k = 11), psycho-education (k = 8), group discussion (k = 6), home practice (k = 6), playfulness (k = 11), story-based context (k = 9).

Interrater-reliability. The first two authors with the same level of expertise independently coded the twenty-six studies and supplementary material sent by the authors. Inter-rater reliability was computed for all components of the MBIs. Inter-coder agreement was excellent in all cases. There was full agreement regarding the categories of breathing awareness, awareness of senses and practices of daily life, body-scanning, kindness practice, and mindful movements (100%); and excellent agreement for working with thoughts and emotions, home practices and additional components (90%). Secondly, any disagreements were discussed between the two coders until a consensus was reached.

Quantitative Analysis

Frequency distributions were computed for each component. Cross tabulation analysis and Fisher exact statistics were used to assess the relationship between the two age groups (early and middle childhood) the frequency of the different components in MBIs. Due to the small sample size and the expected frequencies of less than 5, the Fisher exact test was chosen instead of the Chi-square test (Kim, 2017). A 95% confidence interval and a significance level of less than 0.05 were used to determine the rejection of the independence of components in the two age groups. As the significant Fisher test does not inform us about the degree of effect, displaying the Cramér's V effect size was chosen to show the magnitude of effects (Field, 2013). Secondly, the difference between the total duration of the interventions between the two age groups was evaluated using independent sample t-tests. In order to meet the statistical assumption of normality for a t-test, standardized skewness and kurtosis statistics were required not to exceed ±3.29 (Coolican, 2017). The Levene's test was used to assess the homogeneity of variances. These quantitative analyses were performed with the assistance of the SPSS statistical program (IBM SPSS Statistics Version 20, 2011).

Results

As shown in Table 2, the distribution of the studies with children in their early and middle childhood was well-balanced, given that approximately half of the studies involved children in their middle childhood (k = 15) and the other half of the studies involved children in their early childhood (*k* = 11). Mindfulness programs were mostly implemented in the (pre-)school embedded into the curriculum or as an extracurricular activity, except for two studies (Lo et al., 2019; Lo et al., 2020), in which the intervention was applied in family service centers.

The MBIs duration varied from 4 to 25 weeks, while the total number of sessions varied between 8 and 144 sessions (see Table 2). The total duration of the MBIs ranged between 3.2 and 45 hours, and single session duration varied between 3 and 90 minutes. It is arguable that MBIs for children show substantial differences regarding the duration of the programs. There was a tendency in MBIs for younger children for more sessions on average (M = 48, SD = 52.22) than in MBIs for children in middle childhood (M = 21, SD = 14.08). However, this difference between MBIs for the two developmental stages was not significant ($t(24) = -1.665$, $p = .12$). (As the Levene's test for equality of variances was significant, the *t*-test was adjusted.) Similarly, MBIs for children in early childhood tended to be somewhat longer (total number of hours: M = 16.64, SD = 14.33) than the programs meant for children in middle childhood (total number of hours: M = 11.91, SD = 12.09), but this difference was also not significant ($t(24) = -0.910$, $p = .37$). After Table 2, we explain and synthesize these quantitative results with qualitative findings from the deconstruction of MBIs regarding the core components and activities.

Table 2

Characteristics of the included studies with mindfulness-based interventions

First author, publication year	Age (years)	Name of the program	Leader of the program	Nr. of sessions	Time/ session (min)	Total hours of MBI	Components in the program	Significant positive effects	Nonsignificant effects
Abdi, 2016	8 – 10	mindful awareness practices	expert	8	60	8	BA, WTE, AS, KP, GD, HP, PLA	Working memory, cognitive flexibility, attention	Attention (accuracy)
Akbari, 2014	9 – 10	mindfulness-based curriculum	expert	10	90	15	BA, WTE, AS, BS, MM	Self-regulation	-
Bergen-Cico, 2015	11 – 12	mindful yoga	teacher	48	4	3.2	BA, MM	Self-regulation global and long-term	Short-term self-regulation
Britton, 2014	11 – 12	mindfulness meditation module	teacher	42	7	5	BA, WTE, AS, BS	Positive affect	Self-regulation, anxiety
Crescentini, 2016	7 – 8	Mindfulness oriented meditation	expert	24	30 - 90	8	BA, WTE, AS, BS, KP, MM, GD, PLA	Attention and impulse control	Positive affect

Table 2

Continued

First author, publication year	Age (years)	Name of the program	Leader of the program	Nr. of sessions	Time/ session (min)	Total hours of MBI	Components in the program	Significant positive effects	Nonsignificant effects
Desmond, 2010	11 – 12	Wellness Works in Schools™	teacher	10	25 - 45	6	BA, WTE, MM, GD	Cognitive flexibility, meta-cognition, behavior regulation	Planning, emotional control, inhibition
Flook, 2010	8 – 10	Mindful awareness practices	expert	16	30	8	BA, WTE, AS, BS, KP, MM, GD, PLA	Cognitive flexibility, monitoring, emotional control	Inhibition, emotional control, working memory
Flook, 2015	*M* = 4.67 (*SD* = 0.27)	Kindness Curriculum	expert	24	20 - 30	10	BA, WTE, AS, KP, MM, PE, GD, PLA, SB	Emotion regulation, social competence, prosocial behavior	Delay of gratification, cognitive flexibility
Janz, 2019	5 – 7	Calm Space	teacher	120	3 - 30	40	BA, WTE, AS, BS, MM, PE, GD, PLA, SB	Cognitive flexibility; attention and impulse control, prosocial behavior	Peer problems

Table 2

Continued

First author, publication year	Age (years)	Name of the program	Leader of the program	Nr. of sessions	Time/ session (min)	Total hours of MBI	Components in the program	Significant positive effects	Nonsignificant effects
Lo, 2019	5 – 7	Family-based mindfulness	expert	8	60 - 90	9	BA, WTE, AS, BS, KP, MM, PE, GD, HP	Attention, self-regulation	Aggressive behavior
Lo, 2020	5 – 7		expert	8	60 - 90	9		Attention and impulse control, aggression, anxiety	-
Mendelson, 2010	9 – 11	mindful yoga	teacher	48	45	36	BA, MM	Self-regulation, responses to stress	Positive affect, peer relationships
Moreno-Gómez, 2020	5 – 6	Mindfulness-based intervention	Expert & teacher	144	15	36	BA, KP, MM, PE, GP, HP	Attention and impulse control, social skills, anxiety	Aggression
Napoli, 2005	8 – 10	Attention Academy	expert	12	10 - 40	9	BA, WTE, AS, MM	Attention, social skills, anxiety	-

Table 2

Continued

First author, publication year	Age (years)	Name of the program	Leader of the program	Nr. of sessions	Time/ session (min)	Total hours of MBI	Components in the program	Significant positive effects	Nonsignificant effects
Parker, 2014	9 - 10	Master Mind	expert	20	15	5	BA, WTE, AS, BS, KP, MM, GD, HP	Executive functions; self-regulation, social skills, aggression, anxiety	Attention problems
Poehlmann-Tynan,2015	3 – 5	Kindness Curriculum	expert	24	20 - 30	10	BA, WTE, AS, KP, MM, PE, GD, PLA, SB	Self-regulation	Empathy, compassion
Razza, 2015	3 – 5	Mindful yoga	teacher	120	10 - 30	40	BA, MM, PLA	Delay of gratification, executive functions	Attention and impulse control
Sidhu, 2013	8 – 12	Still Quiet Place	expert	8	45	6	BA, WTE, AS, PLA	Attention	-
Vickery, 2016	7 – 9	Paws b.	teacher	12	30	6	BA, WTE, KP, PE, HP	Affect, meta-cognition	Meta-cognition

Table 2

Continued

First author, publication year	Age (years)	Name of the program	Leader of the program	Nr. of sessions	Time/ session (min)	Total hours of MBI	Components of the program	Significant positive effects	Nonsignificant effects
Viglas, 2015	4 – 6	Mindful Schools adaptation	expert	18	20	6	BA, WTE, AS, KP, MM, PE, HP, SB	Self-regulation; prosocial behavior	Emotional problems, peer problems
Thierry, 2016	*M* = 4.55 (*SD* = 0.33)	MindUp	teacher	15	20 - 30	6	BA, AS, MM	Working memory, planning	Inhibition, emotional control
Torres, 2019	3 – 5	MBI	Expert & teacher	18	20	6	BA, WTE, AS, KP, MM, GD, PLA, SB	-	Executive functions, prosocial behavior
Waldemar, 2016	10 – 12	MSEL	expert	12	60	12	BA, WTE, AS, KP, GD, PLA	Emotion regulation, prosocial behavior	Attention and impulse control
Wimmer, 2016	*M* = 10.80 (*SD* = 0.53)	Mindfulness training	teacher	25	3 - 90	45	BA, WTE, AS, BS	Inhibition	-

Table 2

Continued

First author, publication year	Age (years)	Name of the program	Leader of the program	Nr. of sessions	Time/ session (min)	Total hours of MBI	Components of the program	Significant positive effects	Nonsignificant effects
Willenbrink, 2018	8 – 12	Growing Minds™	Expert & teacher	20	15 - 20	6.5	BA, WTE, AS, BS, KP, MM, PE, GD	Attention and impulse control, cooperation	Social skills, emotion regulation, empathy
Zelazo, 2018	3 – 5	Mindfulness + reflection	Teacher	30	24	12	BA, WTE, AS, BS, KP, MM, PE, GD, PLA, SB	Executive functions	Meta-cognition, affect

M = Mean; *SD* = Standard Deviation, *Nr.* Number, *MBI* Mindfulness-Based Intervention; *MSEL* Mindfulness and Social-Emotional Learning Program, *BA* breathing awareness, *WTE* working with thoughts and emotions, *AS* awareness of senses, *BS* body-scanning, *KP* kindness practices, *MM* mindful movements, *PE* psycho-education, *GD* group discussion, *HP* home practice, *PLA* playfulness, *SB* story-based context.

Breathing Awareness

All of the programs (both early and middle childhood programs) reported to apply breathing awareness practices (see Table 3). Qualitative findings indicated that MBIs for children in middle childhood commonly used sitting breathing meditations during which children practiced to intentionally guide attention on the sensations during breathing even up to 10 minutes. Guided and audiotaped breathing awareness meditations were commonly used (i.e., Abdi et al., 2016; Bergen-Cico et al., 2016; Britton et al., 2014; Mendelson et al., 2010; Parker et al., 2014). In these practices, body parts such as abdomen, chest, and nose tips were often used as somatosensory anchors where children can focus attention when their mind wanders (i.e., Crescentini et al., 2016; Flook et al., 2010; Wimmer, Bellingrath & Stockhausen, 2015). Counting breaths in sets of five appeared in both early and middle childhood interventions, however, younger children were counting on their fingers together with a teacher (i.e., Razza et al., 2015), while older children were instructed to count sets silently in their head (i.e., Britton et al., 2014; Napoli et al., 2005). In MBIs for younger children, the point of this activity was also to stay in a state of focused attention and calmness. However, in early childhood this component was commonly applied with the support of an attention-grabbing toy as attention anchor. For instance, blowing a pinwheel, or putting a stuffed animal (called a Belly Buddy) on the stomach of the child and rock it to sleep made this essential component developmentally appropriate for younger children (i.e., Flook et al., 2015; Janz et al., 2019, Torres, 2019). Some early childhood MBIs used the sound of a fading bell as an anchor for attention, and taking three deep breaths once the sound has ended (i.e., Poehlmann-Tynan et al., 2015; Thierry et al., 2016). These modifications might have been necessary because in early childhood the capacity to maintain attention largely depends on how interesting and playful the task is (Washington State Early Department of Early Learning, 2012). The optimization of the duration of these sustained practices and motivators for younger children align with the recommendations about MBIs adaptation from Hooker and Fodor (2008).

Table 3

Frequency distributions of the components of MBIs and Chi square analysis

	Overall	Early childhood (3-7 years)	Middle childhood (8-12 years)	Chi square statistic

Total number of MBIs	*k* = 24	*k* = 9	*k* = 15	
Core components				
Breathing awareness	100%	100%	100%	-
Working with thoughts & emotions	83%	78%	87%	*p* = .62
Awareness of senses & practices of daily life	75%	78%	73%	*p* = .99
Mindful movements & body practices	75%	100%	60%	*p* = .05 *V* = .447, *p* = .03
Kindness practice	58%	67%	53%	*p* = .68
Group discussion	54%	56%	53%	*p* = .99
Body-scanning	46%	44%	47%	*p* = .99
Psycho-education	44%	70%	27%	*p* = .05 *V* = .428, *p* = .03
Home practice	38%	44%	33%	*p* = .68
Additional components				
Playfulness	42%	56%	33%	*p* = .40
Story-based context	21%	56%	0%	*p* = .003 *V* = .662, *p* < .001

Analysis of difference Fisher Exact test*; p* value of significance*;* V measure of strength of association/effect size (Cramer's V). *Cramér's V was interpreted as:* <.1 little if any association, .1-.3 low association, .3-.5 moderate association, >.5 high association

Working with Thoughts and Emotions

Working with thoughts and emotions was applied in more than three-quarters of MBIs for children. Difference in popularity between early and middle childhood was not significant (see Table 3). Qualitative results from the content analysis suggested that those activities cultivating awareness of emotions were usually about identifying and labeling emotions, nourishing positive emotions, and dealing with negative ones. For instance, positive imagination techniques, such as imagining themselves in a quiet and safe place, were intended to increase feelings of happiness and calmness (e.g., Abdi et al., 2016). In this component, also emotion regulation and non-reactivity was fostered, mainly through self-soothing somatosensory exercises, such as listening to one's own breathing or shaking the jitter out of the body (e.g., Flook et al., 2015; Janz et al., 2019). These activities were also equally implemented in MBIs for early and middle childhood. In some cases, qualitative findings showed that activities reflecting this component were adapted for younger children with puppet shows or story books (i.e., Flook et al., 2015; Torres, 2019). Story-based context was also used to help children labeling their emotions and enhancing skills of meta-cognition and mentalization (i.e., others might have different thoughts).

As it was recommended by developmental scientists (Hooker & Fodor, 2008; Jennings et al., 2012), symbolic metaphors were widely used in the instructions of activities reflecting this component in both developmental stages equally. Thoughts were often described as clouds or soap bubbles coming and going, to teach their constantly changing nature and also to encourage meta-cognition (e.g., Abdi et al., 2016; Akbari et al., 2014; Crescentini et al., 2016; Janz et al., 2019). In contrast, activities related to this component for middle childhood applied elements that required more advanced meta-cognitive skills. For instance, trying to see the main thought in the mind, writing it down, and label the emotions related to the main thought of the moment (i.e., Crescentini et al., 2016). Other programs for older children aimed to teach the 'storytelling nature of our mind': the notion that not all thoughts are facts (Parker et al., 2014; Vickery & Dorjee, 2016). This component was often mixed with psycho-education in case of older children. For example, in the Paws.b program one thematic session was about recognizing the bad habits of our brain, such as how the mind tries to fix difficulties by overt-thinking.

Awareness of Senses and Practices in Daily Life

MBIs for children from 3 to 12 years have been shown to put a great emphasis on the practice of sensual awareness and daily life mindfulness. As Table 3 demonstrated, there was no significant difference in the popularity of this practice between MBIs for early and middle childhood. Qualitative analysis of this component revealed that mindful perception of the environment through the five senses were popular exercises for both age groups, and activities were very similar. For instance, in the Mindful Schools Program, 4 to 6 years old children listened to a bell with closed eyes rang by the teacher in the classroom, and they were asked to raise their hand once they could no longer hear the sound of the bell (Viglas, 2016). Mindful eating of a small portion of food (e.g., raisin, popcorn, gummy bear, or even the daily meal) was also a highly popular task of sensual awareness in MBIs with children (i.e., Abdi et al., 2016; Crescentini et al., 2016; Janz et al., 2019; Thierry et al., 2016; Viglas, 2016; Zelazo et al., 2018). In these activities children were usually asked to slow down eating, describe, and reflect on different sensations: “Is the food hot or cold? Is it hard or soft? What colors can you notice? Could you describe what it looks like to somebody from the Mars (who has never seen such a thing)?”. These findings are in line with previous suggestions of experts to incorporate multiple sensory modalities in programs (Hooker & Fodor, 2008).

In the content of MBIs it was found that introducing different textures and fabrics, such as leather, artificial fur, ice, sand, or clay, was a widely used activity to teach touching with awareness for children in both age groups. For example, in activities related to this component for middle childhood MBIs, children were instructed to held an ice cube in their palms for as long as possible, while concurrently monitoring sensations and describing them without judgement (Abdi et al., 2016; Wimmer et al., 2016). This exercise might evoke negative sensations, like a slight amount of pain felt from the cold. Perhaps that was the reason why it was only implemented with elder children. Another advanced exercise related to this component was a drawing activity where children had to draw complex forms and shapes with closed eyes (Abdi et al., 2016).

Jennings and colleagues (2012) recommended that MBIs for children in early childhood should start their program with a focus on sensory input or bodily movements. This recommendation was applied in most of the programs for early childhood (Flook et al., 2015; Janz et al., 2019; Lo et al., 2019, 2020; Poehlmann-Tynan et al., 2015; Razza et al., 2015; Viglas, 2016; Torres, 2019). Additionally, during the qualitative analysis it was found that many MBIs for early childhood scheduled whole sessions for mindful hearing, seeing, tasting, smelling and touching (Torres, 2019; Zelazo et al., 2018).

Mindful Movement and Body Practices

Mindful movements and body practices were applied in all MBIs for early childhood, and more than half of the programs used it for middle childhood. Moreover, the relationship between the implementation of this component and the age group was significant with a moderate-sized association (see Table 3). As these results show, program designers put a huge emphasize on structured motor development especially in early childhood, which was previously suggested by experts (Hooker & Fodor, 2008; Jennings et al., 2012; Lillard, 2011). Additionally, the qualitative analysis of MBIs revealed that programs for children in middle childhood usually involved shorter sessions of mindful movement and body practices (i.e., 2 minutes) which were mainly applied during transition periods (i.e., beginning of classes) (e.g., Bergen-Cico et al., 2015; Wimmer et al., 2016). For instance, in the study of Crescentini and colleagues (2016) children had to walk around slowly in the classroom and imagine that they are walking on sand or grass, while observing the feeling of every single part of the leg moving. Interestingly, Parker and colleagues (2014) implemented short mindful yoga sessions by involving peer actors as instructors in mindful movement videos, because in middle childhood children are prominently influenced by their peers. Body practices such as tai chi or qigong were also activities reflecting this component in some of the MBIs (e.g., Napoli et al., 2005). In MBIs for middle childhood, teachers mainly used the pose names such as in adult programs, like downward dog, tree pose, warrior pose (e.g., Bergen-Cico et al., 2016). Besides this, sometimes students were taught the health benefits of the poses (i.e., Mendelson et al., 2010). In contrast, MBIs for early childhood often used animal and nature names for yoga postures (i.e., Razza et al., 2015).

The qualitative analysis of MBIs for children in early childhood showed that mindful movement and body activities mostly go hand in hand with playfulness and exploration. In the Kindness Curriculum, activities reflecting this component were mainly dancing, shaking out the jitters from the body or imitating animals when they move (Flook et al., 2015; Poehlmann-Tynan et al., 2015). For instance, in a longer movement-based session (20-30 minute), the teacher asked children to pretend that they are in the jungle, and as they hear sounds of different animals (e.g., lion, giraffe, elephant etc.) they should imitate the characteristic movement of animals (Flook et al., 2015). Another example was the 'Dance like Your Friend' game, when children had to observe and imitate the movements of their friends to music (Torres, 2019). Additionally, activities for early childhood paid a particular attention to body sensations before and after movement (Lo et al., 2019, 2020; Moreno-Gómez et al., 2020).

Kindness Practice

The popularity of this component was not significantly different in MBIs for early and middle childhood (see Table 3). Qualitative findings showed that these activities in MBIs were mainly oriented toward enhancing unconditional, positive states of kindness and compassion, and to promote prosocial skills like empathy, gratitude, forgiving, sharing, and helpfulness. Activities were similar in both age groups, however, MBIs for younger children many times used this component combined with a story-based context (e.g., Flook et al., 2015; Torres, 2019; Zelazo et al., 2018). In the Kindness Curriculum sessions with the theme of kindness began with a storybook, which was followed by a group discussion about the story between children and teacher. In another activity, children planted seed stickers in the

‘Kindness Garden’ when somebody acted with kindness in the group (e.g., played fair by sharing, took turns and included others, or spoke honestly and listened with empathy) (Flook et al., 2015; Poehlmann-Tyanan et al., 2015). Activities related to this component for early childhood often involved the demonstration of kind acts, sometimes by the teacher, or puppets, and the children themselves (Poehlmann-Tynan et al., 2015; Viglas, 2016; Torres, 2019). In activities for middle childhood there were no evidence for such modeling of kind acts, moreover, children were mostly involved in a discussion with their teachers and peers (Crescentini et al., 2016; Waldemar et al., 2016). Additionally, acts of kindness were sometimes rewarded in MBIs for early childhood (e.g., Flook et al., 2015; Poehlmann-Tynan et al., 2015), while there was no evidence for rewarding such acts in MBIs for middle childhood.

In a program for middle childhood, one activity reflecting the kindness component was to draw a mate or a relative and mentally address some friendly wishes to them (Crescentini et al., 2016). In contrast, Viglas (2016) suggested that imagine someone might be too abstract for early childhood, thus younger children might understand this exercise better if they can send the wish directly to someone they see in the moment.

Body Scanning

Interestingly, body scanning was similarly often used in MBIs for children in early and middle childhood (see Table 3). The qualitative analysis of the activities reflecting this component revealed that body scanning for middle childhood was often reported to be longer (i.e., 10 minutes), while such practices in early childhood were usually shorter (i.e., 5 minutes). In the instructions of body scanning activities for both age groups, metaphors such as imagining our attention like a microscope or a scanner were often used (Britton et al., 2014). In the study of Crescentini and colleagues (2016), 7-to-8 years old children were instructed to lay down pretending to be a paper and imagine scanning the body from toe to head. In activities related to body scanning for middle childhood, guided body scanning of a range of body parts was common (i.e., Britton et al., 2014; Parker et al., 2014; Vickery & Dorjee, 2016). However, in MBIs for early childhood, these exercises often involved body sensations during exercise and rest (or basic emotions), to emphasize differences between these states (Thierry et al., 2016; Torres, 2019). In one activity for early childhood, children practiced body scanning with a hula hoop (Zelazo et al., 2018).

Other Components in MBIs for Children

There was a non-significant association between age (early or middle childhood) and the popularity of group discussions, home practice, and playfulness as components in MBIs. As these components were not often used (see Table 1), it was difficult to make a qualitative comparison between age groups. In early childhood programs teachers were mainly asking questions from children about the mindfulness activities, while in middle childhood programs teachers created more interactions between children. Lastly, qualitative examples showed that in early childhood home practice involved parents, while in middle childhood programs autonomous home practice was encouraged.

However, psycho-education was applied in almost three-quarter of the MBIs for early childhood, and in approximately one quarter of the programs for middle childhood. In fact, we found a significant moderate-sized association between psycho-education in MBIs and the targeted age group (see Table 3). The qualitative content analysis indicated a clear difference between psychoeducational elements in middle and early childhood interventions: psychoeducational elements for early childhood involved learning the basic concepts connected to mindfulness, while such elements for middle childhood educated more complex biopsychosocial mechanisms.

Story-based context was present only in MBIs for early childhood. Along with playfulness it was mainly used to make mindfulness exercises age-appropriate (i.e., breathing awareness, working with thoughts and emotions). Story-based context was used in half of the MBIs for early childhood but none of the studies used with interventions for middle childhood. This was a significant large association between the age groups and this particular component (see Table 3).

Preliminary Results on the Impact of MBIs with Specific Components

Regarding the preliminary results, Table 2 summarizes the characteristics of MBIs with the components identified during the content analysis and their effect on specific outcomes. However, it is important to highlight that most programs included a range of different components. Thus, at this point of the scientific literature, it is difficult to disentangle the specific effects of components. When components are confounded in the primary studies, differences in outcomes between programs is not necessarily due to the presence (or absence) of a certain component as the effect might be due to the effects of other components or the combination of different components. In sum, the present results regarding the effects of interventions with different components are highly preliminary and should be interpreted cautiously.

MBIs with the component of working with thoughts and emotions (k = 21) had a wide variety of positive effects on attention, executive functions, self-regulation, social skills, mood and anxiety (see Table 2). As Table 2 shows, most of the MBIs with this component reported significant positive effects on executive functions, attention, self-regulation, meta-cognition, social skills, and anxiety. However, there were some outcomes where the effects were mixed (i.e., less often reported significant). Three from the six studies measuring emotion regulation reported significant positive effects from MBIs with a working with thoughts and emotions component. Three from six MBIs with a working with thoughts and emotions component showed a significant improvement in affectivity (i.e., the way people experience positive and negative emotions). There were only one study measuring the effect of and MBI with a working with thoughts and emotions component, which showed a non-significant impact on delay of gratification.

As shown in Table 2, five from the six studies, using an overall outcome of self-regulation, reported the efficacy of MBIs with an awareness of senses component. Seven from the ten MBIs with an awareness of senses component showed a significant positive effect on attention (see Table 2). Eight from ten studies demonstrated that executive functions were also positively affected by MBIs with an awareness of senses component. Three from the four studies that implemented an MBI with an awareness of senses component demonstrated a significant positive effect on anxiety. However, the effect of MBIs with an awareness of senses component on emotion regulation mostly was non-significant in four studies from the six. Two from the three studies observing the efficacy of an MBI with this component reported a non-significant effect on affectivity.

All MBIs which involved the component of mindful movement and body practices showed a significant positive effect on overall outcomes of self-regulation. Additionally, another outcome was significantly reduced in all studies of MBIs with a mindful movement component, namely anxiety. Executive functions also showed improvement from MBIs with a mindful movement component in seven from nine studies. Eight from ten studies that implemented an MBI with a mindful movement component demonstrated a significant improvement on outcomes of attention. Aggression was reduced in two from the four MBIs with a mindful movement and body practice component. Interestingly, in case of emotion regulation, four from the six studies reported non-significant, and neither of the three MBIs with this component had a positive impact on affectivity.

As shown in Table 2, six from the ten MBIs implementing the component of kindness practices, demonstrated significant effects on social skills. More specifically an impact on prosocial behaviors were reported. Two studies reported significant effect on aggressive behavior, while two studies reported a non-significant effect of MBIs with a kindness component on such behavior.

In six from seven MBIs that involved the component of body scanning, significant positive improvements on attention were found. Significant improvements were found on overall self-regulation (two from three studies), executive functions (five from five studies)), attention (five from six studies), and anxiety (two from three studies). On the other hand, non-significant effects were found on outcomes of emotion regulation (one from two), affectivity (one from three).

Discussion

Mindfulness-based interventions have been growing in popularity in all age groups but there has been a lack of clarity over individual mindfulness components across programs in the literature (Butterfield et al., 2020). The present study aimed to analyze the content of MBIs for children in early and middle childhood, and identify any qualitative and quantitative differences. Additionally, this study provides preliminary results about the impact of MBIs with specific components on mindfulness-related skills and outcomes.

The content of twenty-six primary studies from two previous meta-analyses, which found small to moderate effect of MBIs on children's executive functions and hyperactive-impulsive behavior, was further analyzed in the present study (Takacs & Kassai, 2019; Vekety et al., 2021). The content of MBIs included in these meta-analyses was subjected for further content analysis, because the included MBIs were equally efficient in early and middle childhood as well, however, the developmental characteristics of activities and related components used in such programs were not evident.

Findings indicated that the included evidence-based MBIs were mostly complex programs that applied a range of different components interrelated. Nine core components (breathing awareness, working with thoughts and emotions, awareness of senses, kindness practice, body scanning, group discussion, home practice, psycho-education) and two additional components (playfulness, story-based context) were identified in the content of the primary studies.

Quantitative results showed that all MBIs implemented breathing awareness practices in both age groups. Similar to the results of Zenner and colleagues (2014) with 6 to 18 years old children, this content analysis found breathing awareness exercises to be the most popular component in MBIs for 3 to 12 years old children as well. MBIs including the component of breathing awareness had a wide variety of positive effects on skills from attention, executive functions, self-regulation to social skills, mood and anxiety. It might be an important question for future research whether this single component could be effective, or the positive effects can only be observed when breathing awareness is supplemented with other components.

Mindful movement and body practices, psycho-education, and a story-based context were significantly more often used in MBIs for early than middle childhood. Mindful movements and body practices were applied in all MBIs for early childhood, and more than half of the programs used it for middle childhood. These results are somewhat different from the results of the meta-analysis of Zenner and colleagues (2014) who found mindful movement and body practices in only 21-25% of the MBIs for 6 to 18 years old youth. However, the finding that middle childhood programs applied almost half time less frequently movement and body practices raises an important question if this trend in MBIs is really age-appropriate and beneficial, knowing the fact that in many evidence-based adult mindfulness programs movement practices are still incorporated (i.e., Mindfulness-Based Stress Reduction by John Kabat-Zinn).

The other quantitative finding that story-based context was associated only with MBIs for early childhood is further supported by the Best Start Resource Centre (2015), which stated that storybooks are good motivators and highly encouraged for younger children, because they can also support the development of language and social-emotional skills at the same time. Adding story-based elements to all early childhood MBIs might be because listening to stories is a daily activity for kindergarten and preschool children. The lack of story-based elements in middle childhood programs were somewhat surprising, considering the fact that characters from stories can be models for older children as well, and stories can provide a psychological distance that can be especially useful when exploring negative emotions, behaviors or thoughts experienced by the self in everyday life (Ahmed et al., 2018; Kucirkova & Littleton, 2020; Orvell et al., 2019). Importantly, it has been found that even preschoolers prefer realistic stories over fantasies (Barnes, Bernstein & Bloom, 2015) as processing fantasy can overwhelm neural resources required for daily life, like the executive functions (Lillard et al., 2015), which are crucial considerations for future interventions with story-based elements.

Surprisingly, psychoeducational elements were reported to be more often present in the content of early childhood mindfulness programs, and were mainly about teaching basic psychological concepts of mindfulness for children. It is possible that such psychoeducational elements were present in middle childhood programs as well, however, it was not mentioned in the paper. The qualitative findings showed that when authors reported on psychoeducational elements for this age group, they involved more advanced biopsychosocial topics for middle childhood, such as how to make mindful choices in daily life, or how to deal with stress. The idea to involve the parents in the psychoeducational component of the programs was raised in only one study by Flook and colleagues (2015), in which letters were sent home to parents explaining the new concepts and skills learnt by their children. The widespread practice of including psychoeducational content in MBIs for children might draw future research to investigate both the additional benefits of such elements and pure mindfulness activities.

MBIs for both early and middle childhood applied the components of working with thoughts and emotions, awareness practices with senses, kindness practice, body scanning, group discussion, home practice, and playfulness in a similar ratio. The components of working with thoughts and emotions, awareness of senses, body scanning, and home practice was found comparable to the finding of Zenner et al. (2014) with 6 to 18 years old children. However, the present study found that kindness practice was especially popular in MBIs for children between 3 to 7 years (67%), whereas for youth aged from 6 to 18 years this component was less frequently used (46%) (Zenner et al., 2014). On the other hand, Zenner and colleagues (2014) found group discussion in MBIs for youth (75%) more frequently used than the present content analysis for 3 to 12 years (58%). There were no significant differences regarding the total duration of MBIs, neither the total number of hours, nor the number of sessions in MBIs for early and middle childhood. Moreover, MBIs for early childhood mostly maximized single session duration in 30 minutes, while MBIs for middle childhood maximized this even up to 90 minutes. These findings are somewhat in line with the recommendations of Jennings and colleagues (2012), however 90 minutes of practice may even be long for children in their middle childhood (8-to-12 years).

Furthermore, the qualitative analyses of the content of MBIs suggested that in many core components there were substantial differences in how the related activities were modified for early and middle childhood to ensure age appropriateness. We listed a lot of examples in the results section to illustrate this, which might support the development of fine-grained guidelines for educators and clinicians who would like to implement mindfulness practice. In summary, breathing awareness activities for early childhood were sometimes as short as 1 minute and they were often supported with an attention-grabbing object (e.g., pinwheel). As meta-cognition is not well-developed in this age, the teachers constantly instructed the children during the breathing awareness practice. In contrast, such activities for middle childhood sometimes lasted 10 minutes, and typically had a somatosensory focus (e.g., abdomen). Teachers commonly applied guided breathing awareness practices, but the instructions let more space for children to catch their mind wandering, which was a more advanced meta-cognitive element. The qualitative analysis of working with thoughts and emotions revealed that this component for early childhood mostly involved the identification and labeling of emotions with the support of puppet shows or storybooks. However, in middle childhood activities related to this component were more advanced metacognitive exercises mixed with psycho-education, with themes such as ‘not all thoughts are fact’, ‘identifying the main thought and emotions around’, ‘over-thinking’. The qualitative analysis also revealed that the awareness of senses component was a popular beginner theme in MBIs for early childhood, sometimes devoting whole sessions to the different senses. In contrast, activities related to this component in middle childhood occasionally even included unpleasant feelings, such as holding an ice cube, and more complex sensual exercises as well. The quantitative findings demonstrated that there were significantly more mindful movement and body practice in MBIs for early childhood than for middle childhood. Qualitative results showed that MBIs for early childhood incorporated a wide variety of movement and body practices for children, while activities for middle childhood were mainly some yoga poses or mindful walking in the classroom. The qualitative analysis also revealed that activities related to the component of kindness were often mixed with story-based context in early childhood. For younger children, acts of kindness and prosocial behavior were demonstrated first by the teacher sometimes with puppets, and then the children were encouraged to practice such behaviors (in the next couple of months) for some additional reward (i.e., stickers). In contrast, children in middle childhood practiced kindness and prosocial behavior through individual and paired exercises, or in a group discussion.

As the MBIs in the primary studies were mostly complex programs that applied at least two different components, we cannot yet disentangle the separate effects of single components. Preliminary review results about the impact of MBIs with specific components on outcomes might suggest that MBIs with a breathing awareness and working with thoughts and emotions component had a broad effect on outcomes: benefits beyond executive functions, attention, self-regulation, meta-cognition, social skills, and anxiety. All MBIs with a mindful movement and body practice component significantly reduced anxiety. There were only one MBI without mindful movement component that investigated effects on anxiety, but found non-significant results (Britton et al., 2014). Mindful movement and awareness of senses components were also increasing overall self-regulation, executive functions, and attention in most of the included studies. Most MBIs with a component of body scanning reported a positive effect on executive functions and attention. However, MBIs with one or more of these components (breathing awareness, working with thoughts and emotions, awareness of senses, mindful movement, body scanning) were not likely improving emotion regulation or affectivity among children from 3 to 12 years. One of the reason behind this might be that bottom-up regulation has a huge part in emotions and affectivity, and bottom-up regulation might need more time to develop as an effect of interventions. Top-down regulation, which is reflected in most executive function and attention tests, might be more prominent after MBIs on post measurement, while bottom-up reflections of emotion regulation and affectivity might require more time develop which needs follow-up measurement.

Additionally, most MBIs for early childhood with a kindness component improved prosocial behavior, but they did not reduce aggressive behavior. In accordance with our previous explanations, it might be that effects on outcomes of aggression might only be observable on the long run (6 months follow-up), because children might need more practice and time for further elaboration (Móreno-Gómez et al., 2020). Another possible explanation might be that in case of bottom-up driven regulatory practices, such as aggression, parenting practice is especially important, and the involvement of parents was lacking in most of the studies. There was one family-based mindfulness program in the included studies which found significant reduction in children's aggression (Lo et al., 2020), and one study which reported similar effect with a home practice component (Vickery & Dorjee, 2016).

Implications

The present study offers important practical implications for clinicians, educators and parents choosing to practice mindfulness with children. It provides an overview of the typical components and activities of MBIs with children and gives examples for how to carry out such activities with children of different ages. The current study further support the importance of mindful body practices and story-based context in early childhood MBIs. In contrast, we recommend more psycho-education for future MBIs, given that there was a lack of this component in middle childhood programs, however it would be age-appropriate. Furthermore, it is important to note that mindful body practices were somewhat neglected in MBIs for middle childhood. Involving mindful body practices during extracurricular sport trainings or physical education classes might be a possibility to increase the amount of physical engagement in middle childhood programs as well.

Preliminary review results demonstrated that, all MBIs with a mindful movement component reduced anxiety among children. Complex interventions, which incorporated more components, mostly showed positive pre-to-post test results on top-down regulation related outcomes, such as executive functions and attention. However, bottom-up related outcomes, namely aggression, emotion regulation, and delay of gratification were reported with mixed effect, which reflect that these outcomes might need more time to fully elaborate after a training and reveal effects (i.e., follow-up measurements).

Limitations and Future Directions

First of all, the set of MBIs in this content analysis was based on two previous meta-analyses that investigated the effects of MBIs on children's self-regulation including executive functions, inattentive, hyperactive-impulsive behavior (in text citation are blinded here), and found evidence for their efficacy. The content analysis of these (cluster-) randomized controlled studies with MBIs was conducted in order to present the best practices of evidence-based MBIs for children from 3 to 12 years, at least as far as self-regulation was concerned. However, this also means that this content analysis might have potentially excluded studies testing MBIs using different outcome measures. Future studies might consider a broader systematic search strategy with more included outcome measures (not just self-regulation), to get a more comprehensive picture. Furthermore, in some studies the content of the MBIs was only briefly reported so there is a chance that the variety of practices applied in those programs was underestimated. Future empirical studies with MBIs should report the content of the programs in details, preferably with the list of all the practices implemented. This is especially important given that different program components might have different outcomes regarding children's cognitive and social-emotional skills. For instance, results of a recent study with adults revealed that mindful yoga increased psychological well-being more than sitting meditation or body-scanning, while sitting meditation and mindful yoga were associated with greater improvement in emotion regulation than body scanning (Sauer-Zavala et al., 2013). Lastly, an important limitation of this study was that MBIs involved the combination of components, but not single components. Thus, the results of the review regarding the efficacy of the programs with different components are solely preliminary. Future studies of MBIs should also examine how these components work in isolation.

Conclusions

The present study investigated the content of twenty-six primary studies with mindfulness-based interventions reporting effects on outcomes related to self-regulation. First of all, the content of the included MBIs was analyzed, and components of mindfulness programs for children were identified. The quantitative analysis of mindfulness programs components revealed an age-related difference regarding three components: mindful movement and body practices, psychoeducation, and story-based context showed a higher presence in mindfulness programs for 3-7 years old children. More specifically: (i) mindful movement and body practices were present in all programs for 3-7 year olds, but almost half time less of the programs for 8-12 years old children; (ii) psychoeducation was more often involved in early childhood programs; and (iii) story-based context was applied in more than half of the programs as a developmentally appropriate element for early childhood, but no signs of story-based context were revealed in mindfulness programs for 8-12 years old children. Differences regarding mindful body practices, psychoeducation, and story-based elements raise some important development-related considerations for future mindfulness program developers and researchers. Regarding other components, such as working with thoughts and emotions, breathing awareness, kindness practice, awareness of senses, we have found qualitative differences in how the activities were implemented in early and middle childhood. The presented results and recommendations about how to implementation of mindfulness in early and middle childhood are highly relevant for practitioners working with children, and might contribute to the anchoring of a developmentally focused mindfulness theory and practice (Moreno, 2017).

The present study also reported preliminary results about the efficacy of MBIs with specific components on outcomes of self-regulation. In summary, mindfulness programs with components of breathing awareness and working with thoughts and emotions had a broad effect on outcomes: benefits were beyond executive functions, attention, self-regulation, meta-cognition, social skills, and anxiety. Interestingly, all MBIs with a mindful movement and body practice component reduced anxiety. Moreover, MBIs with a kindness practice component increased prosocial behavior among children. However, regarding aggression, emotion regulation, and affectivity, effects were presented with mixed results. The reason behind this might be a delayed effect of MBIs on these mainly bottom-up related self-regulatory outcomes.

Future studies are highly recommended with single components to assess pure effects, and also with follow-up measurements on outcomes related to bottom-up self-regulation.

CHAPTER 4

STUDY 3:

Feasibility and Effects of Mindfulness Training with a Brain-Sensing Device on Executive Functions and Brain Activity Correlates in Children

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Abstract

The present study aimed to explore the feasibility and effects of a brain-computer interface assisted mindfulness training with EEG-feedback implemented in an elementary school to empower children to learn to regulate their own attention. As proposed by previous theories, mindfulness-related skills and neural mechanisms might improve overall cognitive functioning. This is the first study in children that assessed the effects of mindfulness with EEG-feedback on neural mechanisms and associated cognitive performance. Participants were 31 children aged between 9 - 10 years, who were randomly assigned to either an 8-session mindfulness training with EEG-feedback or a passive control group. Feasibility and mindfulness-related brain activity was measured during the training, while cognitive tests and resting-state brain activity were measured on pre- and post-tests. Mindfulness with EEG-feedback was feasible with children applied within an elementary school setting and proved to be supportive and empowering. Within-group measurement of calm/focused brain states and mind-wandering revealed a significant linear change. Significant positive changes were detected in children's inhibition, information processing, and resting-state brain activity (alpha, theta) compared to the control group. Elevated baseline alpha activity was associated with less reactivity in reaction time on a cognitive test. Our findings show some preliminary support for a potential EF enhancing effect of mindfulness supplemented with EEG-feedback, and effects might have some important implication for children's self-regulated learning and academic achievement.

Keywords mindfulness training, EEG-feedback, neurofeedback, brain-sensing device, executive functions, children

Statement of the Problem

In the context of education, moments of deconcentration, fatigue, and anxiety often occur, and hinder a learners' chance to focus on the present moment (Dario & Tateo, 2020). Mastering the skills related to mindfulness can facilitate learners' self-awareness to recognize moments of mind-wandering, and practice self-regulation by redirecting attention to the here-and-now from task unrelated irrelevant thoughts (Bellinger et al., 2015). One of the most well-known mindfulness practice with children is called breathing awareness, when one focuses attention on the sensation of natural breathing (Satlof-Bedrick & Johnson, 2015; Zenner et al., 2014). This essential self-oriented mindfulness practice can be especially difficult for children because there are no overt signs of awareness, which could be used for feedback by the mindfulness teacher. In that vein, providing scaffolding through feedback on the electrical activity of the brain, that is known to vary as a function of mindful awareness, may assist the learning process and facilitate the effects (Satlof-Bedrick & Johnson, 2015; Van Lutterveld et al., 2017). Moreover, supplementing mindfulness practice with EEG-feedback technology can empower children to regulate their own attention leading to self-regulated or mindful learning within the academic context (Yeh et al., 2019; Zimmerman & Pons, 1986). Despite increasing evidence of the benefits of mindfulness with EEG-feedback on adults' attention and psychological outcomes (Acabchuk et al., 2021; Balconi et al., 2019a, 2019; Balconi et al., 2019b; Bhayee et al., 2016; Crivelli et al., 2019a; Crivelli et al., 2019b; McMahon et al., 2020), its effects on children are less studied (Antle et al., 2018; Martinez & Zhaou, 2018). Two studies with elementary school children found that mindfulness practice with EEG-feedback successfully improved subjective measures of attention and discipline (reported by teachers). The present study aims to extend these prior investigations by examining the effects of mindfulness training with EEG-feedback technology, on objective measures of executive functions and brain activity-correlates. Moreover, in the current study we evaluated the feasibility and sustainability of such a technology-supported mindfulness practice in the school environment. The intervention designed in our study was building on the self-determination theory by Deci and Ryan (2004) highlighting the importance of learning environments that support children's three psychological needs, namely autonomy, competence, and relatedness. The significance of this lies within the fact that learning environments have been undergoing a fundamental change in the last decade, which is driven by the widespread availability of digital technology and the intention to empower children to promote their own mental health and learning (Fairburn & Patel, 2017; OECD, 2017). In that vein, the current study may serve, next to providing implications in applied context, as a guide for future research that plans to further investigate such affordable technology combined with mindfulness within an educational context.

Hypotheses

In particular, we expected that (i) mindfulness with auditory EEG-feedback is feasible with school-aged children, who would adhere to the instructions, understand the feedback they receive, and capable of concentrating during the short mindfulness meditations; (ii) children in the mindfulness with auditory EEG-feedback group would show systematically increased slow neural oscillatory brain activity (specifically alpha and theta) during the 8 sessions, mirrored by the calm/focused and active/mind-wandering states as logged by the Muse application; (iii) the mindfulness with EEG-feedback group would show increased theta and alpha amplitude from pre- to post at resting-state as compared to the control group; (iiii) neuromodulation would be accompanied by improvement from pre- to post-test on measures of executive functions, regarding accuracy and reaction time, as compared to the control group.

Methods

Participants

8 to 12 years old typically developing children were recruited from a local primary school in Budapest, Hungary. From the six classes within this age range, two head-teachers of fourth grade classes were willing to participate in the research program. After a verbal presentation about the research, an information letter and a written consent were provided for all parents. Children with a diagnosis of a psychological disorder were excluded from participating in the study. From the two fourth grade classes, 31 parents applied to participate in the research. Participants were from middle and high socioeconomic status families. Gender distribution was relatively close to equal within the whole group, with 51% of girls and 49% of boys. The age range was 9-10 years (*M* = 9.92; *SD* = 4.35). None of the participants dropped out.

Study Design

This study was a 4-week randomized controlled trial (RCT). In order to assess the efficacy of the mindfulness training with EEG-feedback on EFs and neural oscillations, an intervention group was compared to a control group. After the pre-test, children were randomly allocated, with a random number generator, to either the mindfulness group or the passive control group matched by their age, gender, and executive function pre-test scores. It is important to note that this was a pilot study with a low sample size, a low-intensity training, and only a passive control condition.

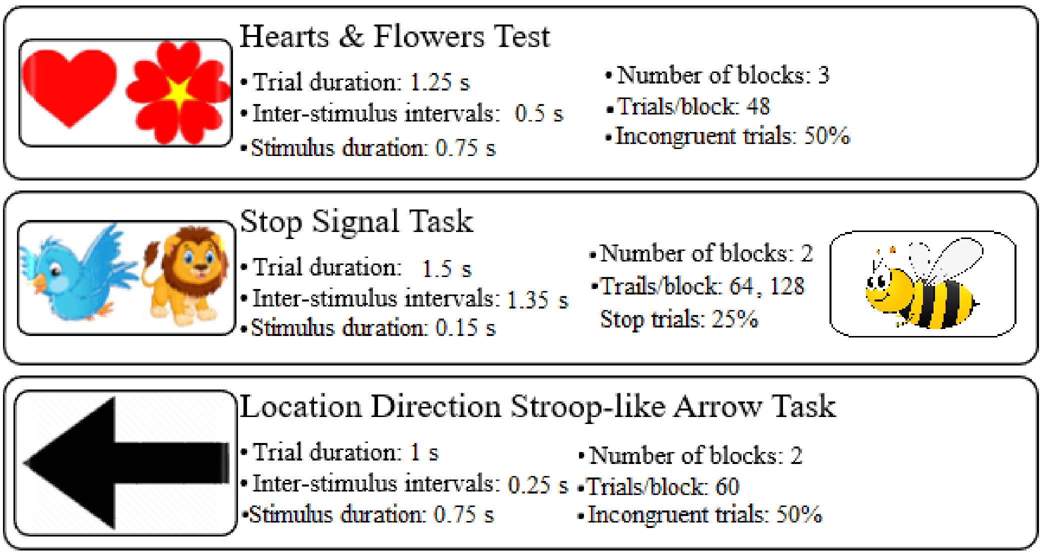
Measures

Location-Direction Stroop-like Test

In this computer-based neuropsychological test of EFs, children are prompted to respond (by pressing a button) either to the location or the direction of an arrow appearing rapidly on the screen (Tsal et al., 2005). In the first block of the test, the rule was to judge the location of the arrow relative to a fixation point, meanwhile inhibit the direction of the point of the arrow. In the next block, subjects had to judge the direction of the arrow, and inhibit the location. Each block began with a practice block of 12 trials with feedback (with a sad or a happy smiley face depending on accuracy), after which point children did not receive any feedback. Half of the stimuli were congruent trials (i.e., the location on the screen and the direction of the arrow matched) and half of them were incongruent (i.e., the location on the screen and direction of the arrow were the opposite), presented in a pseudo-random order. Both blocks had 60 trials. Figure 1 demonstrates the timing of the task. The number of correct responses in each block and reaction time (RT) were metrics of inhibitory performance. Responses less than 0.25 s were excluded for being too fast to be considered a response to the stimulus (Wright & Diamond, 2014).

Figure 1

Timing of the Computer-Based Executive Function Tasks



Hearts and Flowers Test

This task was a computer-based measure of cognitive inhibition and flexibility (Davidson et al., 2006; Diamond et al., 2007). In the first, congruent block of the test rapidly appearing hearts were presented on the left or right side of the screen. The task was to press a predetermined button on the same side of the keyboard. The aim of this block was to „warm up", thus it was not considered to load on executive functions. In the next, incongruent block, red flowers were presented on the left or right side of the screen, but the task was to press a button on the opposite side of the keyboard. This block required inhibitory control meaning that the prepotent tendency to respond toward a stimulus must be inhibited when the stimulus and its associated response were on opposite sides (Hommel et al., 2004). In the final mixed block, hearts (congruent) and flowers (incongruent) were displayed on each of the screen, and the task was to switch between the two previously learnt rules, and press either on the same (i.e., hearts) or the opposite side (i.e., flowers). This part required cognitive flexibility to switch between rules and inhibit incongruent trials. One stimulus was presented per trial in all blocks. Each test block was preceded by instructions and followed by 10 practice trials with feedback (smiley face) after each key response. The timing of the task is presented in Figure 1. Data was gathered regarding RT of correct answers and accuracy (number of errors on congruent and incongruent trials). Based on the protocol of Wright and Diamond (2014) responses less than 0.25 s were considered as too fast to be interpreted as a response to the stimulus and were thus excluded.

Adapted Stop Signal Task (SST)

SST measures inhibitory control (de Jong et al., 1990; Logan et al., 1984; Verbruggen et al., 2013). In the implemented adapted SST, visual go stimuli to which a simple button-press was required were infrequently followed by a subsequent visual stop stimulus that signalled that the prepotent response had to be withheld. Specifically, a go stimulus was a picture of a lion or bird, and participants had to press the L button when the lion was shown, and the A button if the bird was shown (see Figure 1). Participants were requested to respond as fast and as accurately as possible to the go stimuli. A stop stimulus was a picture of a bee, and required to withhold the prepotent response. For each trial, stimuli were presented centrally, sequentially and stimulus duration was set at 150 ms. Trial duration was 1500 ms. The task started with a practice block, which consisted of 64 go trials. The experimental block consisted of 128 trials of which 32 trials (25%) were stop trials. This block started with a go-stop stimulus onset asynchrony of 350 ms. Subsequently, the time between go stimulus onset and stop stimulus onset was dynamically adjusted using a tracking algorithm to yield an approximately 50%

inhibition success. Trials were randomized for each participant. The relevant outcome of the SST was the Stop Signal Reaction Time (SSRT), a measure that is thought to reflect inhibitory control. The SSRT was calculated with the integration method using the inhibition rate together with the reaction time distribution on go stimuli, and the average go-stop stimulus interval (Verbruggen et al., 2013). Shorter SSRT means better inhibition. The percentage of correct go stimuli responses (neutral), no-go stimuli inhibitions, and omissions to go stimuli were also calculated. In the present sample of children, the tracking algorithm and associated corrections of go-stop stimulus onset asynchrony yielded an approximate 50% inhibition rate, validating our implementation of the paradigm.

Trail Making Test (TMT)

This paper-and-pencil test was a neuropsychological measure of visual scanning, attention and cognitive flexibility (Reitan, 1971; Reitan & Wolfson, 2004). In the adapted version for children, Task A was to connect fifteen numbers in circles from 1-to-15 with a pencil in an ascending order following a numerical sequence as fast as possible. Task B was to connect fifteen numbers and letters in an ascending order alternately following a numerical and alphabetical sequence (e.g., A-2, 2-B, B-3). Before each block there was a practice page with a few circles. During the completion, if the examinee made a mistake, the examiner immediately stopped the examinee, pointed to the last correct circle, and asked the examinee to proceed from that point. This required some time which also contributed to the completion time such as in the original protocol of this test. The total time of the completion of Task B was recorded (in seconds) to assess cognitive flexibility. The total completion time of Task A was also recorded but not used, given that visual processing speed was not the subject of the research.

Resting-State Electroencephalography (EEG) Recording

Resting state EEG measurement on pre- and post-tests was performed with the 14-channel Emotiv Epoc+™ EEG headband, and data was transferred to an Asus X556U laptop through the CyKIT 3.0 (Python server) and the OpenVIBE 2.2 software (Renard et al., 2010). EEG data was sampled at 128 Hz from 14 electrodes placed at AF3, AF4, F3, F4, F7, F8, FC5, FC6, T7, T8, P7, P8, O1, and O2 (subset of the 10/10system), and referenced to linked P3, P4. However, half of the electrode positions were excluded from the final analysis (i.e., F7, T7, T8, P7, P8, O1, O2), because EEG data was invaluable in those positions, due to calibration problems or extremely noisy data. It is important to note, that the circumstances within the school context were not alike in the laboratory.

Raw data from the EEG measurement was processed using Python in JupyterLab. The Emotiv Epoc+ automatically bandpass filtered the EEG at 0.2 – 45 Hz, and applied a notch filter at 50Hz. Additionally, EEG data was corrected for DC drift with the whole segment baseline correction of each epoch. EEG was segmented to 2-second epochs. Epochs were baseline corrected using the average amplitude in the given epoch. Epochs with artefacts, +/- 75 µV deviation from the baseline, and epochs with low to no activity (all samples in the given epoch < 5 µV) were discarded. For a similar approach, see Schönenberg and colleagues (2017). With respect to dealing with eye-movement related artifacts a strict approach was used which involved the exclusion of those trials that included EOG-blink activity, because Zeng and Song (2014) have been reported that correction procedures such as independent component analysis cannot fully correct for nonstationary EOG artifacts in the EEG. The remaining non-overlapping epochs were used for estimating power spectra using Bartlett's method. Finally, the absolute power of theta, alpha, beta, and gamma was estimated using the composite Simpson's rule. Predetermined frequencies were fixed for theta (4-8 Hz), alpha (8-12 Hz), beta (12-30 Hz). Variables were averaged from all recorded channels to define a global absolute power of theta, alpha and beta activity.

Electroencephalography (EEG) Recording During Mindfulness Meditation

Data collection and EEG-feedback of brain states during the mindfulness sessions was implemented with the 4-channel Muse brain-sensing headband and application (version 18.6). The Muse headband has four dry electrodes located at AF7, AF8, TP9, TP10 referenced to Fpz. Data was transferred to an Android device through the application which processed raw EEG and provided the following metrics: (i) percentage of calm/focused states during a session; (ii) percentage of neutral states during a session; (iii) percentage of active/ mind-wandering states during a session; (iiii) number of birds during a session (referring to deep sustained focus); (iiiii) number of stars during a session (referring to the regulation of mind-wandering). However, there is no existing research on the reliability and validity of these metrics as measuring mindfulness-related skills or performance to our knowledge.

Feasibility

A researcher-constructed checklist was used, which included a total of fourteen items. The feasibility checklist was rated by two experimenters independently after each session. The applicability of the mindfulness training with the Muse brain-sensing device, engagement and attendance of the children were assessed (see Appendix A). Applicability was measured by the fitting of the Muse headband on each child's head with two items ("Was the headband easily applicable on the child's head?" and "Were the electrodes working properly during the session?"). The applicability of the adopted version of the Muse application's instructions for the breathing awareness exercise was also measured with three items. Each item was rated by giving a 'no', 'yes' or 'not sure'. The engagement of children was measured with seven items such as willingness to follow instructions (i.e., close their eyes during mindfulness meditation, and sit still for the practice), and perceived motivation during a session on a 5-point Likert scale by higher points indicating more engagement. Attendance was measured with two items referring to willingness to participate on each session. One item was rated by giving a 'yes' or 'no', the other was rated only when the child did not participate and explored the cause of the absence (i.e., low motivation, school activity, missing from school). Children's perceived competence was measured with one item. Interrater reliability was measured with Cohen's kappa for each item of the feasibility checklist, and varied between 0.70 and 0.99, which indicated a moderate to high value according to McHugh (2012).

Mindfulness Training with EEG-Feedback

Based on the findings of Gruzelier (2014) about optimal neurofeedback dosage and the Mindfulness-Based Stress Reduction protocol by Kabat-Zinn (2003), the intervention consisted of 8 sessions. Each session has begun with an instruction supporting the comprehension and learning of breathing awareness (see Appendix A). From the third session, we shortened the instruction, given that children were already familiar with it, and added the explanation of other essential elements of mindfulness, like the observation of sensations during breathing (e.g., through the nose tips, in the abdomen, anchors), or the acceptance and non-judgemental attitude towards the constantly changing nature of awareness (i.e., concentration level, mind-wandering). These explanations were designed in an age-appropriate language by using metaphors from previous MBIs to communicate difficult concepts (Hooker & Fodor, 2008).

The length of the sessions was gradually incremented in the following way: a) the first and second session lasted for 1 minute; b) the third and fourth session lasted for 2 minutes; c) the fifth and sixth session lasted for 3 minutes; d) the seventh and eighth session lasted for 4 minutes. This was recommended by Jennings and colleagues (2012) who suggested shorter (3-5 minutes) periods of practice for children during the primary grades as they begin.

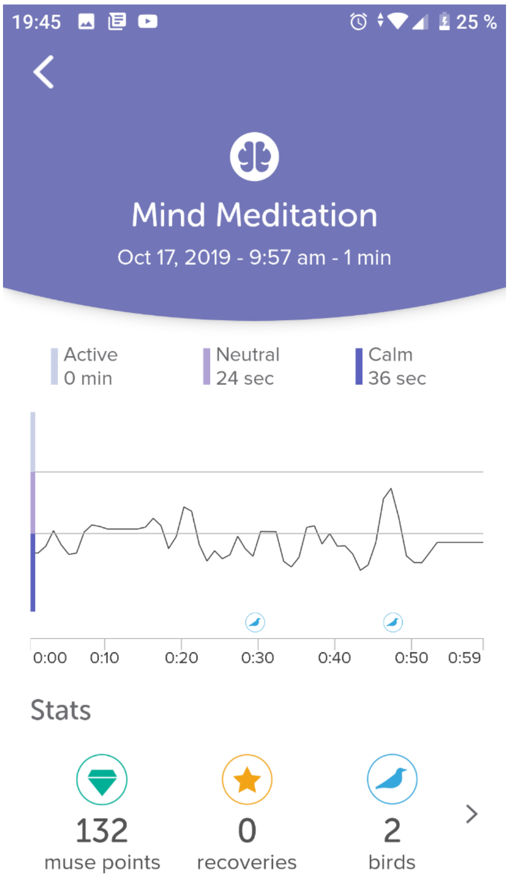
The Muse application provided a calibration period prior to each session in order to customize EEG-feedback to the participant's actual state of mind with a machine learning algorithm. In the calibration period children were asked to sit with their eyes open, then their eyes closed for a couple of minutes (see Figure 2). During each session, children individually practiced mindful breathing with the Muse headband and smartphone application with the experimenter in the room providing support if necessary. Children were instructed by the experimenter to concentrate on their breathing and try to calm down the sound of the rain and hear the birds singing through the headphones. More specifically, the rain sound rumbled when the participant's mind wandered and beta or gamma brainwaves were dominant; meanwhile sound of the rain turned down when attention was focused on breathing and alpha power increased (Kovacevic et al., 2015). Children heard birds twittering as a reward when the most desired deep meditative theta brainwaves increased in power. Each session ended with sharing and explaining the Muse application's metrics and figures with the child (i.e., calm/focused, neutral, active/mind-wandering), and inviting the child to reflect on his/her subjective experience (see Figure 3).

Figure 2

The Muse EEG-headband during mindfulness sessions on a child

Figure 3

Metrics presented in the application of the Muse headband after each mindfulness session



Procedure

Before and after the 8-sessions of mindfulness with EEG-feedback, we assessed EFs and brain activity of all participants. Data collection took place in the rooms of the participating elementary school. Children were taken out of their class for the sessions individually. The research assistant informed children about the examination process, and the children could ask questions. After childrens' verbal consent to the examination, an approximately 30-minute individual testing session began. Firstly, resting state neural activity was measured. Specifically, children were asked to sit calm for 150 seconds with eyes open and 150 seconds with eyes closed, while their brain activity was recorded with a 14-electrode wireless EEG headband (Emotiv Epoc+) on a laptop. Subsequently, children were requested to perform four neurocognitive tests measuring EFs, in a counterbalanced order. The order of the neurocognitive tests was the same on pre- and post-tests for each child. Children were rewarded with a certificate for their participation in the research project at the first meeting, and they could collect stickers on it for each task during the pre- and post-testing sessions. A few days after the pre-tests, the mindfulness training with EEG-feedback began. Post-testing was conducted 3 to 5 days after the last mindfulness session and it followed the same protocol as the pre-testing..

Statistical Analysis

All data was analysed with the IBM SPSS Statistics (for Windows version 20.0) software (IBM Corp, 2011). Average differences across the two groups and the corresponding 95% confidence interval was calculated with the standard 0.05 significance level (two-tailed).

Firstly, to report about the feasibility of the mindfulness training with EEG-feedback, frequency distributions for the items of applicability, attendance, and engagement were calculated.

The effectiveness of the mindfulness meditation program with the Muse brain-sensing device was analysed by comparing the pre-post change resting state brain activity and performance on the executive function tests between the control and the mindfulness group with repeated-measures ANOVA tests. Repeated-measures ANOVA tests with measurement points (levels: pre-test, post-test) were used as a within-subject factor, while condition (levels: experimental, control) as between-subject factors. Additionally, the partial eta-squared (η^2) effect size was calculated as an indicator of the strength of the effect that indicated the proportion of variance explained in the dependent variable by a predictor while controlling for others. Effect size (ηp^{2}) was interpreted as small (< 0.01), medium (< 0.06) and large (< 0.14) (Richardson, 2011). When the equality of the (co)variances assumption was violated, the Greenhouse-Geisser correction was interpreted (Field, 2013). In addition, paired sample t-tests were planned to be performed to reveal any increase or decrease in executive functions or brain activity in the two groups from pre- to post-test. Moreover, exploratory repeated-measures ANOVAs with four measurement points as a within-subject factor were performed to assess the modulation of three mindfulness-related brain states (calm/focused, neutral, active/mind-wandering) measured by the Muse headband and application during the mindfulness with EEG-feedback sessions.

Due to the presence of statistical outliers on the variables of pre- and post-test of EFs and EEG data, two statistical models were applied. In the first model, significant statistical outliers (1.5×IQR) were not excluded from the analysis, and additional analyses were performed with log-transformed variables to reduce non-normal skewness and kurtosis. In the second model, significant statistical outliers (1.5×IQR) were excluded to reduce non-normality in the data of specific variables and effectively exclude participants with potential non-representative/erroneous data (see Appendix C).

Results

Feasibility of the Mindfulness Training with EEG-Feedback for Children

As presented in Table 1, the average attendance rate was high during the overall program, given that children attended 92% of the sessions. In the remaining 8% children were mostly missing from school or in a few cases there were extracurricular classes accidentally scheduled at the same time as the mindfulness session. There was no child who refused attendance due to unwillingness to participate.

The technical applicability of the Muse headband was good regarding appropriate electrode contact and head size fitting. However, there were two children who had relatively small head and forehead circumferences, thus the application of the headband was constantly challenging in their case and it took more time. All children were able to understand the adapted instructions of the mindful breathing exercise enhanced by EEG-feedback. As shown in Table 1, children were mostly engaged during the mindfulness sessions, that is, they were willing to close their eyes and sit still during most of the practice. Perceived motivation varied between moderate and high during the program.

Table 1

Mean Frequency Distribution of Feasibility Metrics in the 8-Session Mindfulness Training with EEG-Feedback

Feasibility Metrics	Mean Frequency Distribution
Attendance	92%
Applicability	
- Muse headband	90%
- Comprehension of instructions	100%
Engagement	
- „Close your eyes."	78%
- „Try to sit still."	89%
- Perceived motivation	20% 'Excellent'

	55% 'Good'
	25% 'Moderate'

Tests of Baseline Differences Between Groups

Table 2 demonstrates the means and standard deviations of all EF and EEG variables. The baseline differences between groups were evaluated using one-way analysis of variance (ANOVA), and an independent sample t-test in the case of age. Between-group statistical comparison at baseline confirmed that the mean age in months (M_{exp} = 119.4, SD_{exp} = 4.99; M_{contr} = 118.7, SD_{contr} = 3.77) did not differ significantly between the mindfulness and control groups ($t(29) = 0.450$, $p = 0.66$). However, there was a significant baseline difference between the number of correct responses during the location block of the Stroop-like arrows test ($F_{(1,21)} = 4.750$, $p = 0.04$). As Table 3 shows, most of the main group effects regarding EF tests and resting-state EEG power were also non-significant ($p > 0.05$), except for the response time of the SST. It is important to note that baseline differences could challenge the interpretation of post-intervention differences between groups. However, by including time as a within-subjects factor that includes the pre-test level, and testing the time × group interaction, we effectively controlled for baseline differences.

Information about missing or excluded data is reported in Appendix C. Missing data were caused by either a logging error issue in computer-based EF pretests or absence from school at post-test. The average data loss of the resting-state EEG measurement varied between 22 and 58% depending on the electrode site. Data loss was as expected and was due to the rejection of epochs consisting of artifacts, noise, muscle activity, and eye movements. In some cases (N = 7), EEG data were excluded because of a very low number of retained segments (<5) due to a high noise ratio.

Table 2

Means and Standard Deviations of all Dependent Variables Included in the Study

Dependent Variable	**n**	**Pre *M* (*SD*)**	**n**	**Post *M* (*SD*)**	**n**	**Pre *M* (*SD*)**	**n**	**Post *M* (*SD*)**
	Mindfulness				**Control**			
Executive function measures								
Hearts and flowers test								
Flowers block RT	13	0.55 (0.07)	13	0.50 (0.06)	12	0.55 (0.08)	12	0.48 (0.12)
Mixed block RT	15	0.85 (0.09)	15	0.75	10	0.90	10	0.73

				(0.07)		(0.08)		(0.14)
Flowers block errors	12	1.92 (1.51)	12	0.92 (0.90)	13	1.46 (1.27)	13	2.00 (2.00)
Mixed block errors	14	5.29 (3.65)	14	4.50 (2.79)	12	5.42 (3.97)	12	4.86 (3.28)
Location–direction Stroop-like arrows test								
Location block RT	15	0.54 (0.04)	15	0.53 (0.07)	15	0.50 (0.06)	15	0.49 (0.07)
Direction block RT	15	0.61 (0.04)	15	0.61 (0.04)	11	0.60 (0.03)	11	0.59 (0.04)
Location block correct responses	12	48 (7.97)	12	55 (5.78)	11	54 (4.71)	11	56 (2.48)
Direction block correct responses	15	25 (10.4)	15	38 (13.4)	15	30 (14.9)	15	41 (11.2)
Stop signal task								
SSRT	10	321 (67.7)	10	274 (58.2)	11	389 (192)	11	262 (82.3)
Response time	9	838 (116)	9	772 (125)	11	618 (195)	11	713 (177)
% of omissions	10	4.79 (4.40)	10	1.77 (2.87)	8	6.38 (3.67)	8	2.47 (3.10)
Trail making test (B)								
Errors	13	0.38 (0.65)	13	0.08 (0.28)	14	0.71 (0.99)	14	0.29 (0.61)
Completion time	13	46.9 (15.7)	13	39.9 (22.6)	15	53.4 (21.8)	15	38.8 (14.7)
EEG measures								
Resting-state eyes-closed condition—Global mean absolute power (µV^2)								
Theta	9	3.69 (3.51)	9	3.58 (3.63)	9	5.56 (15.81)	9	2.18 (1.50)
Alpha	9	2.45 (3.32)	9	2.67 (3.12)	9	3.10 (2.06)	9	1.30 (0.84)
Beta	10	5.48 (4.01)	10	4.20 (3.99)	8	5.86 (1.82)	8	4.80 (3.96)
Resting-state eyes-open condition—Global mean absolute power (µV^2)								
Theta	10	2.92 (2.70)	10	3.69 (3.36)	10	5.21 (3.56)	10	2.19 (1.14)
Alpha	10	1.65 (1.71)	10	1.69 (1.79)	10	2.52 (1.37)	10	1.13 (0.49)
Beta	12	6.93 (5.27)	12	5.26 (4.72)	9	8.83 (4.73)	9	4.60 (3.37)

M Mean; *RT* reaction time in milliseconds (ms); *SST* Stop Signal Task; *SSRT* Stop Signal Reaction Time in milliseconds (ms); *TMT* Trail Making Test; *Completion time* in seconds (s); frequencies were fixed for *theta* (4-8 Hz), *alpha* (8-12 Hz), *beta* (12-30 Hz).

The Effect of Mindfulness Training with EEG-Feedback on Executive Functions and Resting-State Brain Activity

In our first statistical model, there was only one significant difference in pre- to posttest change in the mindfulness group relative to the control group, reflected by a marginally significant time × group interaction regarding the RT during the mixed block of the hearts and flowers test (see Appendix D). Paired *t* tests indicated a significant decrease in mean RT for the mixed block in the mindfulness group ($t(14) = 5.643$, $p < 0.001$) and also the control group ($t(13) = 5.708$, $p < 0.001$). All other time × group interactions were non-significant, and the observed power of the tests was low. However, after exclusion of participants with significant outlying values (see statistical model 2), we found that the mindfulness group outperformed the control group on several measures. Specifically, on two EF tests, accuracy improved significantly more in the mindfulness group than in the control group. With respect to the 'location' block of the Stroop-like arrow test, the mindfulness group showed an increased number of correct responses reflected by a significant time × group interaction (see Table 2), with a significant growth of correct responses in the mindfulness with EEG-feedback group ($t(11) = -4.732$, $p < 0.001$) and no change in the control group ($t(10) = -1.004$, $p = 0.34$). As shown in Table 2, there was a significant time × group interaction in the 'flower' block of the hearts and flowers test, with a significantly greater decrease in errors in the mindfulness group relative to the control. Paired *t* tests revealed a significant decrease in errors in the mindfulness group ($t(11) = 2.872$, $p = 0.02$) and a non-significant increase in the control group ($t(12) = -0.433$, $p = 0.67$). Additionally, in the 'flowers' block of the hearts and flowers test, there was a marginally significant difference between the groups in the pre- to post-test change of reaction time, reflected by a time × group interaction (see Table 2), with the mindfulness group exhibiting a less decreased mean reaction time compared to the control group. Post hoc tests showed a significant decrease in RT during the flower block in the mindfulness group ($t(12) = 5.198$, $p < 0.001$) and a significant decrease in the control group ($t(11) = 6.178$, $p < 0.001$).

Importantly, these effects were mirrored by the effects on the relevant frequency bands. The results from the resting-state brain activity measurements suggested that there was an overall decline in frequency band power from pre- to post-test in both groups, except for the eyes-open alpha and theta activity in the mindfulness group. Namely, in the resting-state eyes-open condition, the analysis of variance showed a significant time × group interaction effect of the changes in theta and alpha absolute power (see Table 2). Paired *t* tests demonstrated that the control group showed a significant decrease in theta ($t(9) = 2.458$, $p = 0.04$) and alpha ($t(9) = 2.564$, $p = 0.03$), while the mindfulness group showed a non-significant change from pre- to post-test for both theta ($t(9) = -1.073$, $p = 0.31$) and alpha ($t(9) = -0.174$, $p = 0.89$). All other time × group interactions of the EF tests and EEG were non-significant ($p > 0.05$).

The exploratory correlation analysis showed a significant positive relationship between the change in RT for the flower block in the hearts and flowers test and the change in resting-state eyes-open theta activity ($r(18) = 0.54$, $p = 0.03$). There was also a marginally significant positive correlation between the change in RT for the flower block and the change in alpha activity in the eyes-open condition ($r(18) = 0.47$, $p = 0.06$). However, the correlation between the change in accuracy in the EF tests and the change in alpha or theta activity in the eyes-open condition was non-significant ($p > 0.05$). The correlation between resting-state alpha and theta activity change was positive and significant, $r(20) = 0.92$, $p < 0.001$.

Table 3

Results of the Repeated Measures ANOVAs

Statistical Model No. 2			
Dependent variable	**Time**	**Group**	**Time × group**
Hearts & Flowers test			
Flowers block RT	$F_{(1, 23)} = 66.347$, $\eta p^2 = .743$ **	$F_{(1, 23)} = 0.256$, $\eta p^2 = .011$	$F_{(1, 23)} = 3.847$, $\eta p^2 = .143^{+}$
Mixed block RT	$F_{(1, 23)} = 65.404$, $\eta p^2 = .740$ **	$F_{(1, 23)} = 1.847$, $\eta p^2 = .074$	$F_{(1, 23)} = 1.485$, $\eta p^2 = .061$
Flowers block errors	$F_{(1, 23)} = 2.879$, $\eta p^2 = .111$*	$F_{(1, 23)} = 0.071$, $\eta p^2 = .003$	$F_{(1, 23)} = 5.353$, $\eta p^2 = .189$ *
Mixed block errors	$F_{(1, 24)} = 3.645$, $\eta p^2 = .190$	$F_{(1, 24)} = 0.016$, $\eta p^2 = .002$	$F_{(1, 24)} = 0.243$, $\eta p^2 = .022$
Location Direction Stroop-like Arrows test			
Location block RT	$F_{(1, 28)} = 1.379$, $\eta p^2 = .047$	$F_{(1, 28)} = 2.844$, $\eta p^2 = .090$	$F_{(1, 28)} = 0.003$, $\eta p^2 = .001$
Direction block RT	$F_{(1, 24)} = 0.033$, $\eta p^2 = .001$	$F_{(1, 24)} = 1.923$, $\eta p^2 = .074$	$F_{(1, 24)} = 0.345$, $\eta p^2 = .014$
Location block correct responses	$F_{(1, 21)} = 14.917$, $\eta p^2 = .415$ **	$F_{(1, 21)} = 2.943$, $\eta p^2 = .123$	$F_{(1, 21)} = 5.433$, $\eta p^2 = .206$ *
Direction block correct responses	$F_{(1, 28)} = 35.856$, $\eta p^2 = .562$ **	$F_{(1, 28)} = 1.026$, $\eta p^2 = .035$	$F_{(1, 28)} = 0.221$, $\eta p^2 = .008$
Stop Signal Task			
SSRT	$F_{(1, 19)} = 6.944$, $\eta p^2 = .268$ *	$F_{(1, 19)} = 0.543$, $\eta p^2 = .028$	$F_{(1, 19)} = 1.454$, $\eta p^2 = .071$
Response time	$F_{(1, 18)} = 0.040$, $\eta p^2 = .002$	$F_{(1, 18)} = 5.023$, $\eta p^2 = 0.218$ *	$F_{(1, 18)} = 4.291$, $\eta p^2 = .193$ *
% of omissions	$F_{(1, 16)} = 11.984$, $\eta p^2 = .428$ *	$F_{(1, 16)} = 0.699$, $\eta p^2 = .042$	$F_{(1, 16)} = 0.196$, $\eta p^2 = .012$
Trail Making Test			
Errors	$F_{(1, 25)} = 5.020$, $\eta p^2 = .167$ *	$F_{(1, 25)} = 1.672$, $\eta p^2 = .063$	$F_{(1, 25)} = 0.135$, $\eta p^2 = .005$

Statistical Model No. 2			
Dependent variable	**Time**	**Group**	**Time × group**
Completion time	$F_{(1, 26)} = 8.867$, $\eta p^2 = .254$ *	$F_{(1, 26)} = 0.192$, $\eta p^2 = .007$	$F_{(1, 26)} = 1.069$, $\eta p^2 = .040$
Resting-state eyes-closed condition – Global mean absolute power (µV²)			
Theta	$F_{(1, 16)} = 2.613$, $\eta p^2 = .140$	$F_{(1, 16)} = 0.033$, $\eta p^2 = .002$	$F_{(1, 16)} = 2.311$, $\eta p^2 = .126$
Alpha	$F_{(1, 16)} = 1.963$, $\eta p^2 = .109$	$F_{(1, 16)} = 0.118$, $\eta p^2 = .007$	$F_{(1, 16)} = 3.241$, $\eta p^2 = .168$
Beta	$F_{(1, 16)} = 0.083$, $\eta p^2 = .063$	$F_{(1, 16)} = 0.142$, $\eta p^2 = .009$	$F_{(1, 16)} = 0.010$, $\eta p^2 = .001$
Resting-state eyes-open condition – Global mean absolute power (µV²)			
Theta	$F_{(1, 18)} = 2.500$, $\eta p^2 = .122$	$F_{(1, 18)} = 0.452$, $\eta p^2 = .022$	$F_{(1, 18)} = 7.093$, $\eta p^2 = .283$ *
Alpha	$F_{(1, 18)} = 5.135$, $\eta p^2 = .222$ *	$F_{(1, 18)} = 0.073$, $\eta p^2 = .004$	$F_{(1, 18)} = 5.804$, $\eta p^2 = .244$ *
Beta	$F_{(1, 19)} = 6.369$, $\eta p^2 = .251$ *	$F_{(1, 19)} = 0.135$, $\eta p^2 = .007$	$F_{(1, 19)} = 1.197$, $\eta p^2 = .059$

RT reaction time in milliseconds (ms); *SST* Stop Signal Task; *SSRT* Stop Signal Reaction Time in milliseconds (ms); *TMT* Trail Making Test; *Completion time* in seconds (s); ηp^2 partial eta squared effect size; effect size ($\eta p^{2)}$ interpreted as : small – 0.01, medium – 0.06, large – 0.14 (Richardson, 2011); $^+$ p < 0.06; *p < 0.05; **p < 0.001, average differences across the two groups and the corresponding 95% confidence interval was calculated with the standard 0.05 significance level (two-tailed).

The Effect of Mindfulness Training with EEG-Feedback on Brain States Across Sessions

Repeated-measure ANOVAs were performed to analyse the modulation of three brain states (calm/focused, neutral, active/mind-wandering) within the mindfulness with EEG-feedback group. Means were calculated to all metrics from two following sessions on the same week, thus there were four time conditions: 1) the first and second sessions (week 1); 2) the third and fourth sessions (week 2); 3) fifth and sixth sessions (week 3); 4) seventh and eighth sessions (week 4) (see Table 4).

The statistical analysis of within-subject variance showed a non-significant effect of time on the percentage of calm/focused brain state, ($F_{(3, 13)} = 2.466$, $p = .08$, $\eta p^2 = 0.150$), however, there was a significant linear contrast of time within the four sessions, ($F_{(1, 14)} = 5.671$, $p = .03$, $\eta p^2 = 0.288$). Also there was a main effect of time regarding the number of birds, reflecting a longer periods of time in a calm/focused brain state, ($F_{(3, 13)} = 3.200$, $p = .03$, $\eta p^2 = 0.186$), with a significant linear within-subjects contrast of time, ($F_{(1, 14)} = 7.489$, $p = .02$, $\eta p^2 = 0.349$). In sum, these results suggest a steady increase in calm/focused brain state across the sessions.

Regarding neutral brain state, the ANOVA test also showed a significant effect of time, ($F_{(3, 13)}$ = 2.09, p = .05, η^2 = 0.172), with a significant linear within-subjects contrast ($F_{(1, 14)}$ = 7.869, p = .01, η^2 = 0.360).

As Table 4 represents, the ANOVA of the active/mind-wandering brain states indicated a non-significant effect of time, ($F_{(3, 13)}$ = 0.130, p = .85, ηp^2 = 0.009), and also regarding the linear within-subjects contrast, ($F_{(1, 14)}$ = 0.004, p = .95, ηp^2 = 0.001). On the other hand, the number of recovery stars from active/mind-wandering state showed a significant effect of time, ($F_{(3, 13)}$ = 22.959, $p < .001$, ηp^2 = 0.621), and the tests of indicated a significant linear within-subjects contrast, ($F_{(1, 14)}$ = 52.069, $p < .001$, ηp^2 = 0.788), with an average increase in recovering from active/mind-wandering states (see Table 4).

Table 4

Within-Group Changes in Brain States During the Mindfulness Sessions with EEG-Feedback (n = 15).

	Session 1 & 2	Session 3 & 4	Session 5 & 6	Session 7 & 8
		Mean (SD)		
Calm/focused state mean (%)	60 (21.65)	56 (18.79)	67 (19.48)	68 (23.70)
Neutral state mean (%)	39 (20.77)	43 (17.99)	32 (18.19)	30 (21.94)
Active/mind-wandering state (%)	1 (3.03)	2 (3.23)	2 (2.57)	1 (1.99)
Birds/minute	4.5 (3.44)	3.9 (2.65)	5.6 (2.84)	6.0 (3.04)
Stars/minute	0.2 (0.42)	3.9 (2.65)	5.6 (2.84)	6.0 (3.03)

Discussion

To the best of our knowledge, this is the first study to test the effects of an EEG-feedback-based mindfulness program on children’s executive functioning and attention related brain activity. Besides assesing efficacy, the aim of the present study was to explore the feasibility and sustainability of such a program adopted for elementary school children to empower their own attention regulation required for self-regulated learning.

Regarding feasibility, the mindfulness training with EEG-feedback offered at a local elementary school was well received by all constituents. Attendance rate was more than 90%; children missing sessions was solely due to absence from school or a school activity scheduled at the same time. The Muse headband, which provided the EEG-feedback, was comfortable and easy to use, however, there were a few children who had smaller head circumferences thus the application of the headband was much more complicated for them. In their case, data streaming during the mindfulness sessions was interrupted multiple times due to insufficient connection of the EEG headband. For this reason, we cannot certainly recommend the currently used model of the headband (Muse 1) for younger children than 9 years with even smaller head circumferences. The adopted version of a breathing awareness exercise from the Muse application was feasible with children, given that they could mostly follow and understand the instructions and adhere to sitting still with closed eyes for 1-4 minutes during this disciplined mindfulness practice. These results align the cognitive developmental theory from Satlof-Bedrick and Johnson (2015) who found that children were mainly able to monitor their own natural breathing (without altering) from the age of 8 years.

Feasibility results also suggested that the perceived motivation of children during the technology-supported mindfulness sessions varied from moderate to excellent. We propose that this high motivation during sessions might be mainly due to a high extent of autonomy provided by the BCI-technology enabling children to perceive themselves as sources of their own behavior. Besides autonomy, Deci and Ryan's theory (2004) identified competence and relatedness as psychological needs to be fulfilled in supportive learning environments. Competence was partially ensured by the gradual increase of practice time, teacher support for practice if needed, and different feedback metrics (i.e., starts for catching mind-wandering) in the Muse application. In fact, mindfulness performance (i.e., being in the calm/focused brain state) varied greatly among children during sessions. There were some children with very high mindfulness performance already in the beginning of the program who could hardly show improvement to the last session. On the other hand, there were a few children with a very low percentage of calm/focused brain state in the beginning, who could also hardly develop until the end of the training. That being said, results showed that these latter children mainly developed in detecting mind-wandering and redirecting their attention to the breathing (as counted by the number of stars in the Muse application). Based on the rather large variability found in the present study, we find it plausible that there are some trait-level characteristics (i.e., temperament, anxiety, dispositional mindfulness) that might moderate the learning and benefits of mindfulness with EEG-feedback. Future research should assess the effects of such potential moderators. Additionally, we find it plausible that a personalized individual training approach, providing optimal challenges in terms of practice length, adult support, and feedback metrics for each child, would might support a sense of competence more prominently. Moreover, we find it possible that teacher support during such a training can be gradually decreased depending on the individual needs of competence, relatedness, and autonomy. Future research should explore when and how to scaffold children during such technology-supported learning process for an optimal development in mindfulness performance.

Regarding the efficacy of the program, we evaluated the effects of the mindfulness program with EEG-feedback on children's executive functions and resting-state brain activity related to mindfulness. To this end, we used both EF tests and EEG measurement to assess neural oscillations during the mindfulness sessions and at neutral resting states. Contrary to our hypothesis, in our first statistical model, no specific positive effects were found on EF tests or resting-state brain activity when we compared the technology-supported mindfulness with the control group. It should be noted that the non-significant results might be due to the retainment of extreme values that were potentially non-representative. This concern was addressed by excluding those participants with extreme values. This second statistical model provided some initial support for a potential effect of mindfulness training with EEG-feedback for children. Positive effects were found on two out of the four EF tests regarding the accuracy of inhibition and attention related responses. More specifically, in the Hearts and Flowers test the mindfulness group made significantly less errors (failed inhibitions), from pre- to post-test, which was accompanied by a tendency of decrease in reaction time from pre- to post-test. It is important to note that the control group showed an even larger decrease in RT from pre- to post-test, but this was not accompanied by less errors. As Diamond (2013) described, errors are often made because of not being able to wait, but if inhibition is well-developed errors can be avoided. These findings might suggest that the mindfulness training with EEG-feedback have empowered children to regulate their immediate responses and slow down, which at least contributed to the enhanced inhibitory performance. Furthermore, the mindfulness group showed significantly more correct responses (successful inhibitions) on the Stroop-like Arrow test from pre- to post-test as compared to the control group. This effect was not accompanied by any changes in RT. A recent meta-analysis by Sumantry and Stewart (2021) concluded that mindfulness led to greater improvements in accuracy-based tasks rather than reaction time which is in line with our findings. Interestingly, in the study of Bhayee and colleagues (2016) with adults, reaction time (RT) results showed a somewhat different effect: the neurofeedback-assisted mindfulness group's inhibitory responses on the Stroop-task became faster, while accuracy did not change. As Davidson and colleagues (2006) concluded, inhibition requires greater effort from children, which can be seen in the errors of difficult trials while RT remains relatively constant, than adults who slow down RT on difficult trials. Our findings extend this literature by showing a change in accuracy (related to inhibition) due to mindfulness, with a preliminary effect on RT similar to adult performance.

Results from the resting-state brain activity measurement suggested that in the eyes-open condition, the mindfulness with EEG-feedback group showed a non-significant increase in alpha and theta absolute power from pre- to post-test, while the control group showed a significant decrease in these low frequency neural oscillations. To fully understand alpha and theta neural oscillations among children it is important to note that longitudinal research has demonstrated infant EEG is at a much lower frequency which increases with aging (Bell & Cuevas, 2012). For instance, in a relaxed wakefulness when the alpha frequency from 8 Hz to 13 Hz is dominant for adults, infants exhibit a lower frequency range from 6 Hz to 9 Hz (Stroganova et al., 1999). Therefore, it might be that the participating 9-10 years old children in our study also exhibited a somewhat lower frequency range for the alpha band than adults, and the observed increase in the theta band might demonstrate an increase rather in the alpha band. To connect our neuropsychological findings to previous research, we can conclude that the non-significant increase in baseline alpha and theta oscillations in the mindfulness with EEG-feedback group accompanied with significant improvement in inhibition and attention was somewhat surprising, given the fact that both neurofeedback and mindfulness separately were found to increase these brain waves in previous studies (Gruzelier, 2014; Lomas et al., 2015). Interestingly, Navarro-Gil and colleagues (2018) also found that baseline alpha was not modulated by an alpha upregulating neurofeedback training, only task-related alpha increased.

Finally, an exploratory correlation analysis showed that pre-post change of resting-state eyes-open theta and alpha activity was positively correlated with the change of RT in the executive function test (where accuracy increased in the mindfulness with EEG-feedback group). These findings show some support the theory of Klimesch and colleagues (2012) who proposed that alpha oscillations have two central roles in information processing, namely timing and inhibition. Our results extend Klimesch’s theory by showing that increase in baseline alpha oscillations (before the EF task) was associated with improved information processing speed during an EF task, thus timing. However, it is important to note that we could notnot inspect whether alpha during the task was associated with timing or inhibition because there was no EEG measurement during the EF task.

Results from the second exploratory analysis showed that there was a linear effect of time regarding the percentage of time spent in a calm/focused state during the mindfulness with EEG-feedback sessions. From the first to the last session, children improved 8% on average on being in a calm/focused state during the session. Also, there was a significant linear effect of time regarding the longer and deeper focused states (birds/minute), showing 1.5 birds/minute more on average on the last session than the first. These indicators, measured by the Muse headband and application, suggest an increase of the lower frequency alpha and theta brain waves during the training, thus a relaxed, yet focused mind state. The variance of analysis regarding the change of neutral states during the technology-supported mindfulness training also indicated a linear effect of time, with a 9% mean decrease from the first session to the last session. Interestingly, mean active/mind-wandering states were generally very low even on the first session among the sample (1% of the session duration), and this stayed true for the last session as well. However, the mean number of recovery stars per minute showed a significant increase from the first to the last session, with a mean of 5.8 recovery stars per minute increase, which suggests that children improved in recognizing mind-wandering states and redirecting their attention to their breathing. These results are somewhat contradictory to the findings of Acabchuk and colleagues (2021) who found non-significant changes in the calm/focused states of adults in the Muse group from pre- to post-test. This non-significant difference between the pre- and post-test might be due to high individual variance in mindfulness performance within sessions, with decreases, stagnation, and increases in performance over the whole training. Our results extend prior research by highlighting the potential to investigate the learning process from session to session instead of only focusing on pre- and post-test measures of mindfulness. It might also raise attention to the need of repeated measures of state mindfulness due to high variance between different mindfulness sessions.

Limitations and Future Directions

There were five perceived limitations in this pilot study: (i) low sample size; (ii) a passive control group; (iii) a low-intensity training protocol; (iv) the lack of blinding of conditions; and (v) the possibility of a carryover effect. We addressed the first limitation in the current study by conducting ANOVAs, which are quite robust and are claimed to be applicable to relatively low sample sizes (Logemann et al., 2014). However, as the power analysis showed, the sample size was underpowered to detect small effects. Regarding the methodological limitations of the study, we highly recommend adding an active control condition to the design (i.e., sham-feedback or mindfulness group) to rule out non-specific (e.g., training or placebo) effects, from effects specific to the supplementation of EEG-feedback to simple mindfulness. In addition, we cannot exclude the presence of expectancy bias from the experimenters and participants due to the lack of blinding of conditions; thus, this could also be addressed in future studies. Another possible confounding effect could be observed in the study from the carryover effect of mindfulness practice on post-test resting-state EEG measurement, as the results showed a clear reduction in alpha and theta activity in the control group from pre-to-post but not in the mindfulness group. We applied the post-test EEG measurement 3–5 days after the last mindfulness session; however, future studies could aim to test the effects at a more delayed post-test or at follow-up. In subsequent research, the carryover effect might be addressed by counterbalancing the order of EEG measurement and cognitive tests, or by planning resting-state EEG measurement as the last measurement after cognitive tests to avoid the sequential order of mindfulness practice and resting-state EEG measurement (Price, 2015).

Another limitation that is also important to note is that the variables obtained from the Muse headset (brain states, birds, and stars) are derived from black-box algorithms, which brings their reliability and validity into question. The study of Kovacevic and colleagues (2015) provided some information about the outline of the algorithms; however, important details were not reported. This lack of a clear EEG-feedback protocol might also be addressed in future research by applying a predesigned protocol (i.e., alpha and theta training); for more examples see (Cahn & Polich, 2006; Gruzelier, 2014).

Moreover, another perceived limitation was that our sample consisted of a restricted age and SES range (9–10 years, middle and high SES). Hence, an applicable nuance should be applied when generalizing these results to other samples. Furthermore, we did not control for demographic characteristics in the statistical analyses (i.e., SES, intelligence, etc.) which could also influence the cognitive outcomes in children, and the statistical analyses were not corrected for multiple comparisons.

Implications

First of all, results showed that mindfulness training with EEG-feedback (from the Muse headband) can be a potential tool to empower elementary school children to regulate their attention which can contribute to raising the number of self-regulated learners and academic achievement. Based on the feasibility findings of the program we can conclude that the application of the headband and the learning process was varying in terms of difficulty among children. For this reason, we concluded that adult support might be crucial for those students with smaller head circumferences, and/or difficulties in reaching a calm/focused state. However, our experiences from this feasibility study, showed that we could create a sustainable learning environment for students with minimal adult support needed for the mindfulness practice with EEG-feedback. Secondly, results showed that such a training have empowered children to regulate their immediate behavioral responses and slowed down in their responses to reach a higher level of accuracy, which reflects an enhanced inhibitory performance required for academic success as well.

Conclusions

Based on our findings, it can be concluded that mindfulness training with EEG-feedback (provided by the Muse headband) was feasible within an elementary school with 9-10 years old children. Average engagement and motivation was generally high during this low-intensity program and might be due to the autonomy and competence provided by the technology-supported feedback and protocol of the mindfulness program which considered psychological needs to be fulfilled in a supportive learning environment proposed by Deci and Ryan’s theory (2004). Calm/focused brain states and the redirection of attention when it has wandered linearly increased during the program. In our 1st line of statistical models, no positive effects on executive functions and resting-state brain activity could be observed when we compared the mindfulness and control group. However, in the 2nd more stringent line of statistical models excluding outliers, significant changes from pre- to post-tests were detected on two out of the four EF tasks, and in the resting-state eyes-open alpha and theta brain activity between the mindfulness and the control group. More specifically, the mindfulness with EEG-feedback group showed a significant improvement in inhibition and information processing compared to the control group. Our findings extend Klimesch’s (2012) theory by connecting baseline alpha brain activity with information processing during a cognitive task. These findings provide some preliminary evidence on technology-supported mindfulness practice embedded in the everyday practice in schools to empower children to practice regulating their own attention without the assistance of an adult. Results from our pilot study also call attention to future research with a larger sample, possibly a longer intervention, a sham-feedback group, and a further exploration of how to support the three psychological needs from Deci and Ryan’s theory in a technology-supported environment to learn mindfulness.

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General Discussion

Overall, the present doctoral dissertation aimed to study the effect of mindfulness-based interventions on 3 – 12 years old children's self-regulation, and identify potential moderators of efficacy. Secondly, we analyzed the content of evidence-based mindfulness programs to uncover qualitative and quantitative differences between MBIs for early and middle chilhood. In general, our aim was to provide recommendations for those professionals who plan and execute mindfulness-based interventions, mainly regarding what are the best mindfulness practices for early and middle childhood. Thirdly, we investigated the feasibility and potential effects of a novel approach with children, namely mindfulness training with EEG-feedback (or neurofeedback).

The findings of our meta-analysis demonstrated that MBIs successfully decrease inattentive and hyperactive-impulsive behavior among 3 – 12 years old children (Vekety et al., 2021). In a previous meta-analysis from our research group, Takacs and Kassai (2019) found that MBIs had a positive effect on children's executive function skills. Together, these results show that mindfulness programs are beneficial for self-regulation in the cognitive and the behavioral domains as well. Interestingly, our meta-analysis pointed out that it was only the teachers who noticed a positive change in inattentive and hyperactive-impulsive behavior, and not the children themselves or their parents. Plausible explanations for these findings are discussed within the discussion of the meta-analysis (see Study 1). These results highlight the importance of the triangulation of measurements in research as suggested by Thurmond (2001). Furthemore, results of the meta-analysis revealed that school-based MBIs are beneficial for all children, but for those who are at-risk for attention and impulse control problems these benefits seem to be even somewhat larger. These are in line with previous findings by Diamond and Lee (2011), who also found that children with underdeveloped self-regulation, due to low SES or EF deficiency, gain the most from interventions which train self-regulation. Moreover, findings show that MBIs were equally beneficial for self-regulation in early and middle childhood as well, thus age might not be a moderator of efficacy. This finding led us to our second study, the content analysis, to find out what are the qualitative and quantitative differences between mindfulness programs for early and middle childhood (Vekety, Kassai & Takacs, 2022).

In the content analysis, we found that MBIs are mostly highly complex programs with more than two intervention components, such as breathing awareness, working with thoughts and emotions, mindful movement and body practices, awareness of senses, kindness practice, body-scanning, psycho-education, group discussions, and home practice. Two additional components were identified, namely playfulness and story-based context, which subserved developmental appropriateness in the programs. In the results and discussion section of the content analysis (see Study 2), we make recommendations from a developmental perspective, about how to practice mindfulness with children in early and middle childhood. There were important quantitative and qualitative differences between how the components were applied with kindergardeners and school-aged children (i.e., unpleasant sensation in sensory awareness exercises for middle childhood, or attention anchoring objects for breathing awareness exercises for early childhood). The content analysis was also supplemented with a preliminary review about the effects of the included MBIs on other mindfulness and self-regulation related outcomes (i.e., agression, emotion regulation, anxiety, affectivity, prosocial skills). In this preliminary review part of Study 2, we studied the effects of mindfulness programs with certain components. First of all, those MBIs which applied components of breathing awareness, and working with thoughts and emotions together, were mainly reported positive effects on children’s overall self-regulation, attention, executive efunctions, meta-cognition, and anxiety. Secondly, all mindfulness programs with a mindful movement and body practice component were effectively reducing children’s anxiety. Thirdly, most of the programs which included kindness practice as intervention component nurtured social skills and prosocial behavior.

However, results from the preliminary review indicated mixed results regarding the efficacy of MBIs on „hot” self-regulation related outcomes, such as agression, emotion regulation, and affectivity. The reason behind this might be that these outcomes require more time to change, for instance, longer interventions or follow-up measurement of outcomes as suggested by Moreno-Gómez and colleagues (2020). These emotion-related outcomes might reflect more trait-level or temperament like characteristics than „cold” cognition and behavior related outcomes. In their neuropsychological study, Taylor and colleagues (2011) found that beginner mindfulness practitioners top-down regulated their emotional processing in the amygdala, which required a cognitive effort. On the other hand, experienced mindfulness practitioners showed mainly bottom-up emotion regulation processing, because they had emotional stability on a trait-level to every emotional stimuli. The brain of experienced mindfulness practitioners showed the deactivation of the DMN, which means that their self-referential processing was less active, and they also had less reactive emotion generation in the amygdala. From this study, it seems like that experienced mindfulness practitioners tend not to impose feelings on themselves, they just accept what comes and let it go effortflessly. Chiesa, Serretti and Jakobsen (2013) also suggest that mindfulness training is associated with 'top–down' emotion regulation in short-term practitioners and with 'bottom–up' emotion regulation in long-term practitioners.

Based on the findings from Study 1 and 2, we designed a developmentally appropriate program for 9 – 10 years old children in a local elementary school, in which we tested a novel technology-supported approach in mindfulness with EEG-feedback (Vekety, Logemann & Takacs, 2022). Findings from Study 3, demonstrated that mindfulness with EEG-feedback was feasible in the elementary school, and children stayed engaged and motivated during the program. It is important to note, that this program mainly included focused attention techniques (with two components: breathing awareness, working with thoughts and emotions) and it was only a short intervention with 8-sessions in total. Effects in Study 3 were measured with a pre-post test RCT design. Short-term improvements were visible on inhibition and reactivity to responses, accompanied with stable baseline resting-state eyes-open alpha and theta brain activity between in the mindfulness with EEG-feedback group. The control group showed non-significant baseline alpha and theta decrease with eyes-open, and non-significant change in inhibitory processes with quicker responses on some cognitive tasks. Stability in alpha and theta brain activity might reflect preliminary changes in bottom-up self-regulatory processes in the mindfulness group reflecting a trait-level relaxed, less aroused state during resting in the mindfulness than the control group (Johnstone et al., 2021). However, a possible explanation can be that the mindfulness group get used to EEG-feedback, thus during the post EEG measurement they were less aroused from the application the EEG headband. For this reason, results regardig brain activity should be interpretted with caution, and future studies should apply active control condition with sham-feedback on mindfulness preformance. Moreover, voluntary control processess, such as attention and inhibition were positively affected in the mindfulness with EEG-feedback group compared to the control group. In their systematic review, Lippelt and colleagues (2014) also found that focused attention mindfulness practice enhanced attentional and inhibitory processes. In daily life, this means that when there are plenty of information competing for our attention, we are able to select a subdominant one and focus on it (Rueda et al., 2015). The development of these voluntary control skills in childhood might be highly essential in today's multitasking world, where new generations perform an average of six everyday tasks simultaneously (Carrier et al., 2009). It has been stated that a moderate amount of multitasking can be beneficial for learning and task performance, however, accuracy is always negatively affected by multitasking (Adler & Benbunan-Fich, 2012). Rosen, Carrier & Cheever (2013) observed student in their natural learning environment and found that students stayed on task 65% of time, while 35% of time they were distracted by technology (i.e., texting, Facebook, TV). These findings further support the relevance of mindful attention and MBIs for supporting the development of self-regulation in children. Future research should explore the effect of mindfulness training with EEG-feedback on self-regulated learning and school performance, along with the sustainability of such an approach added as an extracurricular activity in schools. Additionally, in future studies of mindfulness it would be essential to explore the factors that might moderate the efficacy of mindfulness, as some children showed benefits on self-regulation and others not. Based on previous studies, examples of possible moderators of efficacy can be baseline self-regulation of participants, motivation to practice (Osin & Turilina, 2021), trait mindfulness (Calvete et al., 2021), and gender also (Koncz et al., 2021).

It is also important to note that each study from the doctoral project has its own limitations which are highlighted in the reffering chapters (see Chapter 2-4). In general, future studies should explore other moderators of the efficacy of MBIs on self-regulation, such as children's temperament. When we first planned the doctoral projects, a final efficacy study was planned with a mindfulness with EEG-feedback and a sham-feedback condition investigating whether EEG-feedback (or neurofeedback) provides additional benefits to mindfulness practice. Due to the unfortunate pandemic caused by COVID-19, we had to stop this last project with incomplete data. In view of the current situation and the three completed subprojects, we finally decided that the doctoral research could be concluded and considered as a whole. However, in the following years we plan to implement this larger-scale project in elementary schools.

General Conclusions

Findings from the three studies of the doctoral dissertation suggest that significant positive changes might occur in the psycho-physiological processes of children cultivating mindfulness. Our findings support the theory of Zelazo and Lyons (2018) who stated that mindfulness might be beneficial for both bottom-up and top-down self-regulatory processes. Interestingly, in Study 3, bottom-up level self-regulation changes in children's brain activity have been observed even after a short mindfulness training with EEG-feedback (see Chapter 4). However, it was not discovered whether these changes were long lasting or faded without practice. Moreover, mindfulness-based interventions have been found to nurture top-down or voluntary self-regulation as reflected by the neurocognitive EF tests i(see Study 2-3). Although, in the review part of Study 2, we found mixed results regarding the effects of MBIs on the affective domain, which might be due to the abscence of follow-up measurements (see Study 2). As proposed by previous studies, the effect of MBIs on social-emotional outcomes is more likely to become evident on follow-up measurements which are highly recommended for future studies (Moreno-Gómez et al., 2020; Rashedi et al., 2021).

The meta-analysis (see Study 1) revealed that MBIs effectively reduce behavior problems of inattention, hyperactivity, impulsivity among children as perceived by the teachers, especially fo those who are at-risk for sel-regulatory problems. For this reason, MBIs might be a potential tool to reduce the gap between the self-regulatory skills of at-risk and non-at-risk children, which can also impact overall school functioning and learning. Additionally, the current dissertation further support the high ecological validity of mindfulness programs led by teachers (or experts) in kindergardens and schools which can be beneficial for children with different environmental and personal factors (e.g., SES, ADHD). Based on our findings important theoretical and practical guidance can be provided for professionals and future researches within the field of mindfulness-based interventions for children (see Implications sections in Study 1-3). However, all study of the doctoral dissertation had its own limitations accentuated in Chapter 2-4. Future research is warranted concerning other possible moderators of MBIs efficacy on self-regulation, such as children's temperament, feedback sensitivity. Moreover, it would be important to further investigate whether EEG-feedback provides an additional benefit to mindfulness programs by implementing an active control sham-feedback design. In the future, these results and conclusions from the doctoral dissertation might guide our research to provide more knowledge to the field of mindfulness, self-regulation, and childhood development.

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Appendix A

Feasibility Checklist for the MM training with the Muse™ Brain-Sensing Device for Children

Date:	……………………………………………………………
Experimenter:	…………………………………………………………..
Identification code of the child (ID):	…………………………………………………………..
Session number:	…………………………………………………………..

Attendance

Was the child willing to participate on the session?	Yes/no
If no, why not?	a) School activity b) Sickness c) Low motivation for the N-MM session d) Anything else: ……………………………. …………………………………………….

Applicability of the Muse™ headband (EEG-feedback)

Was the headband properly applicable for the child's head size?	Yes/No
Were all electrodes contacted to the child's head during the mindfulness meditation practice?	Yes/No/Not sure

Applicability - Comprehension of the instruction

Did the child understand the instruction?	Yes/No/Not sure
Did the child need additional guidence to the task?	Yes/No
Other comments:	

Engagement – Following the instructions

How much did the child squirm during the session?	a) Not at all b) Barely nothing c) Squirming sometimes d) Squirming a lot e) Squirming all the time

How long was the child not able to hold his/her eyes closed during the mindfulness meditation?	a) His/her eyes were closed during the whole session b) He/she barely opened his/her eyes c) His/her eyes were open half of session d) His/her eyes were open during almost the whole session e) His/her eyes were open during the whole session

Was the child able to do the whole practice time (e.g., 2 minutes)?	Yes/No

Engagement – Perceived Motivation

How motivated was the child during this session?
1 ------- 2-------3--------4----------5 (1 = not at all, maybe not even present, 2 = present, but low motivation, 3 = moderate, 4 = good motivation, 5 = excellent)

Other comments:

Appendix B

The Content of the Mindfulness Meditation Program with EEG-feedback for School-Aged Children

Session	Objective	Activities
1	Introduction of the Muse Interaxon headband, and the neurofeedback system	• Conversation about attention with/without awareness, and the nature of attention with the puppy metaphor • Breathing awareness meditation • Conversation about the child's current state of attention based on the Muse application results

2	Children will be able to understand the neurofeedback system, and practice how to guide their attention to the breathing	• Reminder: repetition of the instruction • Breathing awareness meditation • Conversation about the child's current state of attention based on the Muse application results
3	Children will be able to notice the body sensations connected to breathing, and use them as an anchor of attentional awareness	• Tips & Tricks: body sensation during inhalation and exhalation, and how to use them as an anchor for awareness • Breathing awareness meditation • Conversation about the child's current state of attention based on the Muse application results
4	Children will be able to use body sensation as anchors to breathing awareness, and to intentionally pay attention to breathing	• Reminder: repetition of bodily sensations as anchors of attention • Breathing awareness meditation • Conversation about the child's current state of attention based on the Muse application results
5	Children will be able to notice their current state of attention, and accept it without judgement or evaluation	• Conversation about the changing nature of attention (e.g., concentration, mind-wandering) and accepting as it is • Breathing awareness meditation • Conversation about the child's current state of attention based on the Muse application results
6	Children will be able to accept their current state of attention, and develop a	• Reminder: repetition of acceptance and non-judgemental attitude towards our own current state

	kind non-judgemental attitude towards themselves	• Breathing awareness meditation • Conversation about the child's current state of attention based on the Muse application results
7	Children will be able to focus their attention for a longer period of time	• Breathing awareness meditation • Conversation about the child's current state of attention based on the Muse application results
8	Children will be able to master the skills required for intentionally paying attention to their own breathing for a longer period of time	• Breathing awareness meditation • Conversation about the child's current state of attention based on the Muse application results

APPENDIX C. Significant statistical outliers and missing data in the statistical models

Statistical model no. 1	**Missing data (n)**
Location Direction Stroop-like Arrow test	absence from school (1)
Hearts & Flowers test	logging error (1)
SST	failure to estimate the SSRT, or Mean RT, or omissions due to incorrect switching of finger-stimulus assignment (10-13)
TMT	logging error (1)
Resting-state eyes-closed brain activity	<5 retained segments of EEG data due to high noise ratio (7)
Resting-state eyes-open brain activity	<5 retained segments of EEG data due to high noise ratio (6)
Statistical model no. 2	**Excluded significant statistical outliers (n)**
Location Direction Stroop-like Arrow test	direction block mean RT (5), location block correct responses (8)
Hearts & Flowers test	flowers block mean RT (4), flowers block errors (4), mixed block mean RT (4), mixed block errors (3)
TMT	errors (3), completion time (2)
Resting-state eyes-closed brain activity	theta & alpha (6), beta (6)
Resting-state eyes-open brain activity	theta & alpha (2), beta (1)

SST Stop Signal Task; *TMT* B Trail Making Test B version

APPENDIX D. Results of the ANOVAs on EFs and brain activity in statistical model No.1

	Statistical model No.1		
Dependent variable	**Time**	**Group**	**Time × group**
Hearts & Flowers test			
Flowers block RT	$F_{(1, 27)}$ = 14.533, ηp^2 = .350**	$F_{(1, 27)}$ = 0.106, ηp^2 = .004	$F_{(1, 27)}$ = 0.167, ηp^2 = .006
Mixed block RT	$F_{(1, 27)}$ = 62.936, ηp^2 = .700**	$F_{(1, 27)}$ = 0.044, ηp^2 = .002	$F_{(1, 27)}$ = 3.852, ηp^2 = .125^{+}
Flowers block errors	$F_{(1, 27)}$ = 0.180, ηp^2 = .007	$F_{(1, 27)}$ = 0.306, ηp^2 = .011	$F_{(1, 27)}$ = 0.979, ηp^2 = .035
Mixed block errors	$F_{(1, 27)}$ = 6.331, ηp^2 = .190*	$F_{(1, 27)}$ = 0.180, ηp^2 = .007	$F_{(1, 27)}$ = 0.614, ηp^2 = .022
Location Direction Stroop-like Arrows test			
Location block RT	$F_{(1, 28)}$ = 1.379, ηp^2 = .047	$F_{(1, 28)}$ = 2.844, ηp^2 = .090	$F_{(1, 28)}$ = 0.003, ηp^2 = .001
Direction block RT	$F_{(1, 28)}$ = 0.513, ηp^2 = .018	$F_{(1, 28)}$ = 6.777, ηp^2 = .195*	$F_{(1, 28)}$ = 0.101, ηp^2 = .0004
Location block correct responses	$F_{(1, 28)}$ = 14.511, ηp^2 = .341 **	$F_{(1, 28)}$ = 1.469, ηp^2 = .050	$F_{(1, 28)}$ = 0.001, ηp^2 = .001
Direction block correct responses	$F_{(1, 28)}$ = 35.856, ηp^2 = .562 **	$F_{(1, 28)}$ = 1.026, ηp^2 = .035	$F_{(1, 28)}$ = 0.221, ηp^2 = .008
Stop Signal Task			
SSRT	$F_{(1, 19)}$ = 6.944, ηp^2 = .268*	$F_{(1, 19)}$ = 0.543, ηp^2 = 0.028	$F_{(1, 19)}$ = 1.454, ηp^2 = .071
Response Time	$F_{(1, 19)}$ = 0.156, ηp^2 = .008	$F_{(1, 19)}$ = 3.996, ηp^2 = 0.174 $^{+}$	$F_{(1, 19)}$ = 1.599, ηp^2 = .078
% of omissions	$F_{(1, 19)}$ = 0.267, ηp^2 = .014	$F_{(1, 19)}$ = 3.308, ηp^2 = 0.148	$F_{(1, 19)}$ = 1.412, ηp^2 = .069
Trail Making Test			
Errors	$F_{(1, 26)}$ = 1.145, ηp^2 = .041	$F_{(1, 26)}$ = 1.482, ηp^2 = .052	$F_{(1, 26)}$ = 0.105, ηp^2 = .040
Completion time	$F_{(1, 26)}$ = 8.867, ηp^2 = .254*	$F_{(1, 26)}$ = 0.192, ηp^2 = .007	$F_{(1, 26)}$ = 1.069, ηp^2 = .040
Theta	$F_{(1, 19)}$ = 4.575, ηp^2 = .194*	$F_{(1, 19)}$ = 0.097, ηp^2 = 0.005	$F_{(1, 19)}$ = 0.582, ηp^2 = .030
Alpha	$F_{(1, 19)}$ = 3.442, ηp^2 = .153	$F_{(1, 19)}$ = 0.070, ηp^2 = 0.004	$F_{(1, 19)}$ = 0.553, ηp^2 = .028
Beta	$F_{(1, 19)}$ = 3.565, ηp^2 = .158	$F_{(1, 19)}$ = 1.137, ηp^2 = 0.156	$F_{(1, 19)}$ = 0.902, ηp^2 = .045
Theta	$F_{(1, 20)}$ = 3.943, ηp^2 = .165^{+}	$F_{(1, 20)}$ = 0.408, ηp^2 = 0.020	$F_{(1, 20)}$ = 0.277, ηp^2 = .014
Alpha	$F_{(1, 20)}$ = 5.164, ηp^2 = .205*	$F_{(1, 20)}$ = 0.452, ηp^2 = 0.022	$F_{(1, 20)}$ = 0.052, ηp^2 = .003
Beta	$F_{(1, 20)}$ = 6.718, ηp^2 = .251*	$F_{(1, 20)}$ = 0.889, ηp^2 = 0.043	$F_{(1, 20)}$ = 2.530, ηp^2 = .112

RT reaction time in milliseconds (ms); *SST* Stop Signal Task; *SSRT* Stop Signal Reaction Time in milliseconds (ms); *TMT* Trail Making Test; *Completion time* in seconds (s); ηp^2 partial eta squared effect size; effect size (ηp^{2}) interpreted as : small – 0.01, medium – 0.06, large – 0.14; $^{+}p < 0.06$; $*p < 0.05$; $**p < 0.001$.