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Towards Determinants and Effects of Long-Term Mindfulness Training in Pre-Adolescence:
A Cross-Sectional Study Using Event-Related Potentials

Abstract

The present study presents the first attempt at investigating long-term mindfulness training in pre-adolescence, adopting an integrative neurodevelopmental approach. Pupils with an established mindfulness practice ($n=33$) were compared with mindfulness-inexperienced pupils ($n=20$) on dispositional mindfulness, executive functioning (EF), emotion regulation, and well-being. We also investigated whether increased well-being in mindfulness-experienced pre-adolescents would be mediated by EF and emotion regulation. Moderating influences of the amount and enjoyment of mindfulness training were considered as well. Self-report questionnaires measured dispositional mindfulness and well-being. Parents assessed their child's emotion-regulation using the Emotion Regulation Checklist (ERC). Performance in a Continuous Performance Task and simultaneously recorded ERPs - Cue-P3, CNV, Nogo-N2, Nogo-P3 – indexed EF. Interestingly, the two groups of pupils did not differ in their dispositional mindfulness. ERP findings revealed that the mindfulness-experienced group demonstrated superior EF in terms of response inhibition, but inferior EF in terms of cue processing. Although the ERC negativity/lability subscale revealed an advantage for the mindfulness-experienced group, no group differences were observed for the ERC emotion regulation subscale or well-being. Mediation analysis results did not support the assumption that mindfulness training leads to increased well-being via improvements in EF and emotion regulation. While outcomes were not moderated by amount of mindfulness practice, enjoying mindfulness was negatively associated with indicators of well-being and EF.

Keywords: mindfulness; children; executive function; well-being; event-related potential; neuroscience

Introduction

An increasing number of investigations into mindfulness-based interventions (MBIs) has demonstrated that these programs can improve a wide range of outcomes in adults, including well-being (e.g., Khoury, Sharma, Rush, & Fournier, 2015) and sub-components of cognition (e.g., Kissane, & Meadows, 2016). While there isn't an agreed definition of mindfulness, in the secular context of MBIs mindfulness is often defined as awareness arising from non-judgmental present-moment attention focus (Kabat-Zinn, 2003). Mindfulness can be trained through MBIs, which predominantly involve formal meditation practices such as body scan and informal mindfulness practice during daily activities.

Given the encouraging evidence base in adults, MBIs were adapted for children and adolescents, mostly in school settings (Kaunhoven & Dorjee, 2017).

The proposed benefits for children and adolescents include enhancement of core self-regulatory capacities such as executive function (EF), and emotion regulation (Jensen, 2014; Schonert-Reichl et al., 2015). These capacities are not only regarded as vital for academic success (Dunning et al., 2019), but are also expected to promote holistic development of the individual (Rempel, 2012). In addition, MBIs have been considered universal prevention programs in the sense that they have the potential to build resilience (an overlapping construct with the capacities of EF and emotion regulation) in view of rising stress levels and mental health challenges for youth (Carsley, Khoury, & Heath, 2018; Greenberg & Harris, 2012; Rempel, 2012; Renshaw & Cook, 2017).

MBIs can be effective in young people, due to their receptivity (Rempel, 2012) and documented longer-term effectiveness of early interventions targeting EF (Diamond & Ling, 2016; Takacs & Kassai, 2019). Within childhood and adolescence, pre-adolescence has been suggested as a particularly susceptible period for the benefits of MBIs, since the brain regions underlying self-regulation, a main target of MBIs, are especially malleable during this stage of life (Kaunhoven & Dorjee, 2017). Another advantage of practicing mindfulness during pre-

adolescence is that learners can acquire effective coping skills before the onset of adolescence, when mental health difficulties often increase to a considerable degree (Dunning et al., 2019).

Although the number of empirical studies that investigated the effectiveness of MBIs in children and adolescents is still lagging behind the evidence base for adults, it is has been growing so fast that several meta-analyses have been conducted over the last decade (Carsley et al., 2018; Dunning et al., 2019; Kallapiran, Koo, Kirubakaran, & Hancock, 2015; Klingbeil et al., 2017; Maynard, Solis, Miller, & Brendel, 2017; Zenner, Herrnleben-Kurz, & Walach, 2014; Zoogman, Goldberg, Hoyt, & Miller, 2015). Due to heterogeneity in study types included and differences in categorization of indicators, the overarching findings are hard to synthesize. The most recent meta-analysis restricted to randomized controlled trials (RCTs) (Dunning et al., 2019) reported small-size benefits on mindfulness, EF, attention, depression, anxiety/stress and negative behaviors. When only RCTs involving active control groups were considered, medium-size benefits emerged for mindfulness and depression, and small-size benefits for anxiety/stress. Taken together, the extant evidence suggests that MBIs improve developmentally important outcomes in children and young people. Notably, there have been more studies looking at adolescents than pre-adolescents.

As a next step, mechanisms of action should be investigated, especially possible neurodevelopmental factors to more fully understand how mindfulness training interacts with age-related brain changes and to support implementation in education (e.g., Kallapiran et al., 2015; Sanger & Dorjee, 2015). According to the School-Based Meditation Model (Waters, Barsky, Ridd, & Allen, 2015), (mindfulness) meditation positively impacts on academic success of pupils in terms of well-being, social competence and academic achievement¹ by increasing pupils' cognitive functioning including attention, learning and memory, and by enhancing pupils' emotion regulation. Hence, processes of cognitive functioning/EF and emotion regulation, which are the core aspects of self-regulation (Blair & Raver, 2015;

Kaunhoven & Dorjee, 2017), are considered central to bringing about mindfulness-based benefits in pupils. This resonates with other proposals regarding underlying developmental mechanisms of mindfulness (e.g., Greenberg & Harris, 2012; Frank, Jennings, & Greenberg, 2013; Schonert-Reichl et al., 2015).

Importantly, the processes of EF and emotion regulation overlap in the function and neural underpinnings (Ochsner & Gross, 2005). In many situations emotions and other cognitive processes compete for limited attentional resources. If mindfulness training improves attention regulation, this could free up attentional capacities needed for emotion regulation and therefore contribute to improved emotion regulation (Sanger & Dorjee, 2015). MBIs also develop specific emotion regulation strategies (Kaunhoven & Dorjee, 2017) such as reduced reactivity to disturbing emotions (Chambers, Gullone, & Allen, 2009). Mindful emotion regulation seems to be especially effective in children and adolescents, because it is less effortful than other top-down strategies of emotion regulation such as reappraisal (Keng, Robins, Smoski, Dagenbach, & Leary, 2013). Indeed, (pre-)adolescents' more effortful top-down strategies of self-regulation are typically relatively poor due to immaturity of the prefrontal cortex (Kaunhoven & Dorjee, 2017; Sanger & Dorjee, 2015).

Another underexplored area in developmental research on mindfulness are moderating effects of practice, such as dosage and length, and participant characteristics (Rempel, 2012; Renshaw & Cook, 2017). Findings regarding dosage and length of practice have been inconsistent. For instance, in the above mentioned meta-analysis of Dunning and colleagues (2019), total training hours at school significantly moderated reductions in negative behaviour, whereas no moderating effect of training duration emerged when analyses were restricted to RCTs with active control groups. Future attempts to identify effects of dosage/length should include not only mindfulness practices at schools, but also at home, since homework is considered an integral part of MBIs (Baer & Krietemeyer, 2006). Important client characteristics that deserve investigation are motivational factors, such as

practice intention and (dis-)liking of mindfulness, especially for school-based MBIs (Jensen, 2014). In adults, attending a MBI is typically a deliberate choice, so that adult mindfulness practitioners are usually intrinsically motivated. When MBIs are offered in school settings as universal interventions in regular lessons overall intrinsic motivation is likely reduced. Understanding the influence of motivational factors of child/adolescent mindfulness practitioners could inform adaptation and implementation of MBIs.

A promising but so far unrealized approach to examine both mechanisms of actions and moderating factors is to look at effects of long-term mindfulness practice in children/adolescents (e.g. Frank, Jennings, & Greenberg, 2013; Rempel, 2012). In the adult literature, initial attempts in this regard have typically involved cross-sectional studies that compared long-term (mindfulness) meditators with matched controls (e.g., Jo, Schmidt, Inacker, Markowiak, & Hinterberger, 2016). To gain a more comprehensive understanding of the underlying developmental mechanisms of mindfulness, the cross-sectional approach should be combined with the integrative neurodevelopmental framework (Kaunhoven & Dorjee, 2017) – this framework links self-report and other-report assessments with evaluations of neurocognitive markers of self-regulation in established cognitive paradigms.

The present study

In this paper, we present the first attempt at investigating long-term mindfulness practice in pre-adolescents in terms of effects, mechanisms of action and moderating influence of practice from neuroscience perspective. In a cross-sectional design, we compared mindfulness-experienced with mindfulness-inexperienced pre-adolescents (MG vs CG) on dispositional mindfulness, EF, emotion regulation, and well-being. We followed an integrative neurodevelopmental framework that combines self- and other-report measures with behavioral performance in a cognitive task, a Continuous Performance Task of the AX type (AX-CPT; van Leeuwen et al., 1998), and event related potentials (ERPs). The AX-CPT is a computerized task following a 2 stimuli Go/NoGo paradigm and has frequently been used

to assess several cognitive and underlying neural processes relevant to EF (Braver & Barch, 2002). Three types of stimuli appear – cue, target, and distractor – in the following trial types: Go trials (cue followed by target) requiring a button press, NoGo trials (cue followed by distractor) requiring inhibition of button presses, and Ignore trials (distractor followed by target) which can be neglected.

In the AX-CPT, indicators of behavioral performance based on accuracy and reaction time, as well as four ERP components can be derived. Two of the ERP components are locked to the 1st stimulus of a trial and two ERP components are locked to the 2nd stimulus of a trial. One of the ERP components locked to the 1st stimulus of a trial is the Cue-P3 - a positive peak between 300 and 600ms after stimulus onset. The Cue-P3 can index cue utilization (Hämmerer, Li, Müller, & Lindenberger, 2010). In typically developing children more positive amplitude of this ERP component has been observed than in adults. This would suggest that a less positive Cue-P3 amplitude mirrors advantageous development of cue utilization. However, atypically developing children also tend to demonstrate a less positive Cue-P3 amplitude (Spronk, Jonkman, & Kemner, 2008; Tye et al., 2014) and prolonged Cue-P3 latency (Tsai, Pan, Cherng, Hsu, & Chiu, 2009) when compared with typically developing peers. Hence, the interpretation of an amplitude change in the Cue-P3 is only accurate if the behavioral response to the cue and latency of the Cue-P3 are taken into account as well.

The other ERP component that is locked to the 1st stimulus of a trial is the contingent negative variation (CNV), a negative broad ramp-shaped component appearing between 1100 and 1600ms after stimulus onset. It is considered a marker of resource optimization (Kononowicz & Penney, 2016). When compared to adults, children's CNV is typically less negative in amplitude (Hämmerer et al., 2010; Jonkman, 2006), which suggests that more negative CNV amplitude in pre-adolescents indicates advantageous levels of resource optimization.

The Nogo-N2, a negative deflection occurring 200 to 300ms after the imperative stimulus, is one of the ERP components locked to the second stimulus of an AX-CPT trial. It is related to conflict processing (Groom & Cragg, 2015; Randall & Smith, 2011). The Nogo-N2 amplitude has consistently been found to decrease in negativity between childhood and adulthood (Hämmerer et al., 2010; Jonkman, Lansbergen, & Stauder, 2003; Jonkman, 2006; Lamm, Zelazo, & Lewis, 2006; meta-analysis: Hoyniak, 2017), which has been assumed to reflect improvements in EF (Lamm et al., 2006).

The second ERP component that is locked to the second stimulus of a trial is the Nogo-P3 – a prominent positive deflection between 300 to 500ms post stimulus indexing response inhibition (e.g., Groom & Cragg, 2015; Spronk et al., 2008). The Nogo-P3 amplitude becomes more positive from childhood to early adulthood (Jonkman, 2006), suggesting development of more proficient response inhibition also indicated by shorter Nogo-P3 latency (Duan et al., 2009; Liu, Xiao, Shi, & Zhao, 2011).

The following hypotheses were tested:

1. MG report higher scores/outperform CG in dispositional mindfulness, EF, emotion regulation, and well-being.
2. Increased well-being in MG is mediated by enhanced EF and emotion regulation.

In addition, the following research question was explored:

Are dispositional mindfulness, EF, emotion regulation, and well-being affected by the amount and enjoyment of mindfulness practice, if so, what is the direction of the influence?

Material and Methods

The study was approved by the Ethics Committee in the School of Psychology at Bangor University, prior to study commencement.

Participants

$N=53$ pupils were recruited from two primary schools in North Wales, $n=33$ from a school with an established mindfulness curriculum, and $n=20$ from a school without any previous

experience with mindfulness. To the best of our knowledge, the former school has an ongoing commitment to teach mindfulness for several years. After an initial invitation to carry out research on this long-term implementation of mindfulness, the headmaster of this school expressed interest to participate. Next, all primary schools within reach (i.e., within a distance of 30 miles from Bangor University) that had not received mindfulness instruction were invited to participate. The latter school was the only one interested in being part of the study. Subsequently, parents and children were invited via information letters distributed at the two schools. Sample characteristics are displayed in Table 1. None of the participants had a brain injury or operation in the past or suffered from epilepsy. Groups did not differ in age, $p=.87$. Self-report questionnaires were completed by all 53 children. Fifty-one children (32 from the mindfulness school, 19 from the control school) performed the computerized task, 45 of them (29 from the mindfulness school, 16 from the control school) volunteered for simultaneous EEG recording. Other-report questionnaire was returned by 24 parents (15 from the mindfulness school, 9 from the control school).

Parents gave written consent for themselves and their children to participate in the study. In addition, children were asked for oral consent on the day of assessment. Data were collected only if both parents and children had given their consent. Children received a small gift, such as a pencil, at the end of the testing session.

Mindfulness training

MG practiced Paws b curriculum² developed by Sarah Silverton, Tabitha Sawyer, and Rhian Roxburgh in collaboration with the Mindfulness in Schools Project (<https://mindfulnessinschools.org/>). Paws b has been designed for classroom-based implementation with children aged 7 -11. The curriculum comprises of approximately 360 minutes in total, which can be flexibly taught over twelve single, 30-minute sessions, or grouped into pairs of six double, 60-minute sessions. Each of the twelve lessons aims to teach a particular mindfulness skill: Lesson one provides basic information about the human brain

and how mindfulness training can change the brain. Lesson two shows how we can concentrate and make helpful choices using mindfulness. In lesson three, children experience how they can broaden and narrow their attentional focus with a mindful attitude. Lesson four is about the application of mindfulness in everyday situations. In lesson five pupils learn about the nature of dynamic changes in our mental and bodily states. Lesson six teaches how mindful attention can help us stabilize our mind and body. Lesson seven explores how we tend to cope in challenging situations. In lesson eight children learn how mindfulness can help them nurture their well-being. Lesson nine is about the power of thoughts and the habits of our minds. Lesson ten teaches how the mind is connected to emotions, behavior, and bodily reactions, and how this connection can be modulated with the help of mindfulness. In lesson eleven pupils learn how to mindfully take care of themselves and others. Lesson twelve is about how to cherish moments of joy and happiness. Further details about Paws b can be found online at <https://mindfulnessinschools.org>.

Schoolteachers in the respective school had received formal training in mindfulness and in Paws b instruction. Firstly, teachers completed an 8-week secular mindfulness course, such as Mindfulness-Based Stress Reduction (MBSR). This course was taught by a mindfulness teacher who had been teaching mindfulness for at least 12 years through a minimum of 36 mindfulness courses. Subsequently, teachers built up a regular personal mindfulness practice over a minimum of two months before they attended the Teach Paws b course involving three days of intensive training. Finally, teachers committed themselves to ongoing implementation of mindfulness teaching.

In the school under investigation, Paws b lessons were integrated throughout the school year into regular lessons; in addition, mindfulness practices were offered during optional lunchtime mindfulness sessions.

Measures

Self-Report. Demographic information including age, gender, year at school, handedness, language skills and occurrence of brain injuries/epilepsy was collected by self-report questionnaire.

In addition, MG answered four questions related to their mindfulness practice. First, participants were asked when they had first learnt about mindfulness (open answer). The next two questions inquired about practice frequency. On a 6-point Likert scale ranging from 0='never', 'about once a month', 'a few times in a month', 'about once a week', 'a few times in a week', to 5='every day' pupils indicated how often they practiced mindfulness at school (question two) and at home (question three). Fourth, children rated enjoyment of practicing mindfulness on a 4-point scale with response options 'I don't like it at all', 'I mostly don't like it', 'I mostly like it', 'I like it very much'.

Participants' dispositional mindfulness was assessed using the Child and Adolescent Mindfulness Measure (CAMM; Greco, Baer, & Smith, 2011), a 10-item self-report instrument for youths starting from age nine. Eleven children (20.75%) in the current sample were younger than nine years (age range 8.08-11.50 years), but CAMM was used because there is no established mindfulness measure especially for children below nine years. Greco et al.'s (2011) preliminary research demonstrated adequate reliability (Cronbach's $\alpha=.81$) in a sample of 10- to 17-year-olds (mean age=12.68, SD=1.66). Internal consistency in the current sample was Cronbach's $\alpha=.60$, i.e., below the level that was reported in the validation study. To check whether the low reliability was due to a part of the present sample being younger than nine years, Cronbach's α was calculated for children that were tested after their 9th birthday. Cronbach's α for the older sample was .62, that is virtually level with the full sample. Calculations to improve reliability by removing single or combinations of items did not yield a better reliability result, therefore it was decided to proceed with the full item version.

The 10-item Positive and Negative Affect Schedule for Children (PANAS-C short version; Ebesutani et al., 2012), a mood scale with a target group of 6- to 18-year-olds, served

as an indicator of emotional well-being. Two scores are derived representing negative and positive affect, respectively. Higher emotional well-being is indicated by a relatively high positive affect score and/or a relatively low negative affect score (for a similar application of the PANAS see Bluth & Blanton, 2014; Lawlor, Schonert-Reichl, Gadermann, & Zumbo, 2014; Schonert-Reichl & Lawlor, 2010). The authors report Cronbach's α coefficients of .86 for the positive affect scale and of .82 for the negative affect scale, coefficients in the current sample were .75 and .46, respectively.

As a second measure of well-being we employed the 5-item Satisfaction with Life Scale adapted for Children (SWLS-C; Gadermann, Schonert-Reichl, & Zumbo, 2010). The authors reported internal consistency to be Cronbach's α =.86, the current sample achieved Cronbach's α =.63.

Other-report. Children's emotion regulation was assessed with the parent version of the 24-item Emotion Regulation Checklist (ERC; Shields & Cicchetti, 1997), entailing the subscales negativity/lability and emotion regulation. The ERC has excellent internal consistency (Cronbach's α =.96 and .83 for negativity/lability and emotion regulation, respectively; current sample: Cronbach's α =.91 for negativity/lability and Cronbach's α =.85 for emotion regulation). The targeted age group is six to 18 years. .

Computerized task. EF was assessed using an AX-CPT (adapted from Brocki & Bohlin, 2004). The following trial types were implemented (cf. Figure 1 and description above): n=40 Go trials, n=40 Nogo trials, and n=40 Ignore trials. Behavioral performance was assessed using the following indicators: Mean reaction time (RT) and SD of RT for correct Go trials, i.e., hits, as well as the following error percentages: Impulsive responses to 1st stimulus - defined as an unexpected button press in response to the cue; target omissions; disinhibited responses - defined as an unexpected button press in response to the 2nd stimulus in a Nogo trial; inattentive impulses - defined as an unexpected button press in response to the 2nd stimulus in an Ignore trial.

Procedures

Participants were tested individually during school hours, using a portable EEG system consisting of acquisition and stimulus presentation laptops, a Brain Products actiCHamp amplifier, and actiCAP active electrodes. Quiet testing spaces were provided on school premises. At the beginning of the testing session all procedures were explained to participants and informed consent was obtained before the start of testing. Measures were taken in the following sequence for all participants: Demographical questionnaire, mindfulness practice questionnaire (for MG only), PANAS, CAMM, SWLS-C, EEG-setup, computerized task. Although the primary language of some participants was Welsh (cf. Table 1), testing sessions were always conducted in English. This was necessary since none of the questionnaire-based measures are available in a validated Welsh version. Furthermore, all children whose first language was Welsh were bilingual, ruling out potential concerns regarding comprehension of materials and instructions.

EEG signal was recorded with 30 Ag/AgCl electrodes, with TP10 as the reference site, the ground at Fpz and a sampling rate of 1kHz. Two electrodes, placed above and below the right eye, recorded ocular movements. The impedance of all electrodes was kept below 25k Ω . Online, the EEG signal was filtered with a bandpass filter range of 0.01–200Hz, 48dB/Oct slope. ERP data was cleaned automatically such that the maximal allowed difference within 200ms intervals was 1500 μ V and the lowest activity in 100ms intervals was 0.5 μ V. Independent Component Analysis using BrainVision Analyzer was employed to regress out eye-blinks. Offline an additional bandpass filter with a range of 0.1-30Hz, 48dB/Oct slope, was applied. Residual artefacts were cleaned manually, after which data were re-referenced to the average of T7 and T8. For the 1st stimulus of a trial data was epoched into 2100ms segments starting at -200ms, and baseline corrected using the signal 200ms before stimulus onset. For the 2nd stimulus of a trial data was epoched into 1000ms segments starting at -100ms, and baseline corrected using the signal 100ms before stimulus onset. Finally, averages

for each condition and participant, as well as grand averages across participants for each condition and group were computed.

Data analysis

Questionnaire measures were analyzed using independent t-tests.

ERP analysis entailed mixed factorial analyses of variance (ANOVAs) assessing mean amplitude and peak latency data (except for the CNV for which latency is not commonly reported due to the broadness of the peak) for electrodes of interest. Initial ANOVAs were run with factors condition (Cue vs. NonCue for the 1st stimulus of a trial; Go vs. Nogo for the 2nd stimulus of a trial) and group (MG vs. CG) for peak latency; for mean amplitude the set of factors was complemented by n-ary electrode factor. An additional factor of time window (early vs. late) was included for CNV mean amplitude. Where significant main effects of electrode and interactions were found, pairwise t-tests were conducted. All artefact free correct trials were included in the ERP analyses for all participants with at least 15 trials per condition. Applying this criterion, seven out of 45 participants were excluded from analyses, resulting in 23 useable data from MG and 15 from CG. Number of analyzed trials did not differ between groups of participants for any of the task conditions ($ps > .26$; in the Go condition, MG children had on average 25.78 trials ($SD = 5.69$, range 17-36), CG children had on average 27.80 trials ($SD = 6.67$, range 17-38); in the Nogo condition, MG children had on average 27.48 trials ($SD = 5.27$, range 20-37), CG children had on average 25.60 trials ($SD = 4.67$, range 19-35); in the Cue condition, MG children had on average 44.26 trials ($SD = 10.48$, range 26-67), CG children had on average 42.60 trials ($SD = 12.47$, range 27-68); in the NonCue condition, MG children had on average 22.09 trials ($SD = 5.05$, range 26-36), CG children had on average 23.00 trials ($SD = 5.03$, range 16-32). The electrode sites of interest were based on previous literature, and visual inspection of peak activity in BrainVision Analyzer. The following clusters of electrodes were selected for analyses for each of the components: Cue-P3- Pz, P3, and P4 across the time window 240-360ms (e.g., Doehnert,

Brandeis, Schneider, Drechsler, & Steinhausen, 2013); CNV- Fz, Cz, and Pz in the time windows 800-1000ms (early) and 1400-1800ms (late; e.g., Jonkman et al., 2003); N2- P3, P4, P7, and P8, in the time window 160-260ms (e.g., Jonkman, 2006, however at predominantly frontal sites); Nogo-P3- Pz, P3, P4, CP1, and CP2, in the time window 280-360ms (e.g., Hämmerer et al., 2010). In case of significant effects of group, correlations with all remaining measures were calculated. For readability of results only significant correlations are reported.

To test hypothesis 2 (Increased well-being in MG is mediated by heightened EF and emotion regulation), mediation analyses were carried out using the PROCESS macro in SPSS (Hayes, 2013; model 6). Each calculation included an indicator of EF and an indicator of emotion regulation as mediators, well-being scores were the outcome.

The impact of mindfulness practice properties was analyzed in a series of moderated regressions, again using PROCESS (model 3). In each regression analysis, the outcome was one dependent measure - predictors were length, frequency, and enjoyment of mindfulness training. The two scores assessing practice frequency at home and at school were combined to a single sum score to achieve an indicator of overall practice frequency.

Results

Descriptive statistics for questionnaire-based and behavioral dependent measures are summarized in Table 1. Outliers more than 3SD away from the sample mean were removed from the dataset, this affected less than 3.78% of data per measure. Results for ERP components are presented with and without outliers, since excluding outliers is less established for these outcomes.

Questionnaires

T-tests revealed a significant difference between MG and CG for ERC negativity/lability only, such that negativity was lower in MG than in CG, $t(21)=4.75$, $d=-2.08$, $p<.001$ (other $ps>.09$).

Since well-being and emotion regulation are developmentally sensitive, bivariate correlations of age with all questionnaire-based measures explored the need to control for a potential impact of age. However, no significant correlations were observed, $ps \geq .08$.

Task performance

T-tests comparing both groups were marginally significant for disinhibited responses, $t(17.97)=1.81$, $d=-0.68$, $p=.086$, in terms of superior performance of MG, and insignificant for the remaining indicators, $ps > .17$.

As with questionnaire-based measures, bivariate correlations of age and all indicators of task performance checked whether age had to be controlled for. Age was significantly correlated with mean RT only, $r=-.429$, $p=.002$. When including age as covariate, the effect of group on mean RT remained insignificant, $p=.49$.

ERP components

Cue-P3 (Less positive amplitude signals superior cue utilization if it is accompanied by reduced Cue-P3 latency and withholding of behavioral response to the cue). ANOVA for mean amplitude detected only a significant main effect of group indicating more positive amplitudes for MG than for CG, $F(1, 216)=10.57$, $\eta_p^2=.047$, $p=.001$ (cf. Figure 2B; other $ps > .41$). After exclusion of outliers, significance remained the same. Cue-P3 amplitude was correlated with SWLS-C, $r=.338$, $p=.04$, but not with age or further dependent measures, $p \geq .09$.

ANOVA for peak latency did not yield any main effects or interactions, $ps > .34$.

CNV (More negative CNV amplitude indicates advantageous levels of resource optimization). ANOVA resulted in a main effect of group, $F(1, 432)=12.32$, $\eta_p^2=.028$, $p<.001$, suggesting less negative amplitude for MG than for CG (cf. Figure 2A); the remaining main effects were significant, too: condition, $F(1, 432)=4.19$, $\eta_p^2=.010$, $p=.04$, time window, $F(1, 432)=5.34$, $\eta_p^2=.012$, $p=.02$, electrode, $F(2, 432)=3.81$, $\eta_p^2=.017$, $p=.02$. Furthermore, there was an interaction of condition with electrode, $F(2, 432)=5.07$, $\eta_p^2=.023$, $p=.006$. Follow-up t-

tests showed more negative amplitude for cued than for non-cued trials, only at Pz, $t(150)=-2.92$, $p=.004$, but not at Fz and Cz ($ps>.36$). There was also a marginal interaction of time window with electrode, $F(2, 432)=3.01$, $\eta_p^2=.014$, $p=.05$. Follow-up t-tests revealed more negative amplitude in the late than in the early time window, only at Cz, $t(150)=3.32$, $p=.001$, but not at Fz and Pz ($ps>.06$). After exclusion of outliers, all significant effects remained the same except for the main effect of condition, which became marginal, $F(1, 430)=3.16$, $\eta_p^2=.007$, $p=.08$.

CNV amplitude was positively correlated with target omissions in CPT, $r=.445$, $p=.04$, and marginally negatively correlated with PANAS-C positive affect, $r=-.319$, $p=.05$ (other $ps\geq.05$).

Nogo-N2 (Less negative amplitude mirrors superior conflict processing). ANOVA for mean amplitude revealed a main effect of electrode, $F(3, 286)=15.86$, $\eta_p^2=.141$, $p<.00000001$ (other $ps>.27$). Pairwise t-tests showed that voltage was most negative at P8, followed by P7 where amplitude was more negative than at P3 and P4 (all $ps<.02$). Amplitudes did not differ between P3 and P4, $p=.47$. When the ANOVA was repeated after exclusion of outliers, significant results remained unchanged.

ANOVA for latency did not detect any main effects or interactions, $ps>.11$.

Nogo-P3 (More proficient response inhibition is indicated by more positive amplitude and shorter latency). For mean amplitude, there was a main effect of group, $F(1, 360)=5.57$, $\eta_p^2=.015$, $p=.02$, indicating more positive amplitude for MC than CG. The main effect of condition was also significant, $F(1, 360)=3.91$, $\eta_p^2=.011$, $p=.049$, in terms of more positive amplitudes for Go than for Nogo trials (cf. Figure 2C). When excluding outliers, main effects of group and condition became marginal, both $ps=.06$. In addition, a marginal main effect of electrode appeared, $F(4, 355)=2.35$, $\eta_p^2=.026$, $p=.054$. Furthermore, there was an interaction of group with electrode, $F(4, 355)=2.91$, $\eta_p^2=.032$, $p=.02$. According to t-tests voltage differed

between groups, in terms of more positive values for MC than CG, only at CP2, $t(72.76)=-4.07, p=.0001$ (other $ps>.21$).

Regarding latency, there was a main effect of group, $F(1, 72)=5.35, \eta_p^2=.069, p=.024$, which suggested shorter latencies for MG than CG (other $ps>.20$).

Mediation Analyses

Mediation analyses were carried out although no direct relationship between mindfulness experience and well-being was found, since a direct effect between independent variable and outcome is no longer considered a necessary condition of mediation (Hayes, 2009). However, to avoid multiple comparisons, analyses were confined to indicators where a positive association with mindfulness experience had been found: Nogo-P3 amplitude (difference score), Nogo-P3 latency, ERC negativity/lability, SWLS-C. Results did not reveal mediating effects of EF or emotion regulation in the relationship between mindfulness experience and well-being (narrowest 95%CI of indirect effect [-.10, .03]).

Practice variables

MG on average reported to have practiced mindfulness for 2.11 years ($SD=1.01$), with a mean frequency score of 2.82 ($SD=1.21$), and a mean enjoyment score of 2.18 ($SD=0.58$). Bivariate correlations of practice length, frequency, and enjoyment were significant for the association between enjoyment and frequency only, $r=.49, p=.004$ (other $ps>.14$).

The only significant moderations suggested a possible adverse impact of practice enjoyment, namely regarding higher PANAS-C negative affect, $b=2.65, SE B=1.21, t=2.20, p=.04$, higher SD of RT in the CPT, $b=47.62, SE B=13.27, t=3.59, p=.002$, less negative CNV amplitude, $b=4.90, SE B=2.25, t=2.17, p=.047$, longer Nogo-N2 latency, $b=24.22, SE B=8.87, t=2.73, p=.02$, (other $ps\geq.06$).³

Discussion

The present paper presented the findings of the first investigation on effects of long-term mindfulness practice in pre-adolescents, and it is also the first published mindfulness study

using neuroscientific methods in a child population. A group of pupils with an average mindfulness experience of 2.11 years was compared with a group of mindfulness-inexperienced pupils on dispositional mindfulness, EF, emotion regulation, and well-being.

Hypothesis one predicted that MG would show higher scores/outperform CG on all of the measures. The evidence obtained was mixed. Interestingly, dispositional mindfulness as measured with the CAMM did not differ between both groups of pupils. This finding could suggest that continued mindfulness training had not led to a heightened mindfulness disposition in everyday life. Since several meta-analyses found dispositional mindfulness to increase after attending a multi-week MBI (Dunning et al., 2019), this explanation seems unlikely. It is possible that self-report on dispositional mindfulness does not provide a precise estimate of the actual capacity at each stage of mindfulness proficiency. Attendees of adult MBIs ironically often score lower on self-report measures of trait mindfulness after course completion, which has been attributed to enhanced meta-cognitive awareness of attentional lapses due to increased mindfulness, a phenomenon called response-shift bias (Sauer et al., 2013). There is evidence that the CAMM could be affected by this sort of bias, too (de Bruin et al., 2014). Thus, one could speculate that MG in the present sample would have scored lower than controls after initial mindfulness training, and that their estimate has then started to rise as a consequence of increased mindful non-judgment, leading to comparable scores in both groups of pupils after approximately two years of practice. Another possibility is that the children in the MG group were dispositionally lower in mindfulness before mindfulness training and the CG scored higher, the cross-correlational nature of the study doesn't allow for us to disentangle these possibilities.

Equal scores in the groups could alternatively indicate psychometric weaknesses of the CAMM. In the adult literature, responses of long-term meditators have been used to validate self-report questionnaires of trait mindfulness (e.g., Walach, Buchheld, Buttenmüller, Kleinknecht, & Schmidt, 2006). This type of validation has so far not been utilized for

CAMM. The present results do not suggest that CAMM can differentiate between mindfulness-experienced and mindfulness-inexperienced children. Furthermore, internal consistency in the present sample was not satisfactory. A part of our sample was younger than the intended target group, yet additional analyses did not suggest that the low internal consistency was related to participants' age.

The relationship between mindfulness experience and EF was complex. MG tended to make less errors of disinhibition in the CPT. Together with shorter Nogo-P3 latency and a tendency for more positive Nogo-P3 amplitude, this suggests superior response inhibition in the mindfulness-experienced group. In contrast, a slight disadvantage for these children emerged regarding cue utilization and resource optimization: MG demonstrated more positive Cue-P3 amplitude. Since groups did not differ regarding behavioral response to the cue and Cue-P3 latency, this finding could be explained by relatively inefficient use of brain resources during cue processing. However, Cue-P3 amplitude was positively correlated with SWLS-C, which conflicts with the assumption that higher Cue-P3 indicates lower EF which is associated with lower well-being indices (Luerssen & Ayduk, 2017). In addition, less negative CNV amplitude was observed in MG, indicating inferior resource optimization. This EF-related disadvantage was corroborated by a positive correlation of CNV amplitude with percentage of target omissions in the CPT. As opposed to the positive correlation of Cue-P3 amplitude with SWLS-S mirroring higher life satisfaction in MG, CNV amplitude tended to be negatively linked with positive affect in the PANAS-C, which suggests lower well-being for MG. More research is required to clarify the relationship between mindfulness experience, cue utilization, and well-being.

Mindfulness experience was partly associated with improved emotion regulation in so far as MG received higher scores on the negativity/lability subscale than CG, although no group difference was found regarding the emotion regulation subscale. Negative or irritable mood that is assessed by the negativity/lability subscale and emerges when children cannot

sufficiently regulate negative emotions may be more accessible to parents' appraisal than emotion regulation in the narrower sense.

There was no direct relationship between mindfulness experience and well-being. As mentioned above, there was an indirect positive association with life satisfaction via more positive Cue-P3 amplitude, and an indirect negative association with positive mood via less negative CNV amplitude. Further research is needed to resolve the inconsistency.

Geared towards mechanisms underlying effects of MBIs, hypothesis 2 predicted that increased well-being in MG would be mediated by enhanced EF and emotion regulation. This hypothesis was not confirmed, as no indirect effects of indicators of EF or emotion regulation were observed in mediation analyses. Considering the evidence of no difference in mindfulness scores and mixed EF findings, this result is not surprising. Studies with larger samples are desired for clarification.

We also investigated whether and to what extent mindfulness, EF, emotion regulation and well-being were affected by the amount and enjoyment of mindfulness practice, both at school and at home. In line with the most recent meta-analysis for RCTs involving active control groups (Dunning et al., 2019), they were not influenced by the amount of practice, but enjoyment of mindfulness was positively correlated with training frequency. This seems to suggest that, even if amount of mindfulness training does not affect the outcomes under investigation, pupils who like mindfulness training practice more often. Interestingly, enjoyment was positively associated with PANAS-C negative affect, CNV amplitude, and SD of RT in the CPT. This is an entirely unexpected and previously unexplored finding, we can only speculate on a potential explanation. Perhaps children were not able to accurately self-report on enjoyment, or, in the sense of social desirability, were reluctant to admit that they did not like mindfulness quite so much; both cases could lead to overestimation of enjoyment.

The present study has several strengths: It is the first investigation of longer-term mindfulness practice effects in children, it tested theory-driven hypotheses and considered

mechanisms of action as well as moderating influences of practice properties, which included mindfulness training at school and at home. Motivation in terms of enjoyment of mindfulness practice was considered as well.

Nevertheless, several limitations restrict the interpretation of the results. Firstly, the sample size, even though appropriate for an ERP study, was relatively low for self-report comparisons, which limits statistical power. Hence, the study was not able to detect small effects. Secondly, differences between MG and CG cannot be interpreted as causal effects of mindfulness training due to the cross-sectional design/self-selection of groups. Systematic group differences other than degree of mindfulness experience could be confounding factors. For instance, both groups were based in two schools that used different media of instruction – MG received school lessons in English, whereas CG were taught in Welsh (cf. primary language in Table 1). Since all children were fluent in English, this means that most CG were proficient bilinguals. Bilingualism, in turn, has been found to be associated with improved EF (Bialystok, 2015). Hence, working with these controls may have prevented us from detecting mindfulness-based benefits on EF. Thirdly, amount and frequency of practice were assessed via retrospective self-report. This was inevitable since no other records, e.g. from the school, teachers, or parents, were available. However, as the accuracy of retrospective self-report is limited, future studies should rely on further data as recorded from diaries, apps, or third parties.

Conclusions

Pre-adolescents with an established mindfulness practice showed superior response inhibition and emotion regulation, equal well-being, and inferior cue processing when compared with mindfulness-inexperienced peers. Larger-scale studies are needed to clarify the interrelations between mindfulness training, EF, emotion regulation, and well-being. Regarding implementation in schools, the present results do not suggest that a certain amount

of mindfulness training over a specific period of time is needed to achieve benefits in inhibitory control and emotion regulation, however this awaits confirmation by future studies.

Data Availability Statement

The data are not publicly available due to privacy or ethical restrictions - parents did not provide permission to share data.

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Footnotes

¹ In the context of the School-Based Meditation Model, well-being and social competence are thought to contribute to academic success, which seems to stand in contrast with some conceptualisations of academic success as mere academic achievement.

² Schoolteachers had also received informal training the The Present curriculum (Silverton, Sawyer, & Dorjee; <http://thepresentcourses.org/>), but they were not formally qualified to teach this curriculum to pupils nor did they implement The Present in a systematic way.

³ When separate analyses were carried out for practice at school and at home, there was no effect of practice enjoyment on any outcome ($ps > .08$).

Table caption

Table 1. *Descriptive statistics/frequencies of demographic variables, questionnaire-based and behavioral dependent measures, for the total sample and separately for the mindfulness-experienced and the mindfulness-inexperienced group*

Figure captions

Figure 1. *CPT: Stimuli and experimental procedure.*

Figure 2A-C. *Mindfulness experience and ERP modulation in a CPT. A: CNV: Linear derivation (Fz, Cz, Pz) of group average waveforms for each of the two conditions (Cue vs. NonCue). B: Cue-P3: Linear derivation (Pz, P3, P4) of group average waveforms for each of the two conditions (Cue vs. NonCue). C: Nogo-P3: Linear derivation (Pz, P3, P4, CP1, CP2) of group average waveforms for each of the two conditions (Go vs. Nogo). A 16Hz low-pass filter was applied for illustration purposes only.*

	Mindfulness- experienced	Mindfulness- inexperienced	Total
Mean age (<i>SD</i>)	9.76 (0.64)	9.72 (1.08)	9.74 (0.82)
Percentage female	60.60	50.00	56.60
Percentage right-handed	87.90	80.00	84.91
Percentage left-handed	12.10	15.00	13.21
Percentage ambidextrous	0.00	5.00	1.89
Percentage first language=English	97.00	20.00	67.92
Percentage first language=Welsh	3.00	80.00	32.08
Mean CAMM (<i>SD</i>)	24.00 (5.10)	23.50 (6.85)	23.81 (5.76)
Mean PANAS-C PA (<i>SD</i>)	18.42 (3.62)	18.40 (5.91)	18.42 (4.56)
Mean PANAS-C NA (<i>SD</i>)	7.12 (2.04)	8.32 (2.65)	7.56 (2.33)
Mean SWLS-C (<i>SD</i>)	20.91 (3.03)	20.15 (3.83)	20.63 (3.34)
Mean ERC Neg (<i>SD</i>)	4.87 (3.93)	13.00 (3.89)	7.70 (5.51)
Mean ERC ER (<i>SD</i>)	20.80 (4.25)	23.25 (4.83)	21.65 (4.51)
Mean RT (<i>SD</i>)	650.90 (169.03)	709.79 (279.80)	672.10 (214.60)
SD of RT (<i>SD</i>)	171.10 (46.16)	183.68 (54.20)	175.63 (49.03)
CPT % impulses to 1st stimulus	0.52 (0.83)	1.23 (2.60)	0.77 (1.69)
CPT % target omissions	2.67 (3.19)	1.71 (1.65)	2.32 (2.75)
CPT % disinhibited responses	0.17 (0.40)	0.97 (1.86)	0.47 (1.23)
CPT % inattentive impulses	2.81 (4.08)	3.77 (3.83)	3.14 (3.98)

Note. CAMM=Child and Adolescent Mindfulness Measure; PANAS-C PA=Positive and Negative Affect Schedule for Children, positive affect subscale; PANAS-C NA=Positive and Negative Affect Schedule for Children, negative affect subscale; SWLS-C=Satisfaction with Life Scale adapted for Children; ERC Neg=Emotion Regulation Checklist, negativity/lability subscale; ERC ER=Emotion Regulation Checklist, emotion regulation subscale; CPT=Continuous Performance Task.

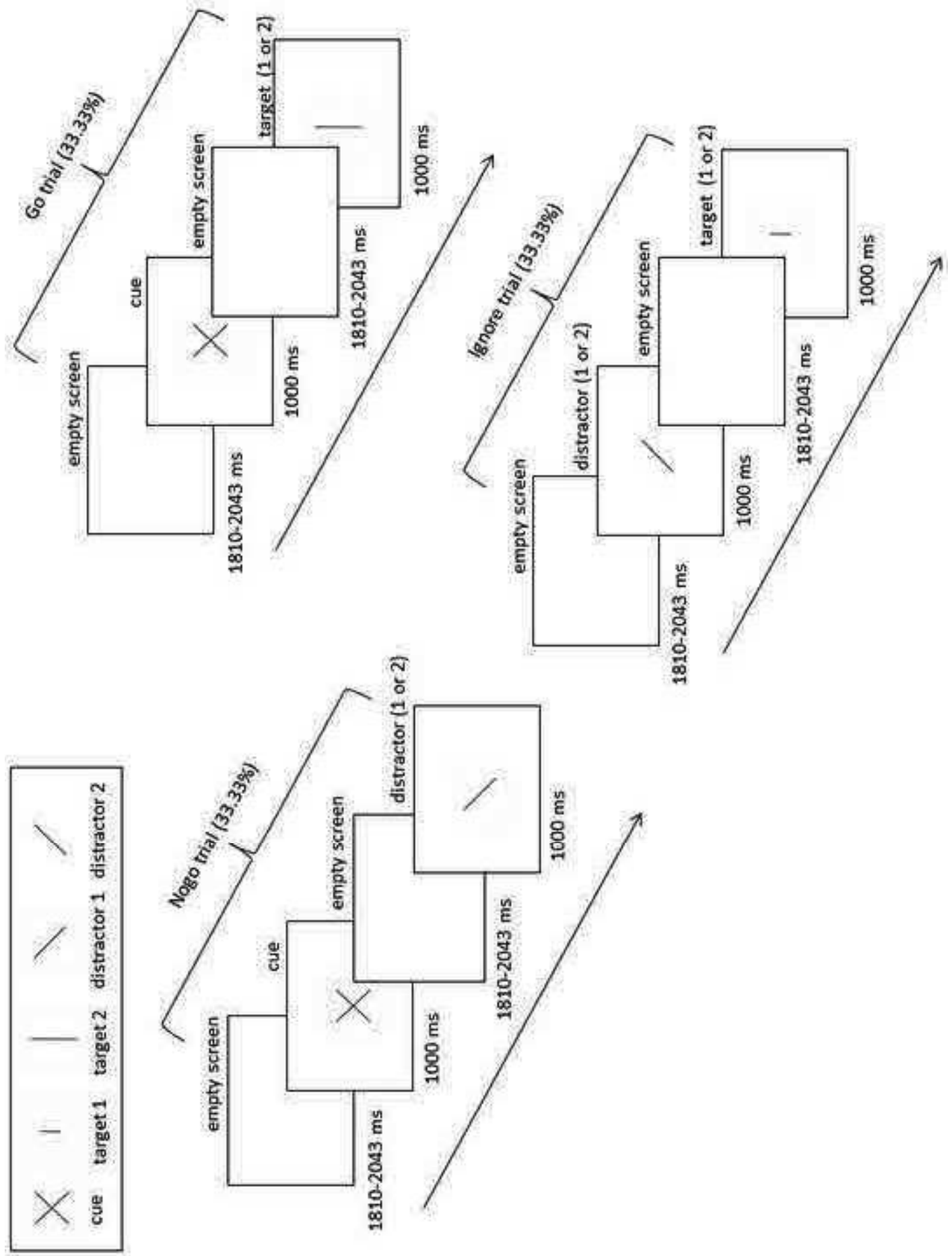


figure 1

