Received: 26 April 2022 | Revised: 28 October 2022 | Accepted: 12 April 2023

DOI: 10.1111/desc.13403

Developmental Science WILEY

RESEARCH ARTICLE

The effectiveness of a school mindfulness-based intervention on the neural correlates of inhibitory control in children at risk: A randomized control trial

Catherine I. Andreu[1,2] | Carlos García-Rubio[3,4] | María Melcón[3] | Kimberly A. Schonert-Reichl[5] | Jacobo Albert[3]

[1]Millennium Institute for Research in Depression and Personality (MIDAP), Santiago, Chile

[2]Polibienestar Institute, University of Valencia, Valencia, Spain

[3]Faculty of Psychology, Autonomous University of Madrid, Madrid, Spain

[4]Nirakara Lab, Complutense University of Madrid, Madrid, Spain

[5]Department of Psychology, University of Illinois at Chicago, Chicago, USA

Correspondence
Catherine Andreu, Polibienestar Institute, University of Valencia, Valencia, Spain.
Email: catherine.andreu@uv.es

Carlos García-Rubio, Faculty of Psychology, Autonomous University of Madrid, Madrid, Spain.
Email: garciarubio.carlos@gmail.com

Funding information
Fund for Innovation and Competitiveness: Millennium Scientific Initiative, Grant [IS 130005—MIDAP]; Spanish Ministry of Education, Culture, and Sport, Grant/Award Number: FPU13/ 01677; Mind and Life Europe Institute: Varela Awards [Grant #2016-EVarela Garcia Rubio, Carlos and Andreu, Catherine]

Abstract

Interest in the applications of mindfulness practice in education is growing in the scientific community. Recent research has shown that mindfulness practice in schools may be beneficial for executive functions (EFs) which are abilities crucial for healthy development. The study of the effects of mindfulness practices on children's neural correlates of EFs, particularly inhibitory control, may provide relevant information about the impact and mechanisms of mindfulness-based interventions (MBIs) in children. The aim of the present study was to investigate the effects of a MBI in elementary school children on the neural correlates of inhibitory control via a randomized controlled trial. Children from two 4th grade classrooms and two 5th grade classrooms located in a school identified as having low socioeconomic status in Santiago de Chile were randomly assigned to either receive a MBI or serve as active controls and receive a social skills program. Both before and after the interventions, electroencephalographic activity was recorded during a modified version of the Go/Nogo task in a subsample of children in each group. Additionally, teachers completed questionnaires of students' EFs and students completed self-report measures. Results revealed increases in EFs assessed by questionnaires together with improved P3 amplitude associated with successful response inhibition in children who received the MBI compared to active controls. These results contribute to the understanding of the ways in which mindfulness practices can promote the development of inhibitory control together with EF improvement, factors identified as critical for children's social and emotional development and positive mental health.

KEYWORDS
children, EEG, executive function, high-risk, inhibitory control, mindfulness

Research Highlights

- This study investigated the effects of a mindfulness-based intervention in children from a low socioeconomic status school on neural correlates of EFs.
- Children performed a Go/Nogo task while electroencephalographic activity was recorded and completed questionnaires before and after a MBI or an active control program.
- Improvements in EFs assessed by questionnaires together with an increased Nogo-P3 activity associated with successful inhibition in children who received the MBI were found.
- The results could contribute to understand how mindfulness practice can promote the development of inhibitory control in children from vulnerable populations.

1 | INTRODUCTION

Socioeconomic status (SES), a measure of one's overall status and position in society, strongly influences an individual's experiences from childhood and through adult life. Growing up in a family with a low SES background is associated with substantially worse health and impaired psychological well-being, and decreased cognitive and emotional development throughout the lifespan, being considered as a risk factor for a healthy development (Hackman et al., 2010). Compared with children and adolescents from higher-SES backgrounds, children and adolescents from low-SES backgrounds show higher rates of depression, anxiety, attention problems, and conduct disorders, and a higher prevalence of internalizing and externalizing behaviors, all of which increase with the duration of living in poverty (Hackman et al., 2010). In addition, childhood SES influences cognitive development: SES is positively correlated with intelligence and academic achievement from early childhood and through adolescence (Farah et al., 2006; Hackman & Farah, 2009).

Childhood SES affects some neurocognitive systems more than others: studies that assessed multiple neurocognitive systems found moderate effects of SES on executive functions (EFs) — particularly on working memory and inhibitory control (Hackman & Farah, 2009; Hackman et al., 2010; John et al., 2019). SES-related differences in the EFs of working memory and inhibitory control have been noted in children as young as 6–14 months of age (Hackman et al., 2015). SES- related differences in executive attentional systems have been reported in 6-year-old children, and SES-related disparities in various tasks of executive function have been described at multiple developmental stages through early adolescence (Hackman et al., 2015).

EFs refer to a group of cognitive control abilities that organize, sequence, and regulate behavior (Diamond, 2013; Schonert-Reichl et al., 2015). One core EF is inhibitory control, which refers to the capacity to control one's attention, behavior, thoughts, and/or emotions to handle a strong internal predisposition and respond in a willful and non-reactive way (Diamond, 2013). More broadly, self-regulation involves the use of inhibitory control and is highly related with effortful control (EC), a temperamental predisposition for better or worse self-regulation (Checa et al., 2014; Diamond, 2013). Children with poor EFs (particularly inhibitory control) have been shown to have poorer outcomes in adulthood such as having worse health, impaired self-regulation (Rueda et al., 2005), lower prosocial behaviors (Aguilar-Pardo et al., 2013), are less happy, commit more crimes, and develop several EFs disorders (Diamond & Lee, 2011; Moffitt et al., 2011). In fact, EFs are critical for every aspect of life, including success in school, academic abilities, positive friendships, mental and physical health, and overall quality of life (Diamond & Lee, 2011). Thus, improving EFs early in life is crucial (Diamond & Lee, 2011). EFs are malleable from an early age, and children with the weakest EFs show the most significant benefits from any intervention to train EFs (Diamond, 2013; Diamond & Lee, 2011). Importantly, school-based interventions improve EFs (Diamond, 2012; Liew, 2011; Meltzer, 2018).

The school is an active critical agent of development and a transformative context (Erikson, 1987; Mills, 2008). One of the functions of schooling is to reduce social inequalities by providing all children with academic and social and emotional skills to diminish gaps in SES and overcome them (Downey et al., 2004; von Hippel, et al., 2018). Schools in the 21st century play a key role in the development of different cognitive and social and emotional abilities (Mind & Life Education Research Network, 2012), and the comprehensive mission of schools is to educate students to be knowledgeable, responsible, socially skilled, healthy, caring, and contributing citizens. Given the large amount of time that youth spend in school, this is an ideal context to implement universal prevention programs that address core elements of social, emotional, and cognitive development (Hale et al., 2014), including the promotion of students' EFs.

School-based social and emotional learning (SEL) interventions have been found to improve EFs and to be cost-effective in the long term (Belfield et al., 2015; Heckman & Mosso, 2014). Research has shown that SEL interventions that incorporate mindfulness attention practices lead to improvements in students' EFs (Schonert-Reichl et al., 2015). Mindfulness is broadly defined as "self-regulation of attention to the conscious awareness of one's immediate experiences while adopting an attitude of curiosity, openness, and acceptance" (Bishop, 2004, p. 174). Mindfulness-based interventions (MBIs) are sustained and systematic training in formal and informal practices of mindfulness meditation to improve mindfulness skills. MBIt's participants learn a more adaptive way to relate to their feelings, thoughts, and emotions supporting the development of greater attentional, emotional and behavioral self-regulation, as well as positive prosocial qualities such as kindness and compassion (Crane et al., 2017). In the last decade, interest in mindfulness-based interventions applied in educational settings have had a rapid expansion, accompanied by the exponential growth of empirical research documenting the benefits of mindfulness practices in schools (for a review, see Weare, 2019).

Theoretically, MBIs in schools have an impact on increasing both EFs and mindfulness skills (Andreu & García-Rubio, 2019; Lawlor, 2016; Lyons & DeLange, 2016; Mendelson, et al., 2010; Mind and Life Education Research Network, 2012; Waters, et al., 2014). In the same line, mindfulness skills in children have been positively related with EFs, particularly inhibitory control (Riggs et al., 2015). Furthermore, recent systematic reviews and meta-analyses have found positive effects of MBIs on EFs in children and adolescents (Dunning et al., 2018; Mak et al., 2018; Maynard et al., 2017). For example, teacher-reported improvements in adolescents EFs have been shown with a school-based mindfulness intervention (Lam & Seiden, 2020). However, Felver et al. (2015) warned that most of the studies in the field did not use rigorous experimental designs: lacked active control groups, used a single informant (typically only children), used a single methodology (typically self-reports), and did not use multi-level measurements to assess outcomes (neural, cognitive, behavioral). Specially significant was the shortage of studies designed to elucidate the impact of MBIs in school on the neural correlates of core cognitive functions in development, such as EFs.

The use of electroencephalography (EEG) to evaluate the neuronal correlates of EFs is well established in adults and children. EEG and the event-related potentials (ERPs) methodology provide several advantages for the neurocognitive research on EFs (Huster et al., 2013; Kaunhoven & Dorjee, 2017; Sanger & Dorjee, 2015). The Go/Nogo task, one of the most classic paradigms used to investigate EFs in the laboratory, has been particularly relevant for the study of neural correlates of inhibitory control. Behavioral indices in a Go/Nogo task include the omission errors in Go trials and the commission errors in Nogo trials, which require inhibitory control ability, as well as the reaction times (RTs) to different types of trials. One proposed ERPs neural correlate of inhibitory control that reflect changes in brain activity needed to inhibit response in a Go/Nogo task is the P3 component (Huster et al., 2013). Indeed, the P3 is thought to reflect represent a temporally precise neural marker of the response inhibition process (Albert et al., 2013; Dykstra et al., 2020; Sánchez-Carmona et al., 2016; Wessel & Aron, 2015). Differential amplitudes of P3 are described both on several EF disorders in adults and children (Luijten et al., 2014; Lopez-Martin et al., 2015).

Several studies have employed experimental tasks to measure the impact of mindfulness trainings in children (e.g., Felver et al., 2014; Napoli et al., 2005; Schonert-Reichl et al., 2015), yet only a few have used EEG or ERP methodology. Siripornpanich et al. (2018) assessed children who have been studied in two schools with different types of school curriculum: mindfulness-based curriculum (i.e., mindfulness practices for all levels of education) versus usual curriculum. Children who received the mindfulness education curriculum showed lower theta power and smaller theta/beta ratio compared to control children, suggesting enhanced maturation of brain areas related to cognitive control and self-regulation. However, in the absence of a randomization process, and the lack of baseline levels of children in the two groups, the possibility that these differences existed previously between groups or were due to other elements of the curricula could not be excluded. In another study with adolescents, the amplitude of the P3b component was measured during an affective oddball task, before and after mindfulness training. The P3b amplitude in the control group decreased between testing sessions but it remained unchanged in the mindfulness group, suggesting a maintained sensitivity to emotional stimuli in mindfulness-trained students (Sanger et al., 2018).

Thus, as previous studies are done in adolescents, to our knowledge there are no published studies who have specifically used ERP methods in children to evaluate possible effects of MBIs in schools on EFs or other cognitive processes. The main aim of the present study was to assess the impact of a school-based mindfulness intervention on the neural correlates of EFs, specifically inhibitory control, in children. Via a randomized controlled trial, we examined the effectiveness of an MBI in 4th and 5th grade children attending a school identified as vulnerable due to its low SES. We measured behavioral and EEG neural responses on a Go/Nogo task to evaluate inhibitory control. We expected lower error rates and decreased reaction times together with an increase in P3 amplitude (particularly in No-Go trials) in the MBI intervention group compared to the control group. Also, we measured the impact of the MBI on children's mindfulness skills via self-report and EFs' via self- and teachers-reports. We expected improvements in mindfulness skills and EFs in children in the MBI group compared to children in the active control intervention.

2 | METHOD

2.1 | Participants

Prior to participant recruitment, the Ethics Committee of the Pontificia Universidad Católica de Chile approved the study. The school in which the study took place was selected based on a low-SES and vulnerable context. According to the Chilean Index of Scholar Vulnerability, the school was rated with an index of 74%, which corresponds to a medium-high risk of vulnerability. The aim of the study was presented to teachers, students, and students from four 4th and 5th grade classrooms were recruited (age range 9–11 years old).

The total sample for the global study was $N = 133$ (67 in the mindfulness group). From this initial group, 68 children were chosen at random ($N = 68$; 34 from the mindfulness group) to become part of this EEG study, and were subsequently evaluated with EEG. The results of the pre-post EEG and questionnaires of this sample are presented here. Of the 68 children who were evaluated with EEG, 46 remained in the final sample, and the data of 22 children were discarded. Thus, the final

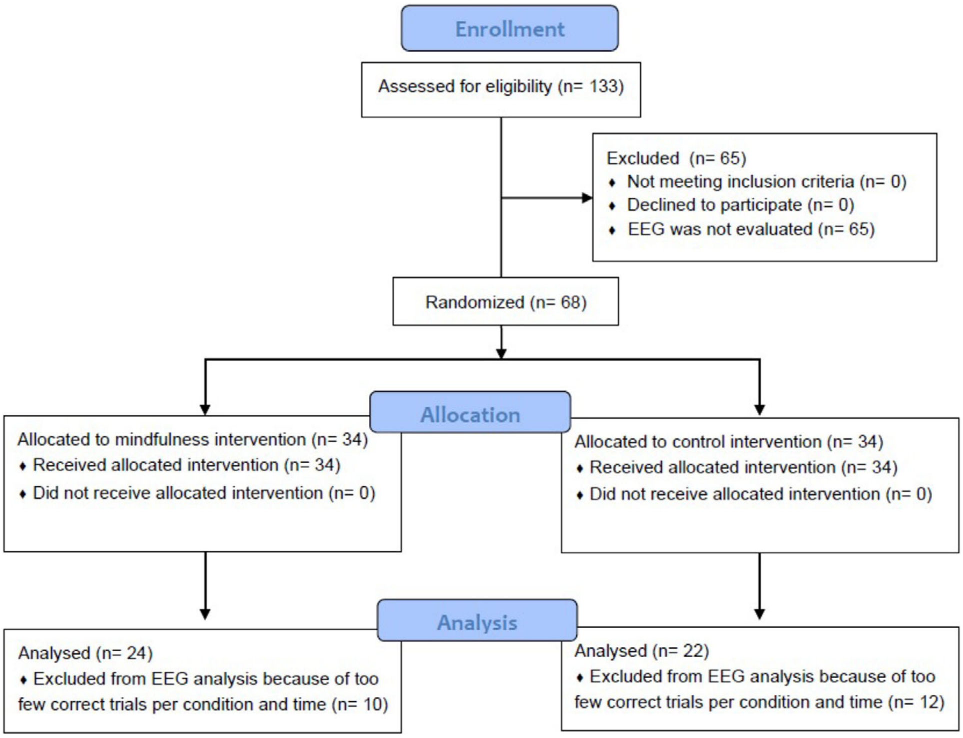

FIGURE 1 Flow chart for participants in the study. This includes enrollment, allocation and analysis of the participants. Reasons for exclusion are mentioned.

sample for all analysis presented in this report consisted of 24 children in the mindfulness group and 22 children in the active control group, after participant elimination. As recommended in the literature, only correct trials were analyzed for Go/Nogo EEG activity, and to ensure an appropriate signal to noise ratio, a minimum of 15 artifact-free trials per condition was set as a criterion for inclusion in the analysis (Huster et al., 2013; Rietdijk et al., 2014). Therefore, the main reasons for excluding participants were a high task error rate and/or a high number of trials with large artifacts that cannot be corrected by the Independent Component Analysis (ICA) procedure, leaving too few correct trials (less than 15) for analysis (please see Behavioral and EEG Data Analysis section for the complete procedure of data analysis). A diagram of the participant flow through the study is shown in Figure 1. A summary of demographic information for the subsample used in this study can be seen in Table 1. No significant pre-test differences were identified between groups (all $p > 0.05$).

2.2 | Procedure

After the collection of baseline data, randomization to study condition was done via a coin flip that assigned two of the four classrooms (one from 4th and one from 5th grade) to receive the MBI and two to receive the program that focused on the promotion of social skills (active control group). At pre-test, all procedures were explained to participants, and informed consent/assent was obtained before. Before and after interventions, EEG and questionnaire data were collected. For EEG data, participants were tested individually during school hours using a Biosemi EEG system mounted in a private and quiet room on school premises. Participants were asked to come to their testing sessions with clean, dry hair and not to use any hair products or conditioner. The same procedure was repeated after the intervention period (post time). EEG signals were recorded using a Biosemi Active-Two amplifier system and 32 scalp Ag/AgCl electrodes mounted in an elastic cap according to the 10–20 system. Four additional electrodes were fixed on the left and right mastoids and below and above the left eye (VEOG). All signals were digitized with a sampling rate of 2048 Hz and 24-bit A/D conversion. For questionnaires, the children self-reports were administered by researchers during school hours. Teachers of each classroom supervised the administration, which took approximately 45 min to complete each assessment. Also, the headteachers completed the EF reports of each child in their classrooms. The headteacher took approximately 15 min to complete each child report at both pre-test and post-test and received a total of 380 dollars in compensation for their time.

2.3 | Mindfulness-based intervention and control intervention

2.3.1 | Mindfulness-based intervention: Growingup breathing program

The experimental group received the mindfulness-based program GrowingUp Breathing (García-Rubio & Luna-Jarillo, 2017; García-Rubio & Luna-Jarillo, 2019). GrowingUp Breathing is a manualized

TABLE 1 Summary of demographic information for both groups.

Variable	Mindfulness group (*n* = 24)	Control group (*n* = 22)
Age	*M* = 9.9; SD = 0.71	*M* = 9.7; SD = 0.70
Gender (%)		
Females	62.5	63.6
Males	37.5	36.4
Family structure (%)		
2 members	14.3	5.5
3 members	28.6	22.2
4 members	33.3	61.1
5 members	9.5	5.6
>5 members	14.3	5.6
Family month income (%)		
<200 USD	0	11.8
200–400 USD	40.9	41.2
400–680 USD	45.5	41.2
680–1000 USD	13.6	5.8

secular mindfulness-based intervention for children ages 7–12 years and is specifically designed to be implemented in a school context. The general aim of the program is to foster the children's development. Specifically, the aims of the GrowingUp Breathing program are to (1) increase mindfulness skills, (2) increase attention and self-regulation processes (EF and emotion regulation), and (3) cultivate prosocial (e.g., kindness, compassion) dispositions. The methodology of the program is experiential, interactive, participatory, and student-centered. It combines traditional third-person knowledge-based learning with first-person experiential learning through mindfulness practices.

The GrowingUp Breathing program consists of nine 50-min sessions, with one session being implemented each week. The nine sessions are divided into three modules (Attention, Self-Regulation, and Kindness modules), plus an integration and summary session. Attentional training allows the improvement of self-regulation processes, which increase the probability of reflexive, non-reactive, and prosocial behaviors. In the Attention Module (3.5 sessions), children learn what mindfulness is, how the attention works, and how to bring it back when it wanders (attentional regulation). The core practices of this module are mindfulness of Breathing, mindfulness of sounds, mindful movement, body scan, and breathing space. In the Self-Regulation Module (3.5 sessions), children learn self-regulation skills (decentering and de-identification) to manage unpleasant feelings, thoughts, and emotions. Children learn to act reflexively and not impulsively. In this module, the core practices are mindful eating, mindfulness of thoughts and emotions, and breathing space (react vs. respond in difficult times). In the Kindness Module (1.5 sessions), children explore how to take care of oneself and others. The core practices in this module are loving-kindness and self-compassion meditation. Executive functions are trained throughout the entire program, mainly through formal meditation practices that are designed to train the contents of each module. In a previous qualitative study, children from the same at-risk context report how the program helped them to have better self-regulation (Andreu et al., 2021).

Other essential elements of the GrowingUp Breathing intervention are the theoretical lessons, exercises, games, and weekly practice. Weekly practices are divided into three different types of practice. First, teachers receive mindfulness-mp3 audios to use it two times per week before the next session with the children. Second, children carry out Breathing Space Practice three times per day during school time. Finally, between sessions, children are suggested to carry out different practices ("challenges") related to the content of the session.

Finally, a fundamental core practice for the learning process in the GrowingUp Breathing program is the inquiry process. The inquiry process is a central component in the pedagogy and methodology of MBIs, and it is the catalyst that encourages reflection and exploration through instructor-student-group dialogue. Through mindful teaching (calm, clear, and kind), the instructor promotes an emotionally supportive classroom climate, which encourages students to engage in mindfulness practices and to share and reflect in the group. The program was taught by an experienced psychologist and mindfulness instructor and was provided universally to children as part of their standard classroom instruction during regular school hours. Details of each session of the program (objectives, themes, core practices, and weekly practices) can be found in the Table S1.

2.3.2 | Active control group: Skills-for life program

Children of the active control group received an adapted version of the Skills-for Life (SFL) Program (Ministry of Education of Chile, 2018). SFL is Chile's government-funded universal prevention program developed for the promotion of social-emotional competencies and academic outcomes, prevention of mental health problems, and improvement of positive coexistence in the educational community. SFL is run by a division (National Association of School Assistance and Scholarship JUNAEB; Junta Nacional de Auxilio Escolar y Becas) of the National Department of Education in Chile, and it is the largest school-based mental health program in Chile providing services to more than one million students in Chile over the past decade (Guzmán et al., 2015). The program is specially designed to be implemented in schools with a population with high socio-economic vulnerability and high psychosocial risk levels. The SFL Program has been shown to decrease the risk factors associated with school and social maladjustment and to improve studentst' autonomy, socio-emotional skills, behavior, and academic outcomes (Delgado et al., 2006; Guzmán et al., 2015; Leiva et al., 2016; Murphy et al., 2014).

For this study, two expert psychologists trained in the SFL Program adapted the program to be implemented with children aged 9–11 years. The curriculum was applied during nine weekly sessions, 50 min per each, in parallel to the mindfulness-based intervention. The methodology of the program was experiential, interactive, participatory, and student-centered. The objective of the program was the promotion of social-emotional skills other than mindfulness and the improvement of the classroom climate. Through different dynamics (e.g., role-playings) and games (e.g., collective mandala), the students reflected in each class on a specific topic and developed emotional and social skills useful for their school and family context. The themes of the nine sessions were: Group Cohesion, Self-concept, Self-esteem, Treating others well, Cyberbullying, Emotional recognition, Emotional expression, Conflict resolution (dialogue) and Summary and Integration. Details of the intervention can be found in the Table S2.

2.4 | Measures

2.4.1 | Go/Nogo task

A previous Go/Nogo task was adapted for this study (Albert et al., 2013). Stimuli consisted of three capital letters ("N," "M," and "W") colored in yellow so they clearly highlighted from the black background on which they were superimposed. Children participants were instructed to press a button, as fast and accurate as possible, whenever the letters "M" or "N" were presented, and to withhold pressing when the letter presented was "W." They were asked to look continuously at the center of the screen in order to control eye-movement interference. The Go/Nogo task consisted of two blocks of 150 trials, with rest time between blocks. Each trial began with the presentation of the letter (400 ms), followed by a black screen (700 or 900 ms). Both letter and fixation cross were superimposed at the center of the black background. The letters "M" (infrequent-Go) and "W" (infrequent-Nogo) were presented with the same probability of occurrence (20%) in order to equalize both types of trials with respect to novelty processing. The letter "N" (frequent-Go) was presented in the rest of the trials (60%) to increase the subjects' tendency to respond. The three types of trials (frequent-Go, infrequent- Go, and infrequent-Nogo) were presented in semi-random order (i.e., avoiding the consecutive presentation of two infrequent-trials). Before the beginning of the experiment, participants completed a practice block of 12 trials (4 infrequent-Nogo) to ensure task instruction understanding. The task took about 10 min to complete, including resting time. After the Go/Nogo task participant completed an Eriksen flanker task adapted for children but results are not reported here.

2.4.2 | Questionnaires

Child and Adolescent Mindfulness Measure (CAMM)

Dispositional mindfulness was measured by the Child and Adolescent Mindfulness Measure (CAMM; Greco et al., 2011). The CAMM assesses mindfulness as the "lack of present-moment awareness as well as judgmental and non-accepting responses to thoughts and feelings" (Greco et al., 2011, p. 609). It comprises 10 items (e.g., "I get upset with myself for having feelings that do not make sense" or "get upset with myself for having certain thoughts'') in a 5-point Likert scale ranging from 0 ("never true") to 4 ("always true"). After recoding the scores on inverse items, higher scores on the CAMM indicate higher mindfulness skills. In this study, Spanish validation of the CAMM was used (García-Rubio et al., 2019), showing adequate reliability ($\alpha = 0.84$).

Early Adolescent Temperament Questionnaire-Revised (EATQ-R)

EC were self-reported by children using The Early Adolescent Temperament Questionnaire-Revised (Ellis & Rothbart, 2001). The EATQ-R is a revised and updated version of the EATQ (Capaldi & Rothbart, 1992) to assess more precisely aspects of self-regulation. EATQ-R consists of 11 scales. In this study, the higher-order factor EC was calculated with the attentional control and inhibitory control subscales. EC is a very close construct to EF (Snyder et al., 2015) and is defined as "the ability to inhibit a dominant response to perform a subdominant response" (Rothbart & Bates, 2006; p. 137), involving the recruitment of attentional and behavioral processes to modulate affective reactivity (Rueda, et al., 2005). Each item was measured on a five-point Likert scale ranging from 1 (almost never true) to 5 (almost always true). Higher scores reflect higher abilities. In the sample of this study, the reliability of the EC was $\alpha = 0.64$.

Behavior Rating Inventory of Executive Function, second edition—Teacher form (BRIEF2-Teacher form)

EFs were measured using the BRIEF2-Teacher Form (Gioia et al., 2015; Maldonado et al., 2017). The BRIEF2- Teacher Form is a teacher report that measures the EF of children and adolescents aged 5–18 years. Specifically, the BRIEF-2 – Teacher Form evaluates everyday children and adolescents' observable behaviors associated with EF in school environments. It comprises 63 items in which respondents record their answers via a Likert type format with N ("Never"), S ("Sometimes"), or O ("Often"), reflecting the frequency to which the child being evaluated performs an indicated behavior. The scale assesses the Global Executive Composite (Executive Function, EF), which is composed of three composite indexes and nine subscales: Behavior Regulation Index (BRI; comprised of the Inhibit and Self-Monitor subscales), Emotion Regulation Index (ERI; comprised of the Shift and Emotional Control subscales), and Cognitive Regulation Index (CRI; comprised of the Initiate, Working Memory, Plan/Organize, Task-Monitor, and Organization of Materials subscales). The Global Executive Composite, the Behavior Regulation, the Emotion Regulation, and the Cognitive Regulation Indexes were analyzed. The Behavioral Regulation Index indicates the teacher's perception of the child's level of difficulty in regulating and supervising their behaviors effectively. The Emotion Regulation Index reports the teacher's perception of the child's ability in regulating and modulating emotional responses, especially in response to changing situations. The Cognitive Regulation Index reflects the child's ability to control and manage cognitive processes and to problem solve effectively. Higher scores indicate greater problems in EF and lower scores reflect better EFs. The BRIEF2 – Teacher Form is widely used and has shown adequate validity and reliability properties ($\alpha = 0.88$–0.98) (Gioia et al., 2015; Maldonado et al., 2017). BRIEF2 – Teacher Form has demonstrated a significant correlation with the ADHD-RS-IV, CBCL-TRF, BASC-2 TRS, and Conners 3-T(S) measures, which are widely used to assess children's attention, self-regulation and mental health (for a review, see Hendrickson & McCrimmon, 2018). In the sample of this study, the reliability of the BRIEF-2 – Teacher Form was excellent ($\alpha = 0.97$).

Attendance, acceptability, and personal practice

Participants' attendance rate to the program was determined by controlling the number of sessions that each student missed (i.e., none, one, two, three, or more sessions). Also, children assessed acceptability and satisfaction with the programs at the end of them. Each student rated 3 items on a 0–10 Likert scale (i.e., Did you like the mindfulness/skills for life program?; Would you recommend a mindfulness/skills for life program to a friend?; Did you find helpful the mindfulness/skills for life program?; 0 = Never; 10 = Always). In addition, the personal practice was assessed asking the children about if they had been used the practices and exercises taught throughout the programs: Have you used in your day-to-day in and outside the school (e.g., home) what you learned on the mindfulness/skills for life program; Have you used inter-sessions the different practices learned on the mindfulness/skills for life program?; 0 = Never; 10 = Always).

2.5 | Data analysis

2.5.1 | Behavioral and EEG data analysis

For EEG, after acquisition, data were segmented in epochs of 1 s (200 ms before and 800 ms after stimulus onset) and only trials with valid responses were analyzed (correct go trials with responses between 150 and 1100 ms after onset, correct nogo trials without response). Data were low-pass filtered below 35 Hz and re-referenced to the average mastoids. Artifact rejection was based on a three-step procedure. First, we used Independent Component Analysis (ICA) to remove eye-blinks or muscular activity, since it uses spatial filtering and preserves ERP contributions, in contrast to other methods such as filtering or regression (Jung, Makeig, Humphries, et al., 2000; Jung, Makeig, Westerfield, et al., 2000). Then, noisy channels were interpolated using data of adjacent electrodes (mean $\pm$ SD of interpolated electrodes per participant and time: 2.2 ± 1.9). Finally, trials in which the EEG signal exceeded $\pm$ 150 mV after baseline correction (−200 to 0 ms) were automatically excluded. Only participants with at least 15 error-free trials per condition were analyzed, yielding a final sample of 46 participants (see Participants section for a detailed description; the number of trials did not differ between groups in any condition at either pre or post-test, all $ps > 0.05$). ERP waves were computed for each condition (Go frequent, Go infrequent and Nogo), participant (46), and time (pre and post). Then, ERP data across participants was decomposed by ICA (3 conditions $\times$ 46 participants $\times$ 2 times ERPs for each electrode). The resulting independent components were explored by means of visual inspection, identifying a meaningful component as P3 based on its scalp topography and time course. For the analysis, the average of amplitude of the P3 maximum amplitude time point $\pm$ 10 ms was used.

Repeated-measures ANOVAs were used with Group (mindfulness-training vs. active control group) and Time (pre, post) in all analyses as factors. For behavioral data, percentage error rates (both omissions and commissions: no responses in Go trials and button presses in Nogo trials, respectively) and mean reaction times (RTs) for the correct frequent and infrequent-go trials were analyzed. Repeated-measures ANOVAs on each behavioral measure were carried out using Trial type (frequent-Go, infrequent-Go, infrequent-Nogo), Group and Time as factors. To examine the effects of mindfulness training on Nogo P3, we conducted repeated-measures ANOVA, with Group and Time as factors. The Greenhouse–Geisser (GG) epsilon correction was applied to adjust the degrees of freedom of the F ratios where necessary, and post hoc comparisons were also made in order to determine the significance of pair-wise contrasts applying the Bonferroni procedure (alpha 0.05). For all analyses, the level of significance employed was 0.05. Effect sizes were computed using the partial eta-square ($\eta^2{}_p$). For interpreting effect sizes, Cohen's (1988) cutoff criteria were followed: $\eta^2{}_p = 0.01$ as small effect size, $\eta^2{}_p = 0.06$ as medium effect size, and $\eta^2{}_p = 0.14$ as large effect size.

2.5.2 | Questionnaires data analysis

Relative to self-reports completed by children, there was no attrition from pre to post-interventions (Nexp = 24; Ncon = 22). With regard to questionnaires completed by teachers, questionnaires for three children were not completed at post-intervention (i.e., the questionnaires of two children from the mindfulness group and one child from the control group were not completed). Hence, we decided to exclude these participants from the teacher reports analysis (Nexp = 22; Ncon = 21). We used the SPSS Missing Value Analysis package to estimate the patterns of missing data for children and teachers. Little's MCAR test (Little & Rubin, 1989) was not significant for child self-report

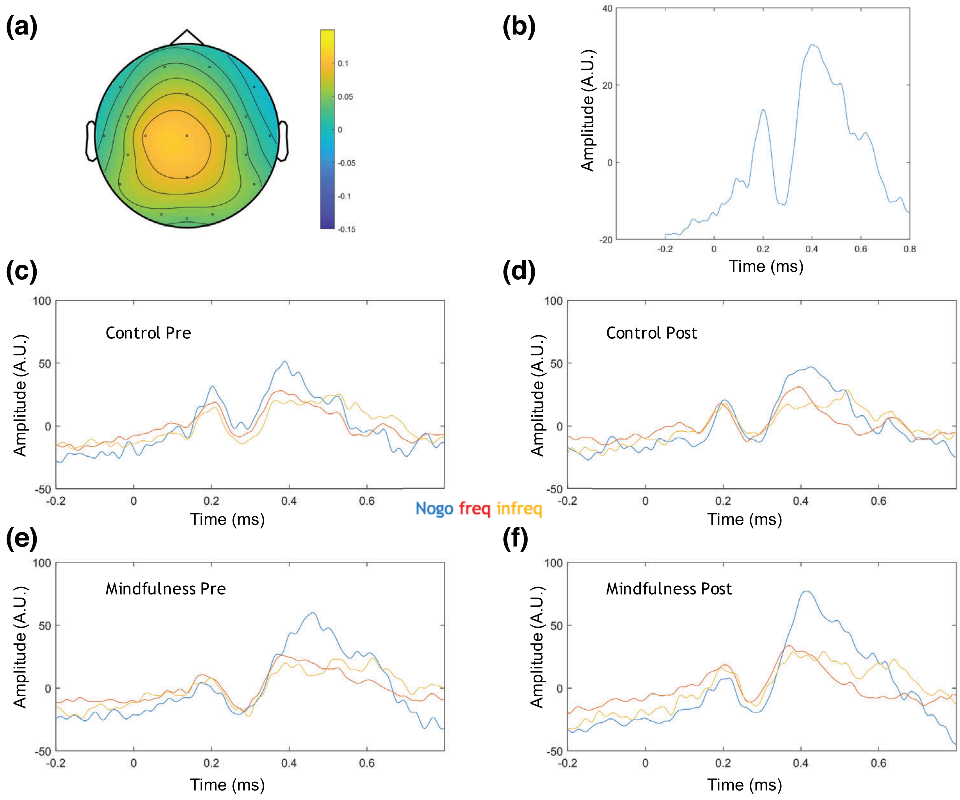

FIGURE 2 Panel A and B show the scalp topographical map and the grand-average waveform for P3 independent component—ERP, respectively. Panel C, D, E, and F show the mean waveforms for each trial, group and time in Cz.

data (χ2 [769] = 13,548, p = 1.000) and for teacher reports data (χ2 [1749] = 6370, p = 1.000), indicating that the missing data did not show a significant pattern and we could consider that data were missing at random.

We examined the baseline differences between groups (i.e., mindfulness and control group) for dependent variables of children's self-reports and teachers' reports by *t*-test. Repeated-measures ANOVAs were used with Group (mindfulness vs. active control group) and Time (pre, post) in all analyses as factors. The Greenhouse–Geisser (GG) epsilon correction was applied to adjust the degrees of freedom of the F ratios where necessary, and post hoc comparisons were also made in order to determine the significance of pair-wise contrasts applying the Bonferroni procedure (alpha 0.05). For all analyses, the level of significance employed was 0.05. Effect sizes were computed using the partial eta-square ($\eta^2{}_p$). For interpreting effect sizes, Cohen's (1988) cutoff criteria were followed: $\eta^2{}_p = 0.01$ as small effect size, $\eta^2{}_p = 0.06$ as medium effect size, and $\eta^2{}_p = 0.14$ as large effect size.

3 | RESULTS

3.1 | ERP data

The ICA applied on the previous computed ERPs revealed a frontocentral P3 component between 377 and 434 ms after stimulus onset. Figure 2 shows its topography and waveforms for both times and groups and all different trials of the Go/Nogo task. No significant baseline difference in Nogo P3 amplitude was found (t (44) = 0.757, p = 0.453). A 2 × 2 ANOVA with factors of Time (pre, post) and Group (mindfulness group, active control group) assessed possible changes across time in mean amplitudes of the frontocentral P3 on Nogo trials (Figure 2). There was a marginally significant main effect of time ($F(1, 44) = 4.176$, $p = 0.047$, $\eta^2{}_p = 0.087$), and no significant main effect of group ($F(1, 44) = 0.141$, $p = 0.709$). Importantly, the time-by-group interaction was significant ($F(1, 44) = 5.287$, $p = 0.026$, $\eta^2{}_p = 0.107$). Results showed an important increment of the Nogo-P3 amplitude in the mindfulness group over time, and a slight decrease from pre to post in the active control group. No other significant interactions were found (Figure 2).

3.2 | Behavioral data

Performance on the Go/Nogo task is shown in Table 2. For the Go trials (frequent and infrequent-go), it shows means of error rates (omission errors in percentages), and means RTs. For the Nogo trials, it shows means of error rates (commission errors in percentage). Preliminary analyses were conducted to examine pre-intervention group differences in behavioral data. There were no significant pre-intervention group differences in error rates and RTs (all $p > 0.05$), except for errors

TABLE 2 Performance on the Go/Nogo task.

	Mindfulness		Control	
	Pre	Post	Pre	Post
Go frequent				
Error	6.29 (4.40)	8.72 (7.60)	9.90 (6.50)	14.02 (12.70)
RT	384.35 (43.78)	361.67 (43.53)	382.75 (49.53)	362.35 (43.79)
Go infrequent				
Error	8.44 (6.01)	10.52 (8.07)	11.99 (8.11)	16.52 (13.08)
RT	395.17 (56.67)	365.85 (48.10)	386.80 (56.37)	373.37 (55.79)
Nogo infrequent				
Error	57.30 (12.63)	49.72 (14.76)	56.39 (15.00)	52.23 (10.64)

Data shown represent means of error rates (omission errors in percentages), mean reaction times for the Go trials (frequent and infrequent-go), and means of error rates (commission errors in percentage) for the Nogo trials. Standard deviations in parentheses.

in frequent-go trials ($t(44) = 2.219$, $p = 0.032$), where the control group showed higher error rate.

With respect to percentage error rates, a significant main effect of trial type was observed ($F(2,88) = 379.6$, $p < 0.001$, $\eta^2_p = 0.896$). Percentage error rates were higher for Nogo trials (i.e., commission errors) than for frequent- and infrequent- Go trials (omission errors), as expected. Also, group difference ($F(1,44) = 4.356$, $p = 0.043$, $\eta^2_p = 0.09$) and time-by-trial type interaction were significant ($F(2,88) = 10.712$, $p < 0.001$, $\eta^2_p = 0.196$), indicated higher error rates among students in the active control group compared to students in the mindfulness group. Moreover, the analysis indicated that students in both groups improved their performance, particularly with regard to commission errors within time. No other significant effects or interactions were found regarding to error rates.

Regarding RTs, a significant main effect of Go-trial type (frequent and infrequent) was found ($F(1,44) = 9.277$, $p = 0.004$, $\eta^2_p = 0.174$). In general, correct responses to infrequent-go trials were larger (higher reaction times) than correct responses to frequent-go trials (slower reaction times). Additionally, a main effect of Time was found ($F(1,44) = 20.9$, $p < 0.001$, $\eta^2_p = 0.322$), showing a general decrease in frequent- and infrequent-go RTs at post-test compared to pre-test. No other significant effect or interaction was found.

In summary, the mindfulness group, relative to the active control group, did not change after the intervention in the reaction times in the Go trials. However, in general, the percentage of errors in the control group was higher than in the mindfulness group.

3.3 | Questionnaires

3.3.1 | Baseline comparisons

Preliminary analyses were conducted to examine pre-intervention group differences across gender, age, and all of the dependent variables in the study. There were no significant group differences at baseline on socio-demographic characteristics: gender ($\chi 2\ [1] = 0.006$, $p = 0.936$), and age ($t(44) = 0.903$, $p = 0.371$). There were no significant pre-intervention group differences in children's self-reports on mindfulness ($t(43) = 0.007$, $p = 0.994$) and effortful control ($t(44) = 1.462$, $p = 0.151$). There were no significant pre-intervention group differences on teacherst' reports of children's EF as assessed via the BRIEF Global Index ($t(41) = 0.697$, $p = 0.489$), behavioral regulation ($t(41) = 1.314$, $p = 0.196$), cognitive regulation ($t(41) = -0.496$, $p = 0.623$) and emotion regulation indexes ($t(41) = 1.120$, $p = 0.269$).

3.3.2 | Intervention effects

Pretest and posttest means and standard deviations as well as differences in change scores for all dependent variables (i.e., mindfulness, EC, EF, behavioral regulation, emotion regulation, and cognitive regulation) by intervention group are reported in Table 3.

With regard to child self-reports, the results for mindfulness indicated a significant change from pretest to posttest, $F(1, 43) = 5.101$, $p = 0.029$, $\eta^2_p = 0.11$, indicating differences between the mindfulness and control group, with a decrease in mindfulness scores in the control group. Also, the results regarding EC were significant in the expected direction, $F(1, 44) = 6.144$, $p = 0.017$, $\eta^2_p = 0.12$. That is, the mindfulness group showed a higher increment of EC from pretest to posttest compared to the control group.

Regarding teachers reports, results showed an improvement from pretest to posttest in total EF of children in the mindfulness group compared to children in the control group, $F(1, 41) = 5.64$, $p = 0.022$, $\eta^2_p = 0.12$. Specifically, children in the mindfulness group showed improvements in behavioral regulation from pretest to posttest, $F(1, 41) = 5.63$, $p = 0.022$, $\eta^2_p = 0.12$, and on the emotion regulation index, $F(1, 41) = 8.02$, $p = 0.007$, $\eta^2_p = 0.16$, with no change in the cognitive regulation index, $F(1,41) = 1.69$, $p = 0.201$, $\eta^2_p = 0.040$. Overall, whereas teachers reported an increase of EF from pretest to posttest of children in mindfulness group, no change of EFs was observed in the control group.

TABLE 3 Descriptive statistics and differences in change scores between intervention groups.

	Mindfulness group				Control group				Between-group differences	
	Pretest		Posttest		Pretest		Posttest		Mindfulness vs. control pre-post	
	M	SD	*M*	SD	*M*	SD	*M*	SD	*F*	η^2
Children self-reports										
CAMM- mindfulness	3.34	0.95	3.55	0.93	3.34	0.91	2.90	0.90	5.10*	0.11
EATQ- effortful control	3.39	0.41	3.62	0.47	3.22	0.35	3.10	0.43	6.14*	0.12
Teacher reports										
BRIEF- executive function	1.61	0.36	1.35	0.34	1.52	0.43	1.54	0.47	5.64*	0.12
BRIEF- behavioral regulation	1.67	0.45	1.34	0.35	1.48	0.49	1.48	0.53	5.63*	0.12
BRIEF—cognitive regulation	1.59	0.37	1.44	0.44	1.66	0.56	1.68	0.49	1.69	0.04
BRIEF—emotional regulation	1.56	0.39	1.28	0.29	1.43	0.39	1.47	0.47	8.02*	0.16

*$p < 0.05$.

3.3.3 | Attendance, acceptability, and personal practice

Because the sessions were regularly scheduled in the curriculum during the academic schedule, there was a high attendance rate for both programs. For the mindfulness intervention group, 50% of children attended all mindfulness sessions, 33% missed one session, 12% missed two sessions, and 5% missed three sessions. For the active control group (SFL), 67% of children attended all SFL sessions, 22% missed one session, 5% missed two sessions, and 5% missed three sessions. There were no differences in the attendance rate between groups ($t(41) = -1.160$, $p = 0.253$). The acceptability was high in both the mindfulness group ($M = 8.45$, SD $= 2.78$), and the active control group ($M = 8.54$, SD $= 2.63$). Also, personal practice was moderately high in the mindfulness group ($M = 6.69$, SD $= 3.95$), and the control group ($M = 7.04$, SD $= 3.40$). There were no differences between groups in acceptability ($t(44) = -0.109$, $p = 0.914$) and personal practice ($t(42) = -0.328$, $p = 0.744$).

4 | DISCUSSION

In this study, we examined the effects of a mindfulness-based intervention in children in a high-risk context on inhibitory control and its underlying neural mechanisms. Compared to an active control group, children that received the MBI showed less error rates in the Go/Nogo task for all trial types. No differences in reaction times were found between groups. Additionally, children in the mindfulness group showed increased EC, global EFs, emotion and behavioral regulation after the intervention, evidenced by child self-report and teacher reports. Furthermore, EEG results revealed significant differences in the P3 amplitude; with children in the mindfulness group showing an increased Nogo-P3 amplitude and children in the control group showing a slight decrease in P3 amplitude over time. Taken together, this is one of the first studies to provide empirical evidence that an MBI in a vulnerable school context increases children's EFs, attention, and inhibitory control. Importantly, the effects were evidenced by both behavioral and neural indices, showing that frontocentral P3 amplitude may underlie this effect. Following recent recommendations (Felver et al., 2015), the use of an active control group allowed us to better control for non-specific effects and particularly, this study used as an active control a very well evaluated social skills intervention that is widely used in vulnerable schools in Chile, making it a very strict comparison.

Behaviorally, children that participated in the MBI showed a general lower error rate in the Go/Nogo task compared to control children. Interestingly, this was true for all task trials and times, including pretest. The Go/Nogo task we used (Albert et al., 2013) allowed us to analyze attention-related effects with frequent versus infrequent go trials and inhibition-related effects with infrequent go trials versus nogo trials (infrequent go and nogo trials have the same proportion). As the effects were observed in all task trials, this result may reflect increased global attention rather than a specific effect of inhibitory control. This result is very interesting since previous evidence shows that mindfulness trains attention in adults but also in children (Zenner et al., 2014) and attention is entirely associated with executive functioning (Checa et al., 2014; Diamond, 2013). Moreover, according to child self-report questionnaires EC (which include attentional control) increased in the mindfulness group over time compared to control group, which is in line with behavioral task interpretation of results. However, it cannot be stated that it is a consequence of the intervention per se, since there was an overall group effect and there were previous differences between groups in the case of frequent-go errors.

Regarding EEG results, we expected increased amplitudes of P3 in the mindfulness group over time, particularly in Nogo-P3 which has been proposed as a reliable neural index of motor inhibition (Albert et al., 2013; Dykstra et al., 2020; Sánchez-Carmona et al., 2016; Wessel & Aron, 2015). Our electrophysiological results closely matched the behavioral results: children in the mindfulness training group showed increased P3 amplitude on Nogo trials, compared to children in the active control condition, who showed a minor decreased amplitude over time. A previous study with the same Go/Nogo task indicated that the frontocentral P3 showed larger amplitudes for Nogo than for infrequent Go trials, suggesting that Nogo P3 is the ERP activity most associated with inhibitory control (Albert et al., 2013). Our results showed, for the first time, a specific mindfulness-related effect in this inhibition-related neural activity in youth, which would indicate increased inhibitory control in children after an MBI. Increased inhibitory control in children after a MBI was shown previously only with behavioral or self-reported data (Mak et al., 2018; Schonert-Reichl et al., 2015). In adolescents, previous EEG studies have shown changes in P3b amplitudes after MBI but using tasks that measure different cognitive/affective processes which are not comparable to a pure inhibitory control task such as Go/Nogo (Sanger & Dorjee, 2015; Sanger et al., 2018). Given the importance of inhibitory control in children and specially in our particular population of high-risk children, we considered that our results are extremely relevant.

Questionnaires data from multiple informants (children and teachers) supports our behavioral and EEG results. Self-reported results from children showed increased EC in the mindfulness-training group compared with control group over time and a significant intervention effect on mindfulness, showing a slight increase in mindfulness for the intervention group and a significant decrease in mindfulness in the control group. Although it may be counterintuitive to see a drop of mindfulness in the control group, these findings may be interpreted within the context of the cognitive changes that occur during the developmental period of early adolescence—ages 9–13 years. Specifically, early adolescence in particular has been described as a time in the life cycle in which there is heightened self-consciousness due to increased competence in cognitive and social cognitive abilities (Schonert-Reichl, 1994) and information processing. Developmental changes may lead to increased attention and reflection on the self, which may then direct the early adolescent to adopt a more critical view of the self (Eccles & Roeser, 2009) and a subsequent drop in present-moment awareness as well as judgmental and non-accepting responses to thoughts and feelings. Hence, this drop in mindfulness in the control group may be reflective of the typical developmental trajectory of early adolescents. The mindfulness intervention may have staved off this typical decline in dispositional mindfulness for students in the intervention group. Assessments from teachers showed increased behavioral regulation, emotion regulation, and global executive functioning in children of the mindfulness group compared to controls over time. Collectively, the results suggested increased EFs, particularly inhibitory and attentional control in vulnerable children after the mindfulness-based intervention. Previous studies have shown improved EFs in children after MBIs in schools (Mak et al., 2018; Schonert-Reichl et al., 2015). Executive functioning has been distinguished in “hot and cool”: top-down processes that operate in emotionally significant situations versus affectively neutral contexts (Zelazo & Carlson, 2012). It is interesting to see that the concept of hot EF suggests that motivationally significant contexts demand different top-down processes than neutral contexts. Following this distinction, the electrophysiological results observed in the Go/Nogo task clearly correspond to cool EF while the results reported by teachers may be associated with hot EF, where children were evaluated in emotionally challenging situations (particularly with inhibition and emotional regulation subscales of the BRIEF). This may explain the absence of behavioral outcomes in the Go/Nogo task, suggesting that brain-related effects were not sufficient to see changes in behavioral cold EFs, but instead translated into changes in hot EFs. If this is true, our results point toward brain changes in the cool EF system that may support behavioral changes in hot EF, important for daily life situations and crucial in high-risk contexts for children.

The present study used a longitudinal design with an active control group, which allows us to draw conclusions about causality and control the non-specific effects, confirming that the reported effects are related to the training of mindfulness per se. Additionally, the use of multiple levels of measurements (questionnaires, behavioral tasks, electrophysiological recordings) and several informants (children and teachers) allow us to draw stronger conclusions. Despite this, our study is limited since only one school was part of the study making difficult to generalize the results. The sample size is a common challenge and limitation of the field of EEG studies with children, where a high number of participants are expected to be eliminated due to eye and/or head movements that cannot be corrected. Therefore, it is likely that the most restless children are not included in the final samples of EEG studies. Future work should replicate our study with an increased number of participants and schools. Also, longer interventions would be useful to determine the time-line effects of mindfulness on EFs in high-risk contexts. Lastly, we did not have a follow-up measurement due to the difficulties of collecting EEG data and did not include parents, teachers, and the school community in the interventions, limiting the sustainability of the improvements obtained.

To conclude, children from vulnerable contexts who participate in a school-based mindfulness intervention displayed improved executive functioning, inhibitory control and attention at the reported and behavioral level, which was accompanied by increased Nogo P3 amplitude, compared to an active control group. Together, our results showed that mindfulness trainings in schools improve EFs and particularly inhibitory control in high-risk children, providing them crucial abilities for a healthier development and preventing future problems. We hope this research will help advance the science and practice of school mindfulness-based preventive interventions that will help vulnerable children flourish.

ACKNOWLEDGMENTS

A special appreciation is expressed to the children who participated in the study, as well as to their parents, teachers and all the school community; all of whom made this study possible. Also, a special thanks to all research assistants for their valuable help in the different phases of this project. This study was funded by the Mind and Life Europe Institute by a Varela Awards given to CIA and CGR [Grant #2016-EVarela-Garcia Rubio, Carlos and Andreu, Catherine]. This work was supported by the Fund for Innovation and Competitiveness (FIC) of the Chilean Ministry of Economy, Development and Tourism, through the Millennium Scientific Initiative, Grant [IS 130005—MIDAP to CIA] and by a grant from the Spanish Ministry of Education, Culture, and Sport [FPU13/ 01677] to CGR.

CONFLICT OF INTEREST STATEMENT

The authors declare no conflict of interest.

DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available from the corresponding author upon reasonable request.

ETHICS APPROVAL STATEMENT

Ethics Committee of the Pontificia Universidad Católica de Chile approved the study.

ORCID

Catherine I. Andreu https://orcid.org/0000-0003-2402-0252
Jacobo Albert https://orcid.org/0000-0001-6538-9801

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How to cite this article: Andreu, C. I., García-Rubio, C., Melcón, M., Schonert-Reichl, K. A., & Albert, J. (2023). The effectiveness of a school mindfulness-based intervention on the neural correlates of inhibitory control in children at risk: A randomized control trial. *Developmental Science*, *26*, e13403. https://doi.org/10.1111/desc.13403