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East meets west: a mobile brain-computer system that helps children living in poverty learn to self-regulate

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Abstract

Children living in poverty often suffer multiple forms of trauma, which impedes their ability to effectively self-regulate negative emotions, such as anxiety, and to focus their attention. As a result, many of these children struggle at school. Our work explores the effectiveness of using a mindfulness-oriented, neurofeedback-based, brain-computer system to help teach children living in poverty to self-regulate anxiety and attention. Our system, called Mind-Full, was specifically designed for illiterate girls who attend an NGO-funded school in Pokhara, Nepal. In this paper, we present the results of a waitlist control field experiment with 21 girls who completed an intervention using the Mind-Full system. Our results indicated that a 6-week Mind-Full intervention was viable and that children were able to transfer self-regulation skills learned using our system into real-world settings and continue to self-regulate successfully after 2 months. We present our findings as a validation of the effectiveness of mobile neurofeedback-based interventions to help young children living in poverty develop self-regulation skills. We conclude with a discussion of the results, methodological challenges of working in the developing world, and advice for future investigations of the effectiveness of neurofeedback applications for children.

Keywords Brain-computer interfaces · Neurofeedback · Self-regulation · Children · Games for learning · Developing countries · Field evaluation

1 Introduction

One billion of the world's children live below the poverty level, living on less than $2.50 a day.[1] Many charities and non-government organizations (NGOs) who work throughout the developing world try to provide education for these children. This paper is about the field evaluation of a brain-computer interface (BCI) application we designed to try helping some of the world's poorest children. When children live in poverty, they often suffer multiple complex traumas. Traumas may be layered and include domestic violence, physical abuse, sexual abuse, neglect, parental mental illness and addictions, homelessness, and civil war. One of the effects of these kinds of layered traumas on children can be delayed or decreased development of children's pre-frontal cortices, an area of the brain responsible for executive functioning (e.g., self-regulation of affect, attention, and planning) [7]. To be able to self-regulate means to be able to consciously change or control affective and/or cognitive brain states (e.g., anxiety, attention). In addition, complex trauma may impact the development of the amygdala, the seat of emotional regulation, making it highly reactive [7]. With an underdeveloped pre-frontal cortex and an overly reactive amygdala, children who have suffered complex trauma often have trouble self-regulating negative emotions (e.g., anxiety) and they can be hyperactive and struggle with attention and focus. In order to successfully learn in a classroom, children must be able to stay

[1] https://www.unicef.org/sowc/archive/ENGLISH/The%20State%20of%20the%20World%27s%20Children%202005.pdf

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calm and focus their attention on learning activities. Children who have suffered complex trauma often have great difficulty with the self-regulation skills and as a result have difficulty learning [7]. What is difficult about learning self-regulation is that it involves mental and embodied processes that are invisible. Those teaching children cannot always see if children are learning, and children often struggle to understand what it means to self-regulate and how to do it.

Combining best practices from the east (mindfulness) and west (mobile health technologies) may be a way to address this challenge. The phrase "mindfulness practices" has been used to refer to a variety of techniques including deep breathing and focusing one's attention on inner or outer experiences, as well as different forms of mediation and self-regulation training. In this paper, we delimit the term mindfulness to mean the approach to mindfulness training that uses breathing and body awareness to learn brain state regulation. Mindfulness can be effectively learned by healthy adults using neurofeedback [5]. Neurofeedback (NF) is a technology-mediated practice that involves using a brain-computer interface (BCI) system to, either passively or consciously, control one's own brain activity. Electroencephalography (EEG)-based NF BCI systems use sensors on the scalp to measure brain activity and display information about current brain states on a computer screen in real time. This feedback enables us to better understand a user's invisible brain processes. For example, an EEG-based NF BCI can determine and display if a person is anxious or calm, or distracted or attentive. Interventions using NF BCIs have been shown to be effective for teaching children how to self-regulate anxiety [16, 23, 34, 36] and attention [4, 22, 28, 38]. They have also been shown to be effective for treating post-traumatic stress disorder in adults and children (e.g., [9, 24, 35]). Using NF BCI systems for self-regulation training that include games provides motivation and has been linked to high training compliance and reduced attrition in clinical studies [11, 42]. In addition, current evidence from the fields of pediatric psychotherapy and health science in developed nations suggests that teaching children mindfulness practices is an effective way to improve executive functioning and help reset the limbic system after trauma [26, 43].

Our overarching research question is: Can a NF BCI system help children living in poverty effectively learn to self-regulate anxiety and attention? In this paper, we begin to answer this question by presenting the methodology and results from our first field evaluation study of a NF BCI intervention for children living in poverty who attend an NGO-funded school in a developing nation. Our contribution is both academic knowledge about the effectiveness of this approach and the potential positive impact on the lives of these children. From an impact perspective, if we can teach children living in poverty to better self-regulate affective and cognitive processes, it may improve their chances of succeeding in gaining an education, which is widely agreed to be one of the best antidotes to poverty [12]. The first step in addressing our overarching question is investigating if a technology-mediated mindfulness intervention can help a small sample of this population to learn to self-regulate, and that is the focus of this paper.

We had the opportunity to work with NGO-funded school and a trauma therapist (co-author Leslie Chesick) to develop and evaluate a mindfulness-based NF BCI system with three games for children living in poverty in Pokhara, an urban city in Nepal. Our goal was to create an intervention that could be used by counselors to help children learn how to effectively self-regulate and better manage anxiety when they were stressed and improve their attention on educational materials. We conceptualized effectiveness as three constructs: viability, transfer, and maintenance. Viability means that children can reliably use the system over the course of the intervention. Transfer means that children can transfer some of the self-regulation skills they have learned during gameplay into other contexts in their everyday life (e.g., classroom, playground). Maintenance means that children can continue to use their newly learned skills after a period of time (e.g., 2 months). For the Mind-Full intervention to be effective, it must be viable and support transfer and maintenance.

In a previous conference paper, we reported preliminary results from the Nepal field evaluation comparing the intervention and control groups at the midpoint of the study on a subset of measures [2]. In this current paper, we provide the full study results across all viability, transfer, and maintenance measures at all three assessment points (pre-test, post-test, follow-up test). By using a waitlist control design, we controlled for naturally occurring versus intervention-related changes in self-regulation. For ethical reasons [1], the waitlist control group also did the intervention after the post-test and we report on their outcomes as well in this paper. We have also published a journal paper in which we describe design knowledge about how we addressed the design challenges of creating NF BCI applications for children from different populations, including those living in poverty [3]. We refer the reader to that paper for a detailed description of the Mind-Full system.

2 Background

2.1 How EEG-based NF BCI systems work

In this section, we provide a summary of how NF BCI systems work for those not familiar with this technology. BCIs are computational systems that sense, process, transfer, and use information about brain processes and states for communicating with computation [6]. In the brain, there are billions of neurons [40]. As we think, feel, sleep, exercise, and learn, neurons communicate with each other, and in doing so, generate synchronized patterns of small electric voltage fields.

Some of this electrical activity escapes through the skull. EEG is a method to record and measure this electrical activity of neurons, using non-invasive electrodes placed on the scalp. The fast Fourier transform (FFT) is a mathematical process used to convert an EEG signal from the time domain into the frequency domain by transforming the signal into its constituent brainwave bands (e.g., alpha, beta, gamma). These bands are measured in hertz or cycles per second. Depending on the location of the electrodes, synchronized neural activity in different brainwave bands can be correlated with different cognitive and affective brain states. For example, EEG sensors on the pre-frontal cortex can be used to detect relaxation, anxiety, and attention (see Table 1). Neurofeedback can be used as a form of self-regulation training, in which the user tries to increase or decrease activity in specific frequency bands, and is provided with visual or audio feedback and positive reinforcement for doing so. Research has shown that functional brain connectivity is substantially reorganized during a child's development [37]. However, many large-scale network properties are preserved over time, making children's functional brain networks comparable to those in adults. As a result, researchers, including ourselves, have made the assumption that NF training frequency protocols for adults may work for children.

The most common approaches to NF training for self-regulation of anxiety involve training to increase activity in the alpha band, increase the ratio of activity in the alpha/theta (A/T) bands, or decrease activity in the high beta band (see Table 1). The most common approaches to NF for self-regulation of attention and hyperactivity involve training to decrease the ratio of activity theta/beta (T/B) bands, increase the amplitude in a range of lower beta (called sensory motor rhythm or SMR) or decrease negativity of slow cortical potentials (SCP) [17]. Unlike NF focusing on specific bandwidth frequencies, SCP are general measures of the amplitude of electrical activity in upper cortical layers. Training for increased negativity, reflecting greater activation of the cortical networks, has been shown to improve attention in individuals with ADHD. However, since SCP training requires specialized equipment, it is out of scope for our research. We mention it here because several studies below used SCP in addition to specific bandwidth frequency training.

The question of whether modulating electrical activity patterns in the brain can be learned and if so, whether changes lead to correlated behavioral improvements has been the subject of investigation in the field of child and adolescent psychiatry for about 40 years [29]. While early studies were plagued by methodological challenges, we are seeing more and more positive evidence, not just in clinical and hospital settings but also in field studies (as described below).

Currently, EEG NF BCI systems are mainly available on expensive, stationary desktop platforms and tend to use complex multi-electrode EEG headsets [15]. They often require intensive pre-training and calibration [6]. In addition, they are difficult to learn to use and require experts to administer them, typically in clinical and hospital settings. However, recently, consumer-grade EEG headsets have become commercially available, making the use of NF BCI systems possible outside of lab and clinical contexts. For example, the NeuroSky MindWave[2] is a commercially available EEG headset that contains a signal processing unit in the headband, uses a single dry electrode to record electrical activity in the left pre-frontal cortex (FP1), and uses an ear clip as ground (A1). The headset uses Bluetooth technology to wirelessly transmit brainwave data to a desktop computer or mobile device. The headsets produce two proprietary eSense™ outputs, one called "meditation" (R value, for relaxation), which is derived from alpha and theta frequencies,[3] and one called "attention" (A value), which is derived from beta frequencies. Each provides a relative indication of the degree of meditation/relaxation or attention, the range of which is from 0 to 40 (low), 41 to 60 (average), 61 to 80 (moderate), and 80 to 100 (high). A predecessor of the system was validated in terms of its ability to reliably measure attentional states using a proprietary algorithm [33]. Other studies have found the NeuroSky sensor and signal processing algorithm to be able to reliably detect and differentiate relaxation and attentive states linked to pre-frontal cortex processes (e.g., [18, 21, 39]). Compared to most EEG units, it is inexpensive, robust, portable, simple to work with, adjustable, and easy to wear due to the single dry electrode. It is the only consumer headset currently approved for use with children.

Despite the availability of affordable EEG headsets, there are still few NF BCI systems or applications (that run on mobile devices) that have been developed for use in schools or homes. There are no systems designed for children living in non-industrialized countries who may be illiterate and have no experience using computers. We address this gap and opportunity through the field evaluation of a portable, robust, easy to use EEG-based NF BCI system and application that we designed for use in a school for children living in poverty to help them learn how to self-regulate anxiety and attention.

2.2 Evaluating NF BCI applications for children

In this section, we provide a summary of other researchers who have evaluated NF BCI's for children and self-regulation training of anxiety or attention. We limit the scope of our review to non-clinical interventions evaluated in the field rather than in clinics or hospitals with complex

[2] http://neurosky.com

[3] The algorithm for calculating the mediation and attention indices is proprietary; however, we know that the mediation index is based on alpha/theta frequencies and attention on beta frequencies. Various studies have validated their accuracy.

Table 1 Brainwave bands, frequencies, cognitive/affective correlates, and NF training target bands and states

Brainwave frequency band	Frequency (hertz)	Cognitive/affective correlates of brainwave frequency bands	Neurofeedback training targets to achieve calm and attentive brain states
Theta (T)	3–8	Sleep, deep meditation	
Alpha (A)	8–12	*Calmness*, relaxation, mediation Border between A and T may be related to musical creativity and performance	Increase activity in alpha band Increase (A/T) ratio Decrease activity in high beta band
High alpha or low beta (SMR)	12–15	Relaxed yet *focused attention*	Decrease (T/B) ratio Decrease negativity of SCP Increase activity in SMR/beta
Beta (B)	15–22	High engagement, *focused attention*	Decrease (T/B) ratio Decrease negativity of SCP Increase activity in SMR/beta
High beta (HB)	22–38	Anxiety, high arousal	

research-grade NF systems. Our goal in presenting this work is to summarize evidence from field studies in industrialized countries, which has been largely positive, and identify methodological challenges that must be considered in the interpretation of results and/or addressed in future studies where possible. This background sets the stage for the knowledge gap we address in this paper, which is determining if a NF BCI intervention used in a school is effective for helping children an non-industrialized country learn to self-regulate.

Early HCI research in BCIs games did not target therapeutic systems, but instead explored BCIs as a way to create compelling gameplay experiences through affective computing [31]. A variety of EEG-based BCI games have since been developed for children (for a review, see O'Hara et al. [32]). There are limited field studies of NF BCI applications for children and self-regulation of *anxiety*. In a randomized controlled experiment with an active control group with 136 participants (aged 87–13), children and youth played one of two platform video games in common rooms (7–19 children) for 5 × 1 h sessions, scheduled twice a week [36]. The intervention group used a NF platform video game called MindLight, developed based on principles of cognitive behavioral therapy, to explicitly expose players to anxiety-producing and -relaxing experiences. The control group played Max and the Magic Marker, a puzzle platform video game. Both groups showed a decrease in anxiety self-reported ratings from pre-test to post-test but no differences between groups. Effects were stable at the follow-up maintenance test. Parent ratings showed a similar pattern. The methodological design was robust with a large sample size, active control group, and standardized, reliable, and multi-informant behavioral measures. Since the children all played in shared rooms, there may have been a contamination effect. The authors also suggest that positive results might be due to non-specific factors such as expectation, motivation, and game mechanisms since other studies have found that video games in general may reduce anxiety, provide distraction, increase self-efficacy, and build resilience. Lastly, without a waitlist control group, it is difficult to determine if improvements were greater than without any intervention. While these results are encouraging, the intervention would not be suitable for our context since our target population are young girls with no computer experience and no access to console or PC platforms, and who live in an environment with unreliable power. However, the need for a waitlist control group, which may account for developmental improvements in self-regulation, informed our study design.

Johnston et al. conducted a randomized waitlist control design to investigate the effectiveness of a combination of working memory (WM) and impulse control (IC) training and NF training with 25 sessions of Focus Pocus over 7–8 weeks conducted at home [22]. Focus Pocus is a series of mini games designed to train WM and IC and has two relaxation and two attention NF games. Eighty-five children (mean age 10 years) with clinical or subclinical diagnosis of attention deficit and hyperactivity disorder (ADHD) were randomly allocated to a training or waitlist condition and completed pre-tests and post-tests after the intervention. Parental ratings (non-blind) showed improvement in ratings of behaviors for the intervention groups related to ADHD but a decrease in engagement and enjoyment for the latter part of the intervention. Teacher and significant other (blinded) ratings did not show improvement for the clinically diagnosed ADHD group, but showed some improvement for the subclinical group. As with other studies with children with disabilities, the NF training tasks did not demonstrate a linear across-session improvement pattern. These findings informed our study design in terms of supporting the use of survey-based behavioral measures rather than BCI data (which is highly variable), determining the length of our intervention, and cautions associated with non-blind reports. This is the only intervention that addressed both anxiety (relaxation) and attention, which is the focus of our intervention.

There have been many evaluations of NF BCI applications for children and self-regulation of *only* attention, largely working with children with clinical or subclinical diagnoses of ADHD and other related disabilities. For example, Mandryk et al. used an approach that turned off-the-shelf computer games into NF BCI games for 16 children (aged 8 to 17) with fetal alcohol syndrome, who had symptoms similar to ADHD [30]. They used brain state data from a NeuroSky headset (with the sensor moved from left forehead to EEG location Cz) to control the display of an opaque graphical overlay on top of a commercially available video game. Children participated in one to two 30–45-min gameplay sessions per week over 12 weeks in a university HCI research lab setting. Children reported that they understood how the NF system worked. Log analysis showed a significant improvement (at the $p < 0.05$ level) from pre-test to post-test ability to lower their T/B ratios during gameplay. However, the authors state that they cannot make claims about efficacy due to study limitations (e.g., no control group, small sample size, large age range of children, no pre-test to post-test behavioral measures, and no transfer or maintenance measures). This study informed our study design in which we included pre, post, and follow-up assessments to better understand the impact of the intervention.

Gruzelier et al. studied NF BCI as a mechanism to improve creativity and well-being of 31 children (aged 11) [14]. Children were split into three groups: A/T NF training, SMR NF training, and a non-training control. The A/T group involved NF training of 9 children to enhance their A/T ratio closed eyes relaxation with audio feedback. The SMR group involved lower beta training of 10 children with visual feedback and a point reward system. The intervention involved 10 sessions at their school. Results showed that the A/T training improved some aspects of musical performance of the children. SMR training improved improvisation, possibly through the mechanism of improved sustained attention. Results from pre-test to post-test on the test of variables of attention (i.e., TOVA test of sustained attention, which may be improved by A/T training due to relaxation) were insignificant, with over half the group being assessed with ADHD. Results showed irregular across-session NF learning, which the author's suggest may be associated with children's varying levels of arousal from day to day. The study showed the viability of in-school training (although several children dropped out and several more did not complete assessments), but did not use validated pre-test and post-test behavioral measures and did not include a follow-up. Again, this research informed our use of pre, post, and follow-up assessments and suggested that we use reliability analysis for our survey-based instruments to improve rigor.

Lim et al. created an EEG-based puzzle for 17 children clinically diagnosed with ADHD (aged 7 to 12) with the goal of helping them improve their ability to self-regulate their attentive state [27]. A child's attentional level, as measured by a NeuroSky EEG headset, was sent to a desktop application and controlled his/her movement forward in a puzzle. The color Stroop test was used in a calibration session for each child. The children participated in 24 sessions over 8 weeks with 3 once a month booster sessions. At pre-test, post-test, and follow-up test at weeks 20 and 24, ADHD-RS questionnaire was filled out by parents and teachers based on their observation of the children at home and in the school (not blinded). The results indicate parent ratings of the combined ADHD scores significantly improved from pre-test to post-test and were maintained (but not impacted by booster sessions) at both follow-up points. BCI-measures of ADHD did not show change from weeks 0 to 20, and although they were moderately negatively correlated to questionnaire scores, it is unclear if this analysis is valid since the BCI scores did not significantly change from week 0 to 20. Despite the small sample size, the results are somewhat positive. However, without a control group, the expectation, learning, and maturation effects cannot be accounted for. These findings indicate that children's behaviors could improve while their BCI data might not reflect behavioral change.

Huang et al. created FOCUS, a reading application designed to improve 24 children's engagement (related to attention) during reading (aged 6 to 8.5) [19]. The system included a 14-electrode Emotiv[4] EEG headset, a physical book, and a pico-projector used to create an augmented display over the book. When a child's EEG engagement index dropped below a threshold, the system's training mode was triggered. Children participated in two reading lessons with the training mode during their task, as well as after their task (within design, order counterbalanced). Results from reading content tests indicated that many children had better reading content test scores and a higher BCI attention score when the NF was integrated into the reading task, than presented after the task. Limitations of the study were the short duration, lack of follow-up, the lack of a control group, and the lack of behavioral measures of attention. The use of an Emotiv headset required pre-calibration. However, this study shows that two sessions of NF training can be viable with children as young as 6 years old. This study provided a precedent for working with very young children (in the industrialized world), although only in two sessions, and reminded us for the need for pre, post, and follow-up behavioral measures.

Gevensleben et al. conducted a randomized controlled clinical study with 94 children (ages 8 to 12) with an ADHD diagnosis [10]. Children were randomly assigned to two groups: 36 sessions at a frequency of 2–3 week for 25 to 30 min of NF training or 36 sessions of computerized attention skills training game (active control). The NF group did 18 sessions of T/B training followed by positivity and negativity SCP training (counterbalanced blocks). Children were assessed by teachers and parents using ADHD surveys at pre-test, after first NF block, and at post-test points. Results

[4] https://www.emotiv.com

showed that change scores for the NF group showed a significant improvement (at the level of $p < .05$ or $p < .01$) with medium effect size for subscales related to inattention and hyperactivity (teachers and parents) and aggressive behaviors (parents). There were no differences in the NF group between the order of T/B and SCP blocks. In a follow-up study of 66 children, the intervention group maintained gains seen at post-test. This research demonstrated a rigorous assessment methodology, which informed our study design.

In summary, previous studies have shown viability and some positive evidence of lasting effects of NF training using various protocols for anxiety and attention for children aged 6 and older in labs, homes, and schools situated in the developed world. The NeuroSky headset has been used in successful studies. No studies with more than two sessions have been done with young children (e.g., aged 5 to 6). No studies have taken place in the developing world. In general, the design of a rigorous field study should address the following methodological challenges if possible:

- Make claims relative to sample size;
- Avoid contamination between groups where possible (e.g., avoid both groups in same space);
- Including an active or waitlist control group to account for maturation and learning effects;
- Use a protocol with two different frequency bands (e.g., anxiety (A/T) and attention (beta frequencies));
- Use a protocol with sufficient number, duration, and frequency of training sessions (e.g., 24 sessions @ 3 times/week);
- Acknowledge bias in non-blind parent and/or teacher ratings;
- Include measures of transfer outside of gameplay context;
- Include measures at follow-up test point to look for maintenance;
- Expect variability between sessions rather than a learning curve.

3 The Mind-Full system

In this section, we provide the context for our research project and present an overview of our NF BCI system to set the stage for our evaluation.

3.1 Context

The Mind-Full research project began after the principal investigator, Antle, traveled to Nepal for the ACE computer conference and visited the Nepal House Kaski (NHK) School, a school for girls living in poverty in Pokhara, Nepal. The organization that operates the school is run by local staff and a Canadian non-government organization (NGO) called the Nepal House Society.[5] The staff work with children at the NHK School and several of the local orphanages. Many of the children who attend the school or live in these orphanages have suffered severe complex trauma as a result of poverty, political violence, and/or domestic violence. The counselors and teachers at the school are being trained by western psychotherapists. One element of this training involves working to improve the children's ability to self-regulate when anxious (calm down/relax) and focus (pay attention). The therapists are teaching the counselors to use validated trauma therapy methods, including mindfulness, breathing, and yoga practices, in order to improve educational outcomes in the school. When the counselors at the school began to teach the children self-regulation techniques, they found it difficult. In part, this was because many of the children had been severely traumatized, which shuts down their pre-frontal cortex, an area of the brain responsible for executive functioning. In addition, the counselors were having difficulty determining if and when the children had learned the practices since anxiety and attention are not always observable through behavior. Lastly, the counselors did not have a way to monitor the children's progress learning self-regulation over time.

Our target audience was non-English speaking children living in poverty, who had suffered multiple traumas and who had never used a computer. Ages ranged from 5 to 11; most of the children were 7 to 8 years old. Compared to children in industrialized countries, these children's development was often slower, making them seem younger than they were. For example, most of the children could not yet read or write. In this section, we briefly describe our EEG-based Mind-Full NF training system for anxiety and attention (Fig. 1a), which was created for this target population. We also describe a secondary networked application, called Mind-View, that runs on another tablet that enabled counselors to monitor the children's brainwaves using the eSense meditation (*R*) and attention (*A*) indices during gameplay and calibrate Mind-Full to each child's brainwave characteristics, customizing difficulty in real time (Fig. 1b).

3.2 Guiding design principles

As described in detail in [3], our main principle was to design the NF games based on familiar activities from the children's everyday lives which would cue or encourage a child to perform physical actions that would shift the child's physiology and corresponding brainwave state to help teach them how to self-regulate around relaxation/anxiety and focus/attention. In addition to visual cues about what to do to self-regulate, we provided visual feedback when they had achieved specific brainwave states (using game goals). Each goal involved

[5] www.nepalhousesociety.org

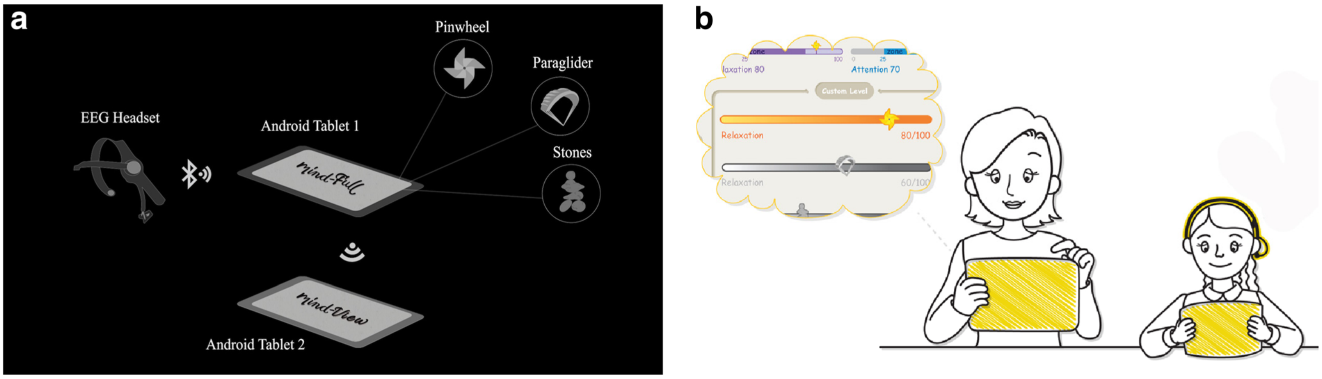

Fig. 1 **a** Mind-Full and Mind-View system diagram. **b** Mind-View (left) and Mind-Full (right) scenarios

reaching a threshold brainwave state and holding it for a set amount of time (which could be adjusted if needed). For example, by blowing on a static pinwheel image displayed on the tablet, a child would likely relax a little, which was sensed by the EEG headset (an enhanced alpha wave state) and sent to the tablet which responded by animating the pinwheel. A second design principle was that the entire UI had to function so that a child could learn how to interact in a single session (5–10 min) with only minor coaching from the school counselors. This included being able to log in, play all of the three games (and switch between them), and understand their progress. A third principle related to calibration. Unlike most EEG applications, we could not calibrate each child's brainwave resting levels prior to gameplay because the children cannot relax or focus or even sit still! To solve this, we built a calibration application, which enabled us to adjust the game while a child was playing (described below). This allowed us to adapt the games to children's skill level in real time; our goal was for the children to learn to self-regulate and practice self-regulation rather than win. Other guidelines were more practical. We needed to build a robust (tablet not laptop), scalable, mobile system that could work without power or internet for extended periods.

3.3 System overview

Mind-Full is composed of modules including user management, user progress, user history, real-time calibration/customization, and three simple games. Each game is based on familiar, everyday activities and actions which, when learned, can elicit behaviors which in turn result in desired brain states related to relaxation or attention. The simple, robust NeuroSky headset monitors the child's brainwave activity and uses eSense pre-processed data outputs for either relaxation (R) or attention (A) to control visual elements of simple, culturally relevant computer games that run on the tablet. This provides visual feedback to the children about their relaxation state (by monitoring their alpha/theta waves) or attentive state (beta waves), depending on the game, and also provides guidance and motivation to change their brain states. Further details of our system are available in [2, 3]. More information about the key features of the Mind-Full system is available through a short video presentation.[6]

3.4 Games

Mind-Full was composed of three games based on the counselors' goals for the girls. The Pinwheel game was an introductory relaxation game (Fig. 2a). The goal was for a child to achieve a relaxed or calm brain state. It functioned as a warm-up exercise and had to be played every session. The game began with an animation of a girl blowing softly on the pinwheel. The pinwheel spun. The girl moved away and "handed" the pinwheel out towards the user. To play, the child had to achieve a relaxed brain state to cause the pinwheel to spin. If they maintained a relaxed state above the specific threshold R value (default $R > 40$) for the specific hold time (default 5 s), they got a token added to the jar (on the left in Fig. 2a). The R and hold time thresholds could be adjusted by the counselor using the calibration device (described below). The child had to fill the jar with five tokens in order to unlock the other two games. Focusing on breathing was a good way to begin learning how to relax; however, breathing was not required to achieve the desired state or to get the pinwheel to spin.

The second game, called Paraglider, was a sustained relaxation game (Fig. 2b). The goal was for a child to achieve and sustain a relaxed or calm brain state. The school sits at the foot of a large mountain range. It is an ecotourism hub and tourists often paraglide from the hills. On any given day, one can see hundreds of paragliders descending to the valley. Children watch paragliders land or swirl back upwards on thermals and build their own toy paragliders from found materials. The goal of this game was to help the paraglider reach the bottom of the mountain. To do this, the child had to achieve and sustain a relaxed state above a specific

[6] https://www.youtube.com/watch?v=2TbLI6mga38&t=29s

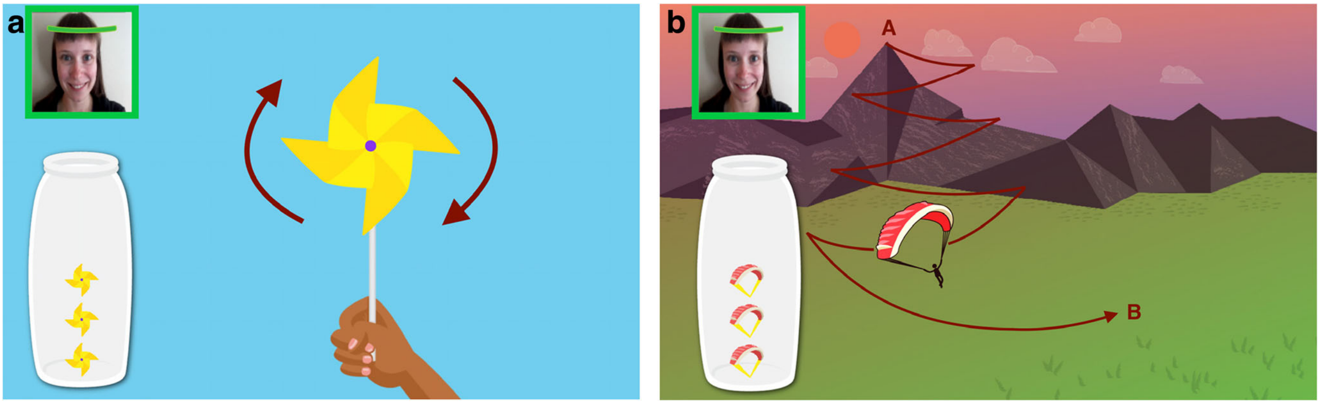

Fig. 2 **a** Pinwheel (relaxation) game. **b** Paraglider (sustained relaxation) game

threshold R value (default $R > 40$) for a specific hold time (default 11 s). If the child's R value fell below the R threshold, then a thermal (gust of wind) pushed the paraglider a little ways back up the mountain. Once the threshold R value was met again, the paraglider continued its descent. The animation for this game showed a girl lying down and relaxing while she watched the paragliders drift down the mountain (Fig. 2b). She moved out of the screen and a paraglider jumped off the hilltop. Reminding the child about relaxing their body and watching paragliders could be helpful to assist them in sustaining a relaxed state. Each successful landing earned a paraglider token in the jar. Five tokens filled the jar to mark game progress.

The third game, called Stones, was a sustained (visual) attention game (Fig. 3a). The goal was for a child to sustain visual attention. In the area along the river where many of the children live, some of the adults earn money by collecting stones from the nearby river. They load stones into wicker baskets that they carry on their backs up to the roadside where they dump them. The stones are picked up for construction. In addition, many of the children's games involve playing with or piling up stones. The child had to focus and sustain their attentive state above the specific threshold A value (default $A > 40$) for the specified hold time (default 8 s) for each of five stones to move each from a basket to build a stone pile. As long as their attention level remained above the threshold A value, then the stone would move across the screen and place itself onto the stone stack. If the child lost her focus, the stone would fall and roll back into the basket (Fig. 3a). The child did not control the lifting or the placing of the stone, just its horizontal traversal across the screen. The animation for the stone game showed a girl turning her head as she watched the stone as it moved across the screen. By focusing her attention on the stone as it traveled, she could learn to focus her attention. This game was a bit of a stretch from reality but was nonetheless based on a familiar activity for the children. We also designed it so that each stone pile was slightly different, adding a fun element to achieving each stack. Five stones were required to make a stack, which earns one token. Five tokens filled a jar marking progress in the game. A user's game progress can be viewed from the progress screen at any time (Fig. 3b).

3.5 Technical implementation

Mind-Full is composed of the NeuroSky MindWave headset and two Samsung Galaxy 10.1 touch tablets that run the

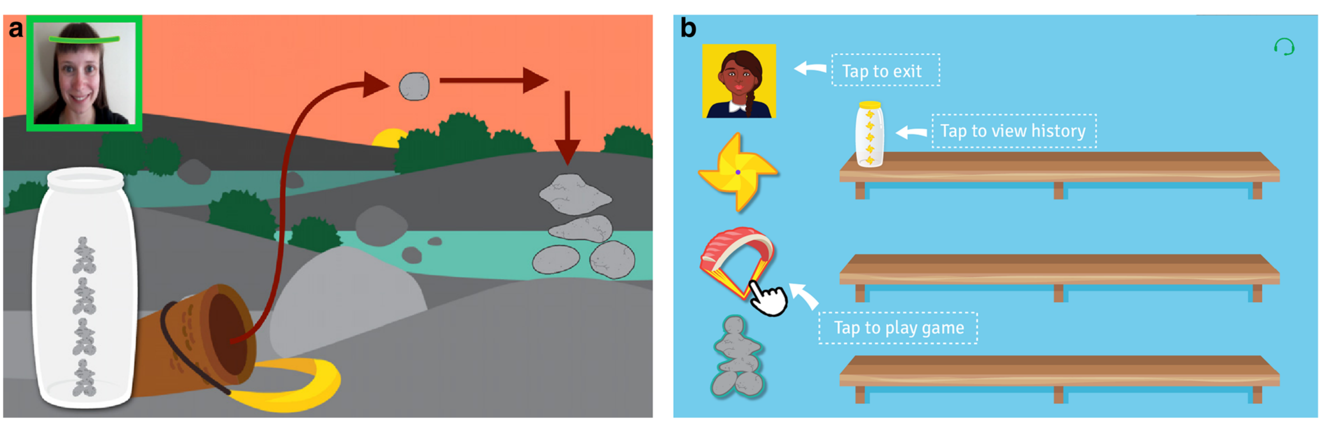

Fig. 3 **a** Stones (sustained attention). **b** Game progress screen with one jar of tokens for Pinwheel game

Android operating system (OS) and Unity 3D (a mobile game development engine). The *Games* tablet was connected to the headset using wireless Bluetooth. This tablet runs the user modules (login, management, and progress) and the three games. The *Calibrate* tablet, which was optional, was connected to the Games tablet using WiFi direct (rather than the Internet for stability). The main program was developed in Unity. The headset connected to the Android OS and Unity using a custom Java bridge program we wrote. This program polled the headset 60 times a second for EEG power spectrum data in all bands, a signal quality data stream and eSense meditation (relaxation) and attention data. Signal quality was used within games to ensure consistent feedback and was visually displayed as a green, yellow, or red frame and headband on the user's photo on all screens (e.g., Fig. 2a). When signal quality was low, the game program held the current state until it improved so that progress was not lost.

Each game had a time and eSense relaxation (*R*) or attention (*A*) threshold which was set to default values, but could be changed using the Calibrate (and customization) application (Fig. 4a). The threshold determined if the game responded visually (e.g., pinwheel spins, paraglider descends, stones stack). When the threshold was met for the amount of time specified, a single progress token was earned for that game. This process happened once per frame at 60 frames per second, so there were about 16.7 ms between updates. Every time a token was earned, a save was triggered to write the current player status to non-volatile storage so that in the event of an accidental exit or power/battery issue, game progress was not lost. When five tokens were earned, the jar was complete and the game reset. Two animations (pinwheel spinning, stones falling down, or stacking) were physics based for realism. The paraglider animation used 120 distinct frames that were sequentially swapped in place of the currently rendered frame while at the same time moving along a predefined motion path based on the eSense threshold value. The paraglider moved downwards when eSense was above the threshold and upwards when not.

Unity provided a data store for saving each user's sessions. Session data consisted of information such as the session date/time, session number, time and threshold values, and number of tokens achieved for each game. Every time a new session started, that player's data was pulled from storage to ensure previous values were used for time and relaxation or attention values. During gameplay, data was saved each time a token was earned or when the game was exited (thus ending the session). All logged data were stored in spreadsheets which were synced to a secure server in Canada at the end of each day by counselors.

4 Field study methodology

We conducted a between group, repeated measures (2 × 3), field experiment at the NHK school with 21 girls. Two matched groups of girls were randomly assigned to either use Mind-Full (the intervention) first, or second (waitlist control group). The girls used Mind-Full in about 24 × 15 min one-on-one sessions with their counselors three to four times per week over two 6-week periods. The group of girls who used the Mind-Full intervention for the first 6-week period is our intervention group. The waitlist control group enables us to account for maturation or other learning effects that may have also led to improved behavior over the course of the study. For ethical reasons, the waitlist control group also completed the intervention in a subsequent 6-week period after a short break for religious celebrations. An active control group with an alternative (placebo) activity is not viable for ethical reasons in a population with severe trauma and a situation with such limited resources. All the participants were assessed using measures of behavior (details below) at pre-test, post-test, and follow-up test points, where test points are defined relative to the intervention group (i.e., post-test was after the

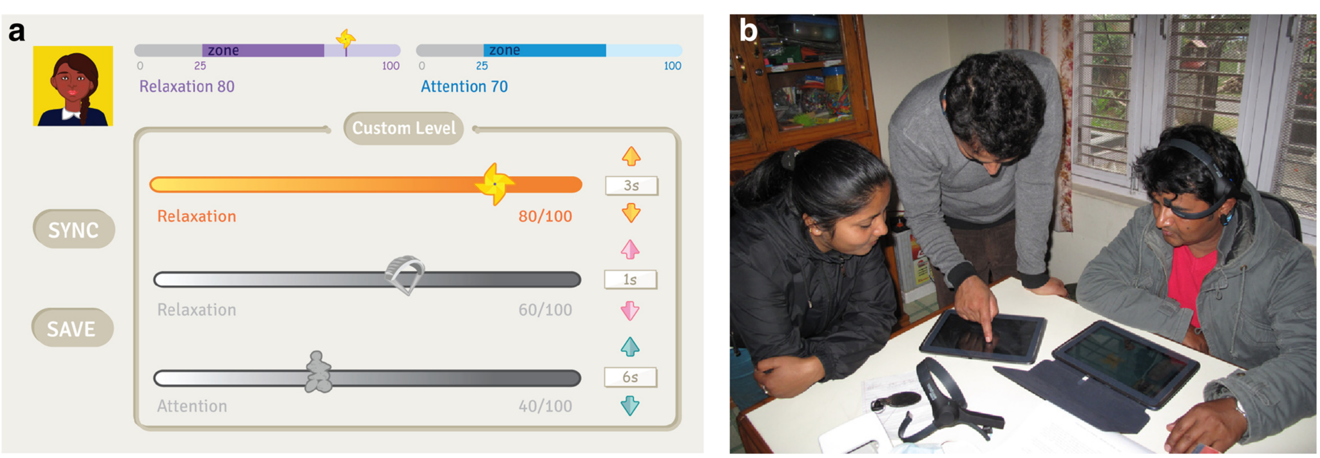

Fig. 4 **a** Mind-View calibration and customization screen. **b** Head counselor training other two counselors at NHK school

intervention group finished their intervention but before the waitlist control group had started; follow-up was after the waitlist control group finished their intervention, providing a follow-up test point for the intervention group).

4.1 Research questions and hypotheses

Our overarching research question is: Can a NF BCI help children living in poverty learn to self-regulate anxiety and attention? We investigate this question using a mixed method experimental design with a waitlist control group. The intervention was comprised of an average of 24 × 15 min one-on-one sessions using Mind-Full, facilitated by each child's school counselor. We looked at the impact of the intervention on children's ability to self-regulate anxiety and attention. We conceptualized self-regulation of anxiety as the ability to calm down in a stressful situation. We conceptualized self-regulation of attention as the ability to focus attention in a variety of situations. We did not rely on brain-based measures of self-regulation during gameplay as evidence of impact, because previous work has shown they are not reliable [22] and we think that self-regulation skills learned through Mind-Full games must transfer to everyday life to be effective and impact children's education. Thus, our primary outcome measures of anxiety and attention were observable behaviors measured through surveys and interviews. These instruments measured children's ability to transfer their skills self-regulating anxiety and attention learned in games to everyday life. The setting of our study in the field with traumatized children precludes neurological measures or specific transfer tests (e.g., of executive functioning), which have been developed for different populations of children and would be extremely difficult to administer reliability with this population. We took measurements at pre-test, post-test, and follow-up points in the study. We supplemented these measures with process measures including session and game performance measures calculated from system log files to ensure that children were successfully able to complete the intervention, that is, that the intervention was viable. However, it is important not to conflate children's performance playing Mind-Full games with their ability to effectively transfer and maintain their self-regulation skills in everyday life. Our research questions concern how we examined viability, effective transfer, and maintenance in our analysis. We also explored how the system supported counselors and teachers to help children. For each research question, we list a number of hypotheses. However, it is important to consider that in our study there are many factors beyond our control in the field, and in particular at a school for children living in poverty. For example, during week 5, as a result of one girl having difficulty seeing the screen, all the girls were all assessed for eye and ear issues. Three girls were given glasses. In addition, a western researcher not related to our study arrived and worked with teachers during the latter part of the first 6-week period to improve control in the classroom. Events in the children's home lives likely also impacted results. For these reasons, we consider our hypotheses as expectations and interpret our findings taking into consideration any factors of which we were aware and which could not be controlled in a field study.

For any intervention to be effective, it must first be viable. For the Mind-Full intervention to be viable, children must be able to use the system to complete all their sessions. During sessions, they must be able to successfully interact with the three games by changing their brain states (i.e., reduce anxiety and focus attention) to control effects in the games and receive tokens. Given the ongoing challenges in these children's lives, we would expect variable performance in NF games over the course of an intervention [14]. However, we hypothesize that with counselors' encouragement and flexible threshold levels, children will be able to complete the games in most sessions. For these reasons, we do not look at improvement over the course of sessions but rather if children can complete the intervention. Our first research question and related hypotheses are then as follows:

RQ1. *Is Mind-Full a **viable** NF BCI intervention that can help children successfully learn to self-regulate anxiety and attention during gameplay?*

4.1.1 Hypotheses: Viability

H1. *Children in both groups will be able to complete the intervention (20–24 sessions).*
H2. *Children in both groups will be able to successfully self-regulate anxiety using Mind-Full over the course of their intervention.*
H3. *Children in both groups will be able to successfully self-regulate attention using Mind-Full over the course of their intervention.*

While satisfying these conditions ensures viability, we must look further and investigate transfer. For Mind-Full to be an effective intervention for children, they must not only be able to use the system but they must be able to transfer their newly learned self-regulation skills into everyday life. Our second research question then is as follows:

RQ2. Can *children **transfer** their ability to self-regulate anxiety and attention learned during their intervention using Mind-Full to other contexts at school?*

Our research design enables us to compare between intervention and control groups at pre-test and post-test on behavioral measures of ability to self-regulate anxiety and attention in different contexts (e.g., classroom, therapy session, playground). Although traditional measures of transfer could include tests of salivary cortisol (anxiety) or executive functioning (e.g., Stroop test for selective attention), these tests have not been developed for our target population of children and difficult to administer reliably. At pre-test, we would expect the two groups to be equivalent on measures of self-regulation of anxiety and attention. If transfer occurs, then at post-test, we would expect a between group difference in which the intervention group is better at self-regulating than the control group in different contexts (e.g., classroom, playground). We can also look within each group to explore pre-post change after completing the intervention as a secondary indication of change in ability to self-regulate. For the intervention group, we look at within group change from pre-test to post-test and for the waitlist control group, we look at within group change from post-test to follow-up.

4.1.2 Hypotheses: Effectiveness & Transfer

Group equivalence at pre-test

H4. *There is no significant difference between the intervention and waitlist control groups on the behavioral measures of ability to self-regulate* ***anxiety*** *at pre-test.*

H5. *There is no significant difference between the intervention and waitlist control groups on the behavioral measures of ability to self-regulate* ***attention*** *at pre-test.*

Between-group effects at post-test

H6. *There is a significant difference between the intervention and waitlist control groups on the behavioral measures of ability to self-regulate* ***anxiety*** *at post-test.*

H7. *There is a significant difference between the intervention and waitlist control groups on the behavioral measures of ability to self-regulate* ***attention*** *at post-test.*

Within-group effects after Mind-Full intervention

H8. *There is a significant improvement within the intervention group on the behavioral measures of ability to self-regulate* ***anxiety*** *from pre-test to post-test.*

H9. *There is a significant improvement within the intervention group on the behavioral measures of ability to self-regulate* ***attention*** *from pre-test to post-test.*

H10. *There is a significant improvement within the waitlist group on the behavioral measures of ability to self-regulate* ***anxiety*** *from post-test to follow-up test.*

H11. *There is a significant improvement within the waitlist group on the behavioral measures of ability to self-regulate* ***attention*** *from post-test to follow-up test.*

For the Mind-Full intervention to be effective, any positive transfer effects must be maintained or last over time. Our study design enabled us to assess the intervention group at a follow-up point. The follow-up point was after the waitlist group had finished their Mind-Full intervention. In this study design, we do not have a follow-up point for the waitlist group.

Our third research question and hypothesis is then as follows:

RQ3. *Do children* ***maintain*** *their ability to self-regulate anxiety and attention over 2 months post-intervention?*

4.1.3 Hypotheses: Effectiveness & Maintenance

H12. *There is no significant difference between the intervention group's ratings on the behavioral measures of ability self-regulate* ***anxiety*** *between post and follow-up tests.*

H13. *There is no significant difference between the intervention group's ratings on the behavioral measures of ability to self-regulate* ***attention*** *between post and follow-up tests.*

Lastly, any intervention is only as good as the people who facilitate it. Our fourth research question is an exploratory question:

RQ4. *In what ways (if any) does the Mind-Full system help counselors and teachers help the children (learn to) self-regulate anxiety and attention?*

4.2 Site and participants

Twenty-two girls (aged 5–11) attend the NHK School. All had suffered trauma resulting from violence in home, substance abuse in home, neglect, and/or parental death. There were three classrooms in the school based on age and ability. Children participate in daily classroom work and weekly therapy sessions (30–60 min), which include therapeutic art and play therapy. The children speak the Nepali language, and a few of the older children can read and write and speak limited English. None of the children can read English fluently or have used a computer. The school employs four counselors, three teachers, and other support staff. The staff take an integrated approach and work with the children and their families to address issues. The staff were trained and are supervised by western therapists in trauma and other counseling practices. All parents gave consent for their children to participate in the study. The parents had all met at the school and gave verbal consent (in the form of a song in Nepali) after a demonstration by the counselors. The counselors had translated the consent script from English to Nepali, translated questions, and recorded responses in Sanskrit translated to English. The 22 girls were split into two groups (intervention/control). The teachers divided the girls into groups by equivalent pairs based on age, grade, temperament, and behavioral issues. Two girls dropped out of the intervention group because they left the school so data is not reported for them. One girl came to the school and was added to the waitlist group, so there is no pre-test information for her. The final number of participants was 21, 9 girls in the intervention groups (ages 5 to 11) and 12 girls in the waitlist group (ages 5 to 11).

4.3 Procedure

In the 10 days before the study, co-author Leslie Chesick worked with all the teachers and counselors to teach them how to use Mind-Full. All of the counselors spoke English. Two of the counselors who were most fluent translated for the others. Chesick took the approach of teaching one of the senior counselors who in turn taught everyone else in order to increase the capacity for NHK staff to work with the children and reduce dependence on non-locals (Fig. 4b). Researcher Alissa Antle arrived a week later and worked to iron out technical issues and to re-develop the survey behavioral assessment instrument in conjunction with Chesick and NHK staff. A draft of the survey was developed in advance based on the counselor's goals for the children, which had been identified during the previous visit and through the system development phase, remotely from Canada. The goals were for the children to be able to calm themselves and to be able to focus their attention in a variety of situations. Remote communication was through email and Skype. Once Antle had arrived, she and Chesick met with the counselors and teachers to discuss and tune the survey. This process helped to align all the school staff to the goals and processes of the project. The final survey questions and scale are described below. Antle and Chesick then created a survey administration manual that included sections on how to identify behaviors rather than events, opinions or inferring the girls' feelings; how to focus on the child's behaviors over the last month; how to check for consistency between questions for the same construct; how to resolve differences between counselors and teachers (e.g., by asking for specific examples); a list of words that were difficult to translate (e.g., proudy in Nepali was translated to bossy in English); and how the assessment facilitator could use prompts to get more details using examples. The administration of the surveys was done mainly in English with counselors translating from written Sanskrit notes and verbal Nepali discussions into written English.

The study with the children began with demonstrations for all the girls (split by class) of how to play all three games, demonstrated by a 14-year-old boy from Canada. One of the counselors translated from English into Nepali. Using a young teen was done in the hopes of reducing researcher power effects by using someone closer to the children's own age, who had developed proficiency using Mind-Full. The demonstration also enabled us to get verbal assent from the girls who would not have been able to understand what we were asking them without a demonstration.

All of the girls were assessed using the survey at the beginning of the study (pre-test). Each assessment was facilitated by Chesick and involved the child's teacher with input from their counselor, depending on the questions. Chesick's role was to facilitate and ensure compliance to the administration manual but not to assess the children herself. The scores for each question were chosen by each child's teacher and/or counselor since they were most familiar with the child's regular behaviors over the last month.

During the first week, the intervention group began to use Mind-Full in addition to current (non-system) instruction in breathing practices and yoga. Each session involved one child using Mind-Full supervised by their counselor (Fig. 5a) for about 10 min, playing all three

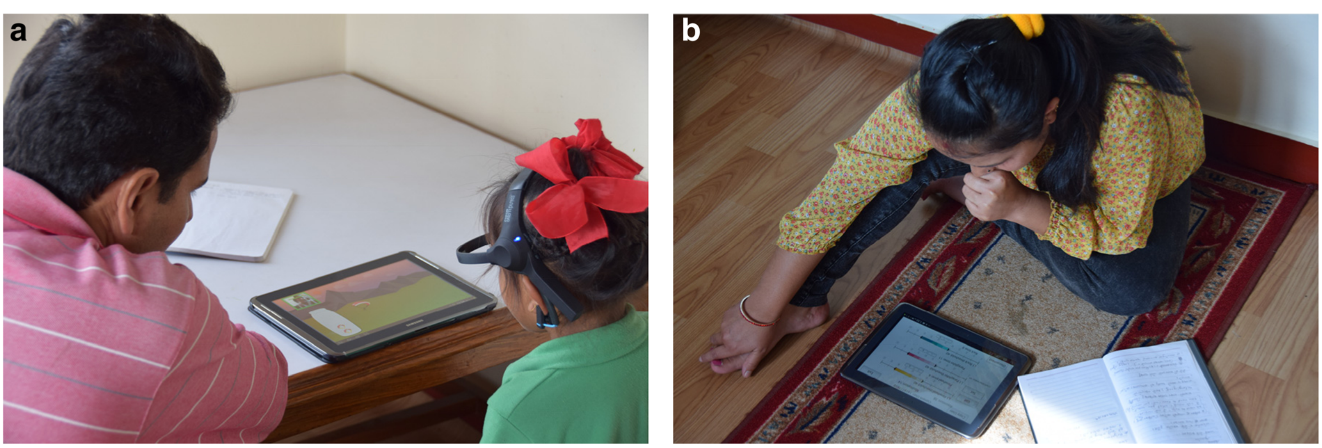

Fig. 5 **a** Session setting with counselor coaching child playing Paraglider game. **b** Counseling using Mind-View during session

games. For efficiency, we deployed two identical systems. Sessions took place in small, quiet rooms with the counselor and child seated at a table. Each session began with the headset being put on and connected to the games. The child's counselor used the Calibration application to view each child's *R* and *A* values during each session and adjust downwards or upwards as needed (Fig. 5b). Each child completed sessions three to four times a week for 6 weeks. There is no empirical evidence concerning the number of sessions required to obtain training affect for children [10]. The study length was based on successful mindfulness interventions for children (e.g., [43]). The session frequency (three to four times a week) meets or exceeds those used in other studies (e.g., [10, 25]) and mirrors that of studies with adults such as Kabat-Zinn's Mindfulness Stress Reduction Program. The session duration of 10 min was determined based on the resources and scheduling available at the school as well as our estimates of how long the children might be able to actively participate in a single session. The duration was shorter than most interventions, which are typically 45 to 50 min with 20 to 30 min of gameplay time. However, it is unlikely that these children could sit through sessions of that length. In addition, the increased weekly frequency may compensate for the shorter session time. The waitlist control group only received instruction in breathing practices and yoga during the pre-post period.

At the end of the 6-week intervention (post-test), all of the girls were re-assessed. The assessment involved the same survey facilitated by a different registered psychologist. She was a volunteer with the Nepal House Society and was trained by Chesick using the administration manual developed at pre-test. She worked with the school staff to administer the survey in the same manner that Chesick had in the pre-test. After a 2-week break for religious purposes, the waitlist control also did the intervention following the same protocol as the intervention group. At the completion of the waitlist groups' sessions, all the children were again assessed (follow-up test). The follow-up assessment was facilitated by a different registered psychology who was volunteering, again trained by Chesick. In summary, the survey behavioral assessment was administered for *all* the girls in both groups before the study started (pre-test); after the first group had completed the intervention (post-test); and after the waitlist group had completed the intervention (follow-up test) using the same protocol and survey instrument.

4.4 Data collection and analysis

In summary, we collected and analyzed quantitative and qualitative survey data related to observable behaviors of children's ability to self-regulate anxiety and attention at the school at pre-test, post-test, and follow-up test assessment points. Authors Antle and Chesick also conducted three focus groups with the counselors and teachers about the intervention group within the first three weeks of the study. We conducted email interviews at the post-test and follow-up test points and collected observational data during a subset of sessions when the Antle and Chesick were on site between pre-test and post-test points. Through email, we collected written reports from counselors and from the teachers over the course of the study. The teachers interviewed all the children after they had completed their Mind-Full intervention and recorded responses in writing, which were translated by the counselors and emailed to us. At the end of each day, all the log files from that day's sessions on both tablets were remotely uploaded using custom software to a secure server in Canada.

4.4.1 Mind-Full system logs (quantitative)

Data collection with log files We collected system log data of individual sessions by uploading three kinds of data files to a secure server in Canada at the end of each day using Android's Drive Autosync[7] utility. We also backed up each tablet every week using Titanium Backup.[8] The first data file contained a log of everything that happened on the tablet during the day. We collected a second file with brainwave data. However, because of processing and storage limitations of tablets and challenges with bandwidth, we could not sample this data at the rate necessary to conduct analysis with it (e.g., 512 Hz). The third file type was individual session records of each session tagged by participant ID, session number, and date. These included start and end times for the session, each game, number of tokens achieved in each game, threshold values for *R/A* and hold time, and signal quality information.

Signal quality analysis We used log files to first to assess the extent of poor signal quality in sessions and determine if the distribution was random across groups and sessions or not.

Calculation and analysis of viability variables We then used our log data to address intervention viability (RQ1) and hypotheses H1–H3 as shown in Table 2. We used the individual session files to determine for each child the total number of sessions completed (SC) and the average amount of gameplay within sessions (GP). We used *t* tests to compare if the number of sessions varied between groups for all each game. Before proceeding with the analysis for percentage of time above the *R/A* threshold per game (PAT), we verified that variations in the number of sessions completed would not affect the analysis. Partial correlations were computed between the number of sessions completed and PAT values. We also

[7] https://play.google.com/store/apps/details?id=com.ttxapps.drivesync&hl=en
[8] http://www.titaniumtrack.com/titanium-backup.html

Table 2 Viability research question (RQ1): calculated variables, operational definitions, and success targets

	Calculated variables	Operational definition/target for success
H1	Complete intervention	Average number of sessions completed/SC ≥ 22 sessions
		Average duration of gameplay in sessions/GP ≥ 10 min
H2	SR of anxiety in Pinwheel + Paraglider	Percentage of time above relaxation threshold/PAT ≥ 70%
H3	SR of attention in Stones	Percentage of time above attention threshold/PAT ≥ 70%

examined the distributions of PAT for each game for the existence of outliers. Data were considered outliers if they had an absolute *z*-score greater than 3.5. We then examined the percentage of time above the *R*/*A* threshold (PAT) per game. We looked at PAT values for only the first three sessions to ensure they were not atypical due to children is focusing on learning how to use the system, which makes it difficult to self-regulate. We looked at PAT values for only the last three sessions to ensure they were not atypical since previous studies have shown that children become disengaged at the end of a NF intervention (e.g., [22]). We also looked at PAT values averaged across all sessions. We set defined success as PAT scores over 70%, meaning that children's brain states were about threshold 70% of the time. This was based on findings that children's performance often deteriorated for the last 75% of individual sessions [20].

Threshold *R*/*A* and hold time values analysis We were also able to extract the threshold *R*/*A* and hold time values for each game in each session. The default threshold values were 40 for all games but counselors could use the calibrate application to reduce or increase these values at any time. As a validity check, we examined these threshold values to ensure that they were within a range of expected values as suggested by NeuroSky (30–100). If a counselor set these values consistently below 30, it would indicate that children could not self-regulate effectively. We also looked at these values across sessions to see if there were patterns, which might indicate improvement or learning curve, although we did not expect to see this pattern due to varying levels of arousal caused by children's day to day experiences (as discussed in Janssen et al. [20]). We also recorded the threshold hold times, that is, the time required to hold a *R*/*A* threshold value to gain a token, for similar reasons. If a counselor set hold times too low (e.g., Pinwheel 5-s hold time reduced by more than 33%), then the hold time is not only very short, indicating poor self-regulation duration, but we reach the limit of headset precision, which is based on a 5-s moving average.

4.4.2 Behavioral assessment survey (quantitative and qualitative)

Data collection Three identical behavioral assessment surveys, with open and closed questions, were administered (1) prior to the study (pre-test), (2) after the intervention group finished their 6 weeks of sessions (post-test), and (3) after waitlist control group completed their intervention, 2 months after the post-test point (follow-up test). The survey data was used to address research questions related to effectiveness of transfer of self-regulation from gameplay into everyday life and maintenance of these skills over time (RQ2 and RQ3). The 2-month duration was due to the time taken to do the post assessment as well as a break after the post-test due to religious holidays. The assessment instrument was developed by Antle, Chesick, the counselors, and a teacher from the school. The goal of the assessment was to determine if the children had met the goals for the intervention, which had been identified by the counselors in the system development phase. Developing a new assessment instrument for this cultural context is in line with recommendations to avoid ethnocentric measures when working in different cultures [41]. The final survey instrument contained two open questions, five closed statements for the construct *Calm*, three closed statements for the construct *Attention*, and space for comments. The open questions were designed to identify each girl's main issues and learning disabilities. The ratings and comments were designed to assess each girl's ability to self-regulate anxiety (i.e., calm themselves) and focus or pay attention in and outside the classroom. We did not use existing validated survey instruments (e.g., BASC-3 attention and anxiety subscales) because they are not culturally or contextually appropriate to our situation or intervention goals. In addition, the number of questions per subscale would be prohibitive to administer with the resources and training level of staff at the school. We conducted a reliability analysis of our calm and attention measures as detailed below.

The behavioral assessment survey instrument included two open questions about main issues and learning disabilities:

O1. What are the main behavioral issues with this child in the classroom and at school?
O2. Do you think this child has a learning disability? If so, explain why you think this?

The next section used mixed measures to assess the construct of *Anxiety* (i.e., ability to self-regulate anxiety). Since anxiety is largely an invisible process, we used the proxy of "ability to calm down" which is observable. We call this measure *Calm*.[9] There were five closed statements with a 5-point interval rating system (from 0 to 4) in which the staff rated the child's ability to calm themselves in a variety of contexts. The rating section was followed by an open comment field which was used to provide additional information. The statements covered contexts including the classroom, playground, and therapy sessions. The statements were as follows:

C1. Child can calm themselves eventually when they are upset.
C2. Child can calmly talk about something upsetting that happened in the past.
C3. Child shows self-control in playground.
C4. Child can calm down when they have done/been told they have done something wrong.
C5. Child can stay calm when helping other children.

The rubric was based on the International Baccalaureate learner profile rubric for young children's social-emotional development and was worded so to represent equal intervals between each of the five categories (Table 3).

The last section used similar mixed measures to assess the construct of *Attention* (i.e., ability to focus attention). The closed statements, rated with a similar 5-point interval scale, were as follows:

A1. Child can pay attention in the classroom.
A2. Child can follow instructions.
A3. Child can get back on task when distracted.

The rating section was followed by an open comment field which was used to provide additional information about attention and focus.

Analysis We analyzed the quantitative ratings from the survey closed questions with descriptive statistics followed by inferential statistics using a 2 × 3 mixed ANOVA. The independent variables were group (intervention, control), which was our between factor, and assessment point (pre-test, post-test, follow-up test), which was our within factor. This analysis enabled us to address RQ2 transfer and RQ3 maintenance and H4–H11. We ran an analysis for each of the two dependent variables, which were the average ratings for *Calm* and *Attention*. If assumptions of equality of variances and sphericity were met, then we used a mixed ANOVA, otherwise the non-parametric equivalent. A statistical interaction occurs when the effect of one independent variable on the dependent variable changes depending on the level of another independent variable. In our design, we expect that the effect of assessment point (pre-test, post-test, follow-up test) on the values of the dependent variables will change depending on the group (intervention, control). Where we found this significant interaction effect, we look at simple main effects for each group separately to determine the effect of assessment period on *Calm* and *Attention* ratings. Where there is not a significant interaction effect but the main effect of assessment on ratings is significant, we look at effects independent of group. Positive changes in ratings over the period of the study independent of group may be attributable to maturation or other educational factors (e.g., counseling, classroom interventions). Negative changes in ratings over the period of the study may be attributable to negative community events (e.g., flooding, civil war). In addition, it is likely that individuals within both groups continue to be exposed to traumatic events during the course of the study.

[9] Note that now that we have defined our measures, we replace descriptive construct names from the initial statement of hypotheses (e.g., behavioral measures of ability to self-regulate anxiety) with our operationalized construct names (e.g., *Calm*).

Table 3 Five-point scale for *Calm*

4	Can do this mostly by themselves.
3	Can do this with some support/reminders.
2	Is developing the ability to do this with support.
1	Cannot do this unless they have a lot of support.
0	Cannot do this at all even with support.

We analyzed the translated written responses from the survey open questions using an iterative thematic analysis with two raters independently looking at the data [8]. The first question (O1), which identified the main behavioral challenges for each child, was used to look for between and within group effects. The second question (O2), which identified suspected learning disabilities, was analyzed primarily to identify individuals who may be outliers, and was used to inform our interpretation of results. The open questions for *Calm* and *Attention* were used to provide additional evidence that might help explain the closed question ratings for each construct.

4.4.3 On-site focus groups (qualitative)

Antle and Chesick conducted informal focus groups with staff after the first two sessions and a week later before each of them returned to Canada. Sessions were audiotaped and both researchers took notes. The primary purpose of these focus groups was to ensure children could use the system by identifying usability issues (RQ1 viability) and understand how the system might help the counselors and teachers to help the children (RQ4). No usability issues were identified. Due to the informal nature of the focus group, this data was treated as supplementary to the more rigorously administered surveys. Primarily, we looked for interesting or repeated comments related to the intervention.

4.4.4 Session observational notes (qualitative)

Antle observed, videotaped, and took notes during the first two sessions and another session a week later. The primary purpose of these observations was to address viability (RQ1) in terms of observing if the children could easily learn to use the system and self-regulate during gameplay. Antle also verified that the sessions were being run according to the session protocol. No usability issues were identified.

4.4.5 Counselor written reports and follow-up emails (qualitative)

Counselors sent periodic email updates on progress and issues throughout the study and a written report alongside the second assessment at the end of the first 6 weeks. At post and follow-up points, we asked the counselors and teachers if they had seen any evidence of changes in the children's ability to self-regulate. We asked them to explain anything they had noticed with behavioral examples to help reduce the bias of subjective opinions. Again, this data was treated as subjective and supplementary. Primarily, we looked for interesting or repeated comments about behaviors in counseling sessions, classes, or on the school grounds. We also asked about ways in which the system may have helped the counselors and teachers help the children (RQ4).

4.4.6 Teacher written reports (qualitative)

At the conclusion of the intervention, and again at the conclusion of the waitlist group intervention, the teachers were asked to fill out a report in which they were asked if they saw any changes in the girls' behavior, if they used words of images from Mind-Full in the class to coach the children and if they had any other comments. The teachers reported back to the counselors who translated into English and emailed the reports to us at post-test and follow-up test points. Since data was translated before we saw it, we treated it as tertiary, analyzed to look for behaviors related to self-regulation in class or on the school grounds, and then compared between and within groups.

4.4.7 Teacher written reports based on interviews with children (qualitative)

At the conclusion of the intervention, and again at the conclusion of the waitlist group intervention, the teachers were asked to interview the children with four questions. The teachers asked the children questions about their overall impression, likes, dislikes, if and how they thought Mind-Full was helping them, and any other comments they wanted to make. The teachers reported back to the counselors who translated into English and emailed the reports to us at post-test and follow-up test points. The children did not volunteer much data, which counselors reported is typical for them. Again due to reliability issues, this data was treated as tertiary and analyzed to identify interesting or common responses.

5 Results

We address our research questions in order using data from the system log files to address RQ1 *Viability* and behavioral assessment surveys to address RQ2 *Transfer* and RQ3 *Maintenance*. We used qualitative data from to supplement findings for RQ1–RQ3 and to address RQ4. We compare the two groups at post-test as well as looking at within group changes over the course of the study. In a stable environment with healthy children, we might expect children to improve from the intervention. We might also expect the waitlist control group to improve slightly over the first period to maturation or learning. However, these children live in poverty and trauma continues to happen individually and to their community. As a result, over time, we would expect children to exhibit worse behaviors, in particular if it is known that additional trauma occurred. However, for our intervention to be effective, it must counter ongoing negative events and we would need to see evidence that children's behaviors related to self-regulation improved over time. Therefore, if our intervention is effective, then we would expect the intervention group to improve across all qualitative and quantitative measures from pre-test to post-test and the control group to deteriorate or possibly remain stable due to counseling and other educational factors. From post-test to follow-up assessment points, we would expect the intervention group to deteriorate if traumatic events occur or at best case we would see no change (maintenance). Since the waitlist control group did the Mind-Full intervention in this time period, we would expect this group to improve across all qualitative and quantitative measures from post-test to follow-up test points. If we see this effect, we can only make weak claims these gains since we no longer have a control group, and thus cannot rule out that the effect was caused by maturation or other counseling and education factors.

5.1 Data pre-processing

5.1.1 EEG headset signal quality

Signal quality can be poor and variable for commercial-grade headsets. We had designed our application to accommodate poor and variable signal quality (see [3], for a full discussion). However, we used our log file data to explore the extent of the issue and conducted an analysis to determine if the distribution of poor signal quality was random. Descriptive statistics showed means and standard deviations for the three games for all participants as shown in Table 4. We did our analysis at the level of participant, because we noticed that headset reliability was often lower for specific children (e.g., perhaps due to forehead structure or shape). For each of the three games, we analyzed the distribution of good signal quality across sessions and participants. Shapiro Wilk tests for each game showed that the data was not normally distributed. We used a log transform but the Shapiro Wilk test still revealed a non-normal distribution. We then used the non-parametric Friedman test for each game. For Pinwheel the Friedman test revealed that there were no significant differences in the amount of good signal quality across participants or sessions ($\chi^2(21) = 18.22$, $p = 0.63$). For Paraglider, the Friedman test revealed that there were no significant differences in the amount of good signal quality across participants or sessions ($\chi^2(21) = 16.53$, $p = 0.73$). For Stones, the Friedman test revealed that there were no significant differences in the amount of good signal quality across participants or sessions ($\chi^2(21) = 27.85$, $p = 0.1$).

5.1.2 Behavioral assessment survey

Missing data and outliers In the survey data, we found that one participant in the intervention group completed the intervention and first two survey assessments but then left the school before the follow-up assessment. Since our expectation for the intervention outcomes is no change from assessment 2 to 3, we substituted session 2 values to session 3. A participant joined group 2 in time for the intervention and assessments 2 and 3. Since we assume a participant in group 2 will not change (other than through development) between assessment 1 and 2, we substitute session 2 values for missing session 1 values.

Before analyzing the survey data, we examined the distributions of each dependent measure for the existence of outliers. The dependent measures were divided into cells at the same level for which they were analyzed. Data were considered outliers if they had an absolute z-score greater than 3.5. No outliers were found.

Reliability We developed the survey instrument based on the specific goals of our field study, which were largely determined by the school staff. We did this to ensure that we did not bring our own cultural biases to the survey assessment criteria. However, this then resulted in a brand-new survey instrument, which may or may not be reliable. In order to validate our survey closed statements, we conducted a reliability analysis for each of the two constructs. We assessed the internal-consistency reliability of our five *Calm* questions. (C1–C5, above). As the Cronbach's alpha for the five items was strong ($\alpha = 0.844$), they were treated as a five-item scale in analysis. We assessed the internal-consistency reliability of our three *Attention* questions. (A1–A3, above). As the Cronbach's alpha for the five items was strong ($\alpha = 0.821$), they were treated as a three-item scale in analysis.

Table 4 Good signal quality mean and standard deviations across all participants and sessions

Game	Mean (%)	SD (%)
Pinwheel	73.5	27.0
Paraglider	88.0	17.8
Stones	86.9	19.8

5.2 Research question 1: viability

RQ1. *Is Mind-Full a **viable** NF BCI intervention that can help children successfully learn to self-regulate anxiety and attention during gameplay?*

H1. *Children in both groups will be able to complete the intervention.*

The average number of sessions completed is shown in Table 5 and exceeds our target of 22 sessions. Since children completed a variable number of sessions, three independent-measures t tests were conducted to verify that the number of sessions completed did not differ between the groups for any of the games. Results indicated that there were no significant differences between groups for any game (all $p > .08$).

The average session length of active gameplay in a session was 8:26 min (intervention group) and 9:26 min (waitlist group). We had designed the sessions to be about 15 min, which included putting the headset on the child, starting the application, connecting the headset, and adjusting if necessary. Longer sessions typically involved re-calibration or re-starting when the WiFi direct connection was lost, or headset Bluetooth connection was weak. We determined that some issues with connectivity were due to dirt on the girls' foreheads and also on the headset sensor.

In summary, we found evidence to support our first hypothesis (H1). On average, the children in the study completed the targeted number and length of sessions in the Mind-Full intervention.

Table 5 Average number and duration (length) of sessions completed for each game and group

Group	Number of sessions completed (SC)		Duration of gameplay in sessions (min) (GP)	
	Mean	SD	Mean	SD
Intervention	25.7	4.1	8:26	0:53
Waitlist	23.8	4.0	9:26	0:42

H2: *Children in both groups will be able to successfully self-regulate anxiety using Mind-Full over the course of their intervention.*

Partial correlation analysis between number of sessions completed per game and percentage of time above the *R*/*A* threshold per game (PAT) values showed that all correlations were not significant. No outliers were found. Because we found no outliers or correlations between sessions completed and our dependent measures, and no significant differences in the number of sessions completed between the groups, the PAT analyses proceeded without correcting for variations in the number of sessions that each child completed.

The percentage of time above relaxation threshold (PAT) in the Pinwheel (relax/calm) game was above 70% for both groups (see Table 6). The adjusted values for threshold *R* and hold time were not outside of expected ranges.

The percentage of time above relaxation threshold (PAT) in the Paraglider game was on average above 70% for both groups (see Table 7). The adjusted values for threshold *R* and hold time were not outside of expected ranges.

H3: *Children in both groups will be able to successfully self-regulate attention using Mind-Full over the course of their intervention.*

The percentage of time above relaxation threshold (PAT) in the Stones game was on average above 70% for both groups (see Table 8). The adjusted values for threshold *A* and hold time were not outside of expected ranges.

Qualitative finding Our qualitative findings mirror the quantitative results and provide behavioral examples. Based on observations we determined that all the girls in the intervention group were able to quickly understand how to play the Pinwheel game in the first session. The counselors gave them minimal instructions. For example, they said things like "take a deep breath to make the pinwheel spin" or "remember how the boy took deep breaths to make the pinwheel spin" (referring to the demonstration for the assent session). The children were also able to play Pinwheel successfully again in the second and ongoing sessions. With coaching, patience, and minor re-calibration (e.g., reduced the Stones hold time from 8 to 5 s per stone), all of the girls managed to complete one jar of five tokens for all three games in the first session.

Based on observational notes, feedback during the focus groups held after the first two sessions and in the second week, and ongoing emails, we were confident that all of the girls easily learned to use their bodies to calm or focus their minds in order to successfully play all three games. After the first session, all of the girls understood that they should take deep breaths to blow on the Pinwheel and make it spin. All of the girls were able to do this within the first 1 to 5 min of each session and attain a relaxed brain state so that *R* was above the default threshold of 40 for 5 s, five times to get five pinwheel tokens in their jar. In some sessions, this was more difficult but counselors encouraged them. None of the children required real-time calibration to make the Pinwheel game easier by lowering the relaxation threshold or decreasing the hold time. We found that all the girls understood how to play the Paraglider and Stones games, although all of the children found these games harder, which is expected since they require sustaining a relaxed or attentive state for longer. Most girls found either one of Paraglider or Stones harder and this tended to be consistent across sessions. Counselors reported that some of the girls needed minor re-calibration and encouragement to successfully achieve tokens, but these were not outside of expected ranges, as reported above.

Summary In summary, we found positive evidence for all of our hypotheses related to intervention *viability*. Quantitative results rating behaviors were backed up by qualitative observations, focus group and written report findings about behaviors.

Table 6 Percentage of time above threshold for Pinwheel game

Group	First 3 sessions (%)	Last 3 sessions (%)	All sessions (%)
Intervention	*M* = 71.5; SD = 12.3	*M* = 75.7; SD = 7.6	*M* = 73.6; SD = 10.1
Waitlist	*M* = 79.5; SD = 11.4	*M* = 77.2; SD = 11.9	*M* = 78.3; SD = 11.4

Table 7 Percentage of time above threshold for Paraglider (sustained relaxation) game

Group	First 3 sessions (%)	Last 3 sessions (%)	All sessions (%)
Intervention	*M* = 78.1; SD = 7.3	*M* = 87.7; SD = 10.4	*M* = 82.9; SD = 10
Waitlist	*M* = 83; SD = 8.4	*M* = 83.4; SD = 10.7	*M* = 83.2; SD = 9.4

Table 8 Percentage of time above threshold for Stones (sustained attention) game

Group	First 3 sessions (%)	Last 3 sessions (%)	All sessions (%)
Intervention	*M* = 75.4; SD = 12.3	*M* = 81.7; SD = 5.2	*M* = 78.6; SD = 9.7
Waitlist	*M* = 76.5; SD = 6.7	*M* = 67.0; SD = 13.0	*M* = 71.8; SD = 11.2

5.3 Effective transfer of self-regulation skills from gameplay into everyday behaviors

RQ2. *Can children **transfer** their ability to self-regulate anxiety and attention learned during their intervention using Mind-Full to other contexts at school?*

First, we must establish that the groups are equivalent at pre-test [H4, H5]. Then, we compare the behavioral assessment results between the two groups at post-test [H6, H7]. If we see the expected positive impact of Mind-Full for the intervention group compared to the control group, then we can also look at the change in behavioral assessment scores within the intervention group from pre-test to post-test [H8, H9] and within the waitlist group from post-test to follow-up test [H10, H11].

H4. *There is no significant difference **between** the intervention and waitlist control groups on Calm scores at pre-test.*

H5. *There is no significant difference **between** the intervention and waitlist control groups on Attention scores at pre-test.*

We report between group pre-test comparisons under H6 and H7 (below) since this comparison is part of the 2 × 3 mixed ANOVA results for *Calm* and *Attention*, respectively. In summary, there were no significant differences between groups on *Calm* or *Attention* scores at pre-test. The groups were equivalent.

H6. *There is a significant difference between the intervention and waitlist control groups on Calm scores at post-test.*

Descriptive statistics comparing *Calm* scores for each group at each assessment point are shown in Table 9. We ran a two-way mixed ANOVA on a sample of 21 participants to examine the effect of group and assessment period on average *Calm* score. As expected, results indicated a significant main effect for the assessment point ($F(2,19) = 34.26$, $p < .0001$) but not for group ($p = .454$). The assessment main effect was qualified by a significant interaction between the effects of group and assessment period on *Calm* score ($F(2,19) = 9.17$, $p = .001$) with a small to medium effect size (partial $\eta^2 = .325$).[10] This means that the *Calm* scores, which are a behavioral measure of children's ability to transfer self-regulation of anxiety training from the Mind-Full intervention into everyday life, were different at different assessment points for the intervention and waitlist control groups (Fig. 6a). In terms of group equivalence (H4), simple main effects analysis showed no difference ($p = .217$) at pre-test between the intervention group ($M = 1.5$, SD $= 0.8$) and waitlist control group ($M = 1.9$, SD $= 0.5$). As expected (H6), simple main effects analysis showed a significant effect of intervention on *Calm* at post-test $F(1,19) = 4.954$, $p = .038$) between intervention group ($M = 2.6$, SD $= 0.5$) and control group ($M = 2.0$, SD $= 0.6$).

[10] Cohen suggested that $d = 0.2$ be considered a "small" effect size, 0.5 represents a "medium" effect size, and 0.8 a "large" effect size (ADD REF).

Table 9 Descriptive statistics for *Calm* score

Dependent variable	Group	Mean	SD	Number
Average *Calm* score (pre-test)	1	1.5	.8	9
	2	1.9	.5	12
Average *Calm* score (post-test)	1	2.6	.5	9
	2	2.0	.6	12
Average *Calm* score (follow-up)	1	2.8	.2	9
	2	2.5	.4	12

H7: *There is a significant difference **between** the intervention and waitlist control groups on Attention scores at post-test.*

Descriptive statistics comparing *Attention* scores for each group at each assessment point are shown in Table 10. We ran a two-way mixed ANOVA on a sample of 21 participants to examine the effect of group and assessment period on average *Attention* score. As expected, results indicated a significant main effect for the assessment point ($F(2,19) = 39.39$, $p < .0001$) but not for group ($p = .784$). The assessment main effect was qualified by a significant interaction between the effects of group and assessment period on *Attention* score ($F(2,19) = 11.60$, $p < .0001$) with a small to medium effect size (partial $\eta^2 = .379$). This means that the *Attention* scores, which are a behavioral measure of children's ability to transfer self-regulation of attention training from the Mind-Full intervention into everyday life, were different at different assessment points for the intervention and waitlist control groups (Fig. 6b). In terms of group equivalence (H5), simple main effects analysis showed no difference ($p = .113$) at pre-test between the intervention group ($M = 1.3$, SD $= 0.7$) and control group ($M = 1.9$, SD $= 0.8$). Simple main effects analysis showed a trend towards a significance difference ($F(1,19) = 4.248$, $p = .053$) between the intervention group ($M = 2.7$, SD $= 0.5$) and control group ($M = 2.0$, SD $= 0.9$) at post-test.

H8: *There is a significant improvement **within** the intervention group on Calm scores from pre- to post-tests.*

As expected (H8), our simple main effects within group analysis showed that for the intervention group ($n = 9$), there was a significant increase ($p < .0001$) in *Calm* scores from pre-test ($M = 1.5$, SD $= 0.8$) to post-test ($M = 2.6$, SD $= 0.5$) assessments. For the waitlist group ($n = 12$), as expected, there was no significant change in *Calm* scores from pre-test ($M = 1.9$, SD $= 0.5$) to post-test ($M = 2.0$, SD $= 0.6$).

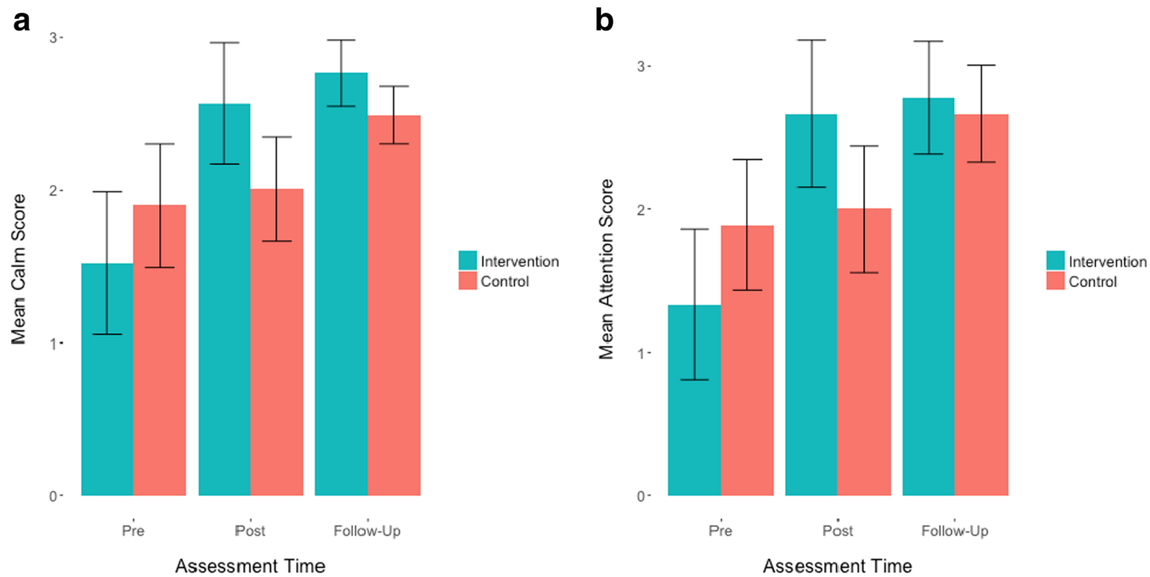

Fig. 6 Group and assessment time (period) effects on **a** mean *Calm* score and **b** mean *Attention* score (scales 0–4)

H9. *There is a significant improvement* ***within*** *the intervention group on Attention scores from pre- to post-tests.*

As expected (H9), our simple main effects within group analysis showed that for the intervention group there was a significant increase ($p < .0001$) in *Attention* scores between the pre-test ($M = 1.3$, SD 0.7) to post-test ($M = 2.7$, SD = 0.5) assessments. For the control group, there was no significant change in *Attention* scores from pre-test ($M = 1.9$, SD = 0.5) to post-test ($M = 2.0$, SD = 0.6).

H10. *There is a significant improvement* ***within*** *the waitlist group on Calm scores from post to follow-up tests.*

As expected (H10), our simple main effects within group analysis showed that for the waitlist group there was a significant increase ($p < .003$) in *Calm* scores from post-test ($M = 2.0$, SD = 0.6) to follow-up test ($M = 2.5$, SD = 0.4) after they did the intervention.

Table 10 Descriptive statistics for *Attention* score

Dependent variable	Group	Mean	SD	Number
Average *Attention* score (pre-test)	1	1.3	.7	9
	2	1.9	.8	12
Average *Attention* score (post-test)	1	2.7	.5	9
	2	2.0	.9	12
Average *Attention* score (follow-up)	1	2.8	.4	9
	2	2.7	.7	12

H11. *There is a significant improvement* ***within*** *the waitlist group on Attention scores from post to follow-up tests.*

As expected (H11), our simple main effects within group analysis showed that for the waitlist group there was a significant increase ($p < .001$) in *Attention* scores from post ($M = 2.0$, SD = 0.9) to follow-up test ($M = 2.7$, SD = 0.7) after they did the intervention.

Qualitative findings Thematic analysis of open question O1 in the survey: *What are the main behavioral issues with this child in the classroom and at school?* and the open questions for Calm and Attention for both groups resulted in the identification of common themes, which were then compared between and within groups at different test points. The girls were commonly described as 1. Hyperactive, 2. Having attention or concentration challenges and often losing items, 3. Unruly, 4. Angry and aggressive, and 5. Fearful, anxious, reserved, and exhibiting low self-esteem.

Overall, many of these behaviors that were described for each girl in the intervention group at pre-test assessment were somewhat or entirely reduced at post-test. For example, four (of nine) girls in the intervention group were reported to have poor attention and concentration at pre-test, and only three were reported at post-test. There were reports of unruly behavior, such as not listening to teachers, stealing and lying. These were reported for six girls at pre-test and no girls at post-test. One girl was reported to attend school irregularly but she came to school when they had sessions. Six girls were reported to display anger and aggressive behaviors at pre-test and only three sat post-test. Five girls at post-test were reported to have emotional issues, such as fear, being reserved with friends and having low self-esteem, which was reduced to four girls at post-test. These improvements were not mirrored in the control group findings. In the control group, most of the issues mentioned at pre-test remained at the same frequency at post-test.

In addition to negative behaviors, there were several positive comments from the teachers after the intervention at post-test. The girls were able to concentrate well, openly express themselves with friends, acted more disciplined in class and on the playground, followed instructions more effectively, and reduced the amount they hit other girls. One counselor reported that he was enjoying doing the tablet with the children and seeing some of the changes, "… more focused, more relaxed, happy to be part of doing the game, and happier in general … in their daily life from doing it."

In the teacher reports, one of the teachers reported that the children who had done the intervention were paying more attention in class. Another teacher reported, "There are different experiences with the different girls. For example, one girl often comes from home upset and it was difficult to make her focus before the tablet game but now when she comes with a problem of being upset, when coming from the tablet game (session) she gets calm and relaxed and able to concentrate; she is actually happier." Another teacher reported that she saw changes in many, but not all of the children. She reported that she saw changes in the children specifically on the playground where the children are not pushing each other as much. Also in her classroom, she saw changes with one child seeming more calm (not laughing in class as much); another child (who was very withdrawn previously) was more involved with friends and was talking more to teachers and friends; another child was not hitting and biting as before; another child used to be irritated by little things and was not showing so much irritation after the intervention. And lastly she reported that the children in her class were not complaining about the disruptive behavior of one child. She also found that "the girls who are working with the tablet are not as difficult to manage in the classroom and are working better on their homework and paying attention in class." Another teacher reported that she noticed changes in some of the girls (five of nine in intervention). The changes were different for each child but all the children were more calm. One child was talking more rather than remaining silent in class. One child was less disruptive in class and the teacher thought that the children were trying hard not to be a challenge. A teacher reported that one child's memory "seems to be improving." This teacher also thought that glasses and tablet are both making a difference for that child. "The glasses are helping her doing the tablet game (her eyes are not hurting her now)." Overall, reports documented positive changes for most of the children. We do not know if those children not mentioned in teacher reports did not show progress in the school environment.

When the children in the intervention group were asked if they thought the Mind-Full was helpful, their teachers reported, "Some girls have said that it's helpful for their study … to help them be quiet for a long time … helpful to help them to obey the teacher." Other comments included the children asking, "Is it the day for tablets today?" Another teacher reported that a child said, "It is easier to focus with the teachers (in class) and with their friends (they feel more calm)." She said that the children were more aware of their breathing." One child said, "I like the tablet and after it I feel comfortable and I can draw a picture." Another said, "I practice deep breathing at night."

5.4 Maintenance

RQ3. *Do children **maintain** their ability to self-regulate anxiety and attention over 2 months post-intervention?*

H12. *There is no significant difference **within** the intervention group on Calm scores between post and follow-up tests.*

Although it is common for intervention effects to taper off over the maintenance period, there was no significant change ($p = .523$) in *Calm* scores from post-test ($M = 2.6$, SD = 0.5) to follow-up test ($M = 2.8$, SD = 0.2), which means that intervention effects were maintained. Our analysis showed that for the waitlist group there was no significant increase ($p = 1.00$) in *Calm* scores between the pre-test ($M = 1.9$, SD = 0.5) and post-test ($M = 2.0$, SD = 0.6), meaning that there was no improvement due to maturation or learning. However, as expected there was a significant increase ($p = .003$) from post-test ($M = 2.0$, SD = 0.6) to follow-up test ($M = 2.5$, SD = 0.4) after the waitlist group had completed the Mind-Full intervention.

Although not part of our hypotheses, simple main effects results showed that at the follow-up test point, after the waitlist group completed the Mind-Full intervention, both groups improved. There was a trend ($p = .056$) for the intervention group to have higher *Calm* scores ($M = 2.8$, SD = 0.2) than the waitlist group ($M = 2.5$, SD = 0.4) at the follow-up test point.

H13. *There is no significant difference **between** the intervention group on Attention scores between post and follow-up tests.*

Although it is common for intervention effects to taper off over the maintenance period, there was no significant change ($p = .1.00$) in *Attention* scores from post-test ($M = 2.7$) to follow-up test ($M = 2.8$), which means that intervention effects were maintained. Our analysis showed that for the waitlist group, there was no significant increase ($p = 1.00$) in *Attention* scores between the pre-test ($M = 1.9$) and post-test ($M = 2.0$) assessments, meaning that there was no improvement due to maturation or learning. However, as expected, there was a significant increase ($p = .001$) from post-test

($M = 2.0$) to follow-up test ($M = 2.7$) assessment, after the waitlist group had completed the Mind-Full intervention.

Although not part of our hypotheses, simple main effects results showed that after the waitlist group had completed the Mind-Full intervention, both groups improved and there was no significant difference ($p = .659$) between on *Attention* scores for the intervention group ($M = 2.8$, SD = 0.4) and the waitlist group ($M = 2.7$, SD = 0.7) at the follow-up test point.

Qualitative findings Little difference was found in the intervention group when comparing common behaviors from post to follow-up test points.

5.5 How Mind-Full helps counselors and teachers help children

RQ4. *In what ways (if any) does the Mind-Full system help counselors and teachers help the children (learn to) self-regulate anxiety and attention?*

Based on informal email reports over the course of the study, and written counselor and teacher reports at post-test, the counselors were mostly positive about how Mind-Full also helped them support the girls and noticed many changes in the intervention group's behaviors. For example, at the end of the 6-week period the head counselor wrote that "some of the girls are paying more attention in the class (reported to me from the teachers). For some children (2 out of 4 girls I work with), their attention and relaxation time has increased during tablet sessions. They can focus longer than before. Even when the tablets aren't working the children are not getting frustrated very much. They are remaining calm. I'm enjoying doing the tablet with the children and seeing some of the changes (more focused, more relaxed, happy to be part of doing the game, and happier in general) in their daily life from doing it." One of the counselors also reported that four of the five children she worked with who were in the intervention group were more open and willing to talk in their counseling sessions after the intervention was done. Most negative comments were about issues with the WiFi signal being dropped between two tablets (likely due to spectral interference), or EEG data quality issues (see below under limitations). For example, one counselor reported, that children said the following during sessions, "It's taking too long.", "When will it be fixed?", and "Why is it taking so long?" Another counselor said that the girls seemed more open with them in therapy sessions after the tablet games were done. This counselor mentioned that the girls were aware of their breathing and if there was a problem with Mind-Full (e.g., headset data quality), they did deep breathing while waiting. The counselors also asked the girls what they thought about Mind-Full. They reported that the girls felt like it was easier to focus with the teachers (in class) and with their friends they felt more calm.

There were several important unexpected benefits that counselors pointed out or were observed during sessions. The main benefit was that all four counselors immediately commented that seeing the girls use Mind-Full and seeing their real-time brainwave data enabled them to know more about how the girls were feeling or what was going on for them with respect to anxiety or attentional issues. For three girls in the intervention group, they identified discrepancies between what they thought they knew about each girl, and what Mind-Full's brainwave data showed. This enabled them to better understand what was going on with each girl and change the way they planned to counsel and/or teach her. Based on these early cases, the counselors started to use Mind-Full as an informal diagnostic tool. For example, one Counselor said, "This girl isn't at all focused in class but she did very well at Stones … this tells us she can do it … she's got a lot of chaos in her family… that's what the trouble is … [knowing] this helps us work with her." Another girl who presented as a very calm child but had trouble learning was diagnosed with a learning disability. However, she had a great deal of difficulty with the Paraglider game and her brainwave data showed that she was very stressed, while appearing outwardly calm. This led the counselors to investigate her family situation and later change their assessment of her as learning disabled. They instead focused on counseling and trying to understand and treat her stress levels rather than her ability to learn. Another older girl, who had been with the school longer than most because she was not meeting learning objectives, had been assessed with severe difficulties concentrating in class, similar to how a child with ADHD or post-traumatic stress disorder might behave. However, contrary to everyone's expectations she quickly and easily completed the Stones game in the first and subsequent sessions. Her counselor commented that this would change how they approached her counseling sessions, where their main focus had been on getting her to pay attention. Now they might use the time to explore her interests and feelings. It would also change how they treated her in class, perhaps enabling her to work independently in a quiet space, like the set up for the sessions. Another girl had difficulty focusing on the screen and her eyes (and ears) were subsequently tested. She required glasses.

There were several other unforeseen benefits. The western trauma therapist commented that when she is in Canada, if she sees that something has changed in the log data or reports coming from counselors, she can follow up via Skype call with counselors and check in to see what is happening and coach them if needed. Other benefits emerged from the process of creating and administering the assessment instrument. When doing the assessments, the counselors and teachers all commented that they learned new things about some of the children that they had not known. They learned more through the process of working together to assess each girl. In particular, the western trauma therapist said that she learned many things about the children that would help her in supervision of therapy sessions at the school and remotely when she was back in Canada. Working together to administer the first assessment helped create a common language for the therapist and staff in terms of how to describe the children's issues. The counselors said that they learned more about how to describe observable behaviors during the first assessment. For example, when they described a child as fearful, we asked how this manifested as behavior. This new focus enabled them to better assess whether their interventions, as well as Mind-Full, were effective in mitigating pre-existing trauma.

None of the teachers reported explicitly using techniques, other than breathing, from the Mind-Full intervention. However, their reports (above) indicate that they saw behavioral improvements in most of the children during and after their interventions.

6 Discussion

Our quantitative and qualitative results suggest that the Mind-Full intervention, which trained A/T and beta bands, was viable and effective for self-regulation of both anxiety and attention. It is one of the only studies to address both, and it is the only study working with children living in poverty in the developing world. All children who remained at the school completed on average 24 sessions in which gameplay accounted for 8:30–9:30 min split across three games (relax, sustain relaxation, sustain attention). On average children were able to self-regulate effectively in the games for about 70% of the gameplay time. Although not blind to condition, the teacher surveys, which were facilitated by a western trained therapist and psychologists, showed that the two groups were equivalent at pre-test, and that children in both groups significantly improved in their ability to self-regulate anxiety (calm down) and attention (focus) after the intervention in the school setting. At post-test, there was a significant difference in the *Calm* and a trend towards a significant difference in the *Attention* ratings between the intervention and the control groups, largely ruling out maturation or learning factors. This difference between *Calm* and *Attention* between group results may due to the inclusion of two games for relaxation and one for attention in Mind-Full. In addition, counselors and teachers reported children improving in behaviors related to self-regulating over the course of their interventions, which differed for each child depending on their challenges. Within groups analysis showed significant improvements in *Calm* and *Attention* for both groups after the intervention, and the number and nature of negative behavioral themes was also reduced after interventions (as reported in surveys). Because we did not have an active control group, we cannot rule out the role of expectation in positive outcomes. At follow-up test point, 2 months after their intervention ended, the intervention group either maintained or continued to improve on ratings of *Calm* and *Attention*. The Mind-Full system helped counselors help the children by identifying internal states that were contrary to outward behaviors, and became used as an informal diagnostic tool, which impacted subsequent counseling and teaching practices for that child. Ironically, connectivity issues with the headset gave the children opportunities to practice self-regulation while waiting for the technology to respond in some sessions.

It is interesting to note that while the waitlist control groups had higher *Calm* scores at pre-test than the intervention group (1.9 vs 1.5), by the end of the study, the waitlist group did not improve as much (2.5 vs 2.8). It is possible the maintenance period contributed to the higher end ratings of the intervention group, or that they had more room to improve. It is also important to note that we did not conduct behavioral transfer tests (e.g., executive functioning tests) but rather used ratings of behaviors to establish transfer. Given that other research has reported individual differences in band boundaries in healthy populations (e.g., [13]), it is interesting that counselors did not need to adjust threshold *R/A* values. When they did adjust thresholds, it was to make games initially a little easier, or later a little harder, but these variations are not significant. This provides evidence that a commercial-grade headset, like NeuroSky MindWave, in tandem with simple games that do not require precise EEG data, is a viable system for field work with children, although there were ongoing challenges with the headset connectivity and signal quality.

In general, our positive results are in line with several other field studies that utilized non-blind survey raters with children with anxiety challenges [36] and attentional challenges [10, 22, 27]. Our findings are contrary to other findings with healthy populations that only some people are able to successfully use NF to learn to self-regulate (learners) and others much less so (non-learners) [13].

The advantages of the Mind-Full training intervention include the lack of negative side effects associated with medication, the ability to conduct sessions in the field rather than at a clinic, there is no need for parent training, which in our case was impossible, and that the effects of the intervention can be maintained over time. Although we did not officially sanction this, many of the children received booster sessions over the subsequent year, which may act as a reminder to them of the skills they have learned. In addition one or two systems can be used by the adults and children in a small school setting. Training time needed to administer the intervention is minimal and once our system is technically stable in a new environment, it requires very little technical maintenance.

6.1 External and Mind-Full design factors

The successful outcomes in our study are likely based on several factors related to the intervention itself as well as external factors. For example, previous work has stressed the importance of external factors including practice, motivation, and engagement with the facilitator [14]. We also suggest that the pairing of each child with their current counselor for the Mind-Full sessions may have improved the process of playing Mind-Full games and led to positive outcomes. The drawback to this approach was that counselors, who were the most appropriate staff members to assess the children, were not blind to condition. Another external factor that has been shown to have significant impact is expectation. While it is possible that children's expectations impacted their ability to practice self-regulation in the school setting, it seems unlikely that our target population had the conceptual skills to reason about and therefore expect that the system might help them self-regulate.

In previous work, we outlined five challenges that the design of a NF system for children must meet and described how the system we used in Nepal (and two other systems) addressed these challenges [3]. While we cannot directly provide evidence that these factors were critical in the successful outcomes we see in this study, we suggest that these factors are important when designing NF systems for children:

(1) *Interaction model*: Prior work has shown that children must understand the interaction model; they must know how to change their brain state to interact with the system. That is, children must know *what to do* to interact with the BCI and *how to do it*.

(2) *Feedback*: Prior work has shown that children must get feedback related to their brain state that shows them—in a way they understand—that they have done it right; and if they have not, they need corrective feedback that guides them.

(3) *Input*: Prior work has shown that children must be able to complete the NF training task(s) and to use other functions of the BCI by enacting input actions that do not detract significantly from the brain state they are trying to achieve.

(4) *Calibration*: Working with children requires that the system must not require lengthy calibration or training procedures, in particular any that require children to be able to attain a specific brain state for a prolonged period.

(5) *Sensing*: In order to use commercially available headsets (which are accessible, inexpensive, and easy to put on), the system must function reliably even when the sensed data is noisy and/or the signal quality is poor.

Other important factors are that the sessions included repetitive practice with the same simple activities, a factor which has been shown to be important [10]. We think that the laddering (i.e., ordering) of games from a simple relaxation warm up to a sustained relaxation game to a sustained attention game may have enabled children to leverage their relaxed state in the final attention game, explaining why having two relaxation games and only one attention game resulted in similar (although slightly lower) gains in attention compared to anxiety. In addition, our feedback design made invisible brain processes visible to children in ways they could understand, which is in line with studies that stress the importance of explicit learning in NF training [25]. Lim et al. mention the importance of a structured training environment as a factor that may have led to positive outcomes in their study with children with ADHD [27].

6.2 Methodological challenges and limitations

The constraints imposed by the location and nature of our field study led to some limitations in our study design which would not be found in clinical trials run in industrialized countries. For example, our small sample size was a result of running a study at a single school. We did include all the children who attended the school in our study. However, attrition contributed to a slightly smaller sample size.

One of the challenges of working in a developing country is trying to find measurement instruments for children's behavior that have construct validity but are also understandable and accessible to those administering them. For example, there are several validated survey instruments for children used in developed countries to assess attention and anxiety (e.g., BASC-3, STAID). However, none of these instruments have been developed for children living in poverty and many include questions that are not relevant for the situation of these children. The sheer number of questions and the type of language used in them would make them difficult to administer in ways that would maintain their construct validity and reliability. Many of the terms used in the questions are not those familiar in English or through translation to the counselors and teachers we were working with. It is unlikely that the counseling staff would have been able to administer them reliably even with training from our psychologist support team.

In response to this challenge, we developed a measurement instrument with the teachers and staff based on their goals for the children in terms of their ability to calm down and focus their attention. We used terms and scenarios that were familiar with the staff at the school and taught them how to focus on identifying observable behaviors. We also developed an administration manual and trained counselor how to differentiate between what they could directly observe and their opinions. For example, with anxiety, which is largely an internal process, we looked for external behaviors associated with anxiety and the ability to calm down and discouraged the counselors from basing their ratings on how they thought the child might be feeling. In order to improve the validity of our instrument, we had a western therapist or psychologist work with each teacher and counselor as they filled out the survey. Their role was to discuss each question with the staff to ensure they understood the question, discuss the behavior they had observed that led to their ratings, and mediate any conflicts between counselor and teacher when they did not agree. We also use both closed and open questions so that we could probe for details related to their ratings to improve validity. We feel that creating a custom instrument was particularly important because we were working with a vulnerable population in a situation with limited resources, and because we were not part of this population's culture. It is important to be aware that models of child development developed in industrialized countries may not apply elsewhere [1]. In addition, to ensure research with vulnerable populations has benefit, we must work closely with those involved in that populations to develop evaluation approaches that are in line with their goals for that population. Creating a custom survey in this way may have actually improved internal validity of our measures. In our analysis, we ran a reliability analysis on our scales for *Calm* and *Attention*, which provides us with some confidence that the instrument was reliable. Although still less rigorous than validated survey instruments, there were several unforeseen practical benefits of our approach. One was that the development of the assessment survey and administration manual resulted in counselors being trained to assess children based on behavioral observations rather than their thoughts or beliefs about the children. The instrument was then used to assess the children, replacing the reliance on a report card that lacked this form of rigor. Additionally, the three assessment processes enabled the visiting trauma therapist (Chesick) and following psychologists to quickly understand some of the challenges of each child at the school. The instrument provided a common language for the counseling team and teachers to talk about the children.

Another limitation of our study was that the counselors and teachers, who provided the survey ratings, were not blind to condition. There is a trade-off between having a double-blind study design and providing adequate support to vulnerable children. In one study, researchers tried to address this challenge by creating a double-blind study with a placebo neural feedback application for children diagnosed with ADHD [25]. The authors state that they address the ethical challenge of providing inadequate support to vulnerable children by enabling the children to stay on their medication during the study. In our study design, children are not medicated. It was also our opinion that this kind of study design placed an unfair burden on the school, which already had limited resources. That is, having half the children participate in a placebo application was unethical in the context of working with children living in poverty in developing countries. In addition, results from this double-blind controlled study showed no difference in improvement between the neurofeedback and the placebo group and the authors suggest, in part, that this is because of the double-blind study design. The authors suggest that having the child's counselor blind to condition means that they could not manually adjust the reward thresholds in the NF application. Our calibration application enabled counselors to do exactly this. If the counselor is blind to condition they cannot provide customized support and coaching. However, we think that the existing relationship between the counselor and the child is an important factor in the intervention. [25] suggest a study design in which the facilitator of the intervention is not blind to condition, while other raters were blind to condition. However, we think that the counselors working with each child's teachers are the best people to assess the child. Having a non-NHK therapist and psychologists trained in the Canada facilitate the assessments may have helped reduce this bias. In our study context, it would not be feasible to have parents administer a survey, largely because they are illiterate, often unavailable, and do not have the educational background to understand the concepts involved in survey assessments. It is extremely likely that survey ratings from parents would be invalid and unreliable. In addition, because each of the assessment points was about 6 to 8 weeks apart, we believe that counselors and teachers would have no explicit memory of their previous survey scores. However, it is still possible that they were biased towards positive ratings. Overall, we believe that when working with vulnerable children our choice to not have a blind study design is an appropriate trade-off between rigorous research and ethical considerations for vulnerable populations [1].

One of the limitations of our analysis was not using correlation to try and establish a direct association between the ability to self-regulate a desired frequency band (e.g., measure through a learning index) and the improvement in behavior (as suggested by Gruzelier [13]). We agree that is establishing this relationship would add validity to our results. However, when we explored the learning performance of children across sessions (e.g., PAT), we found a high success rate in each game in each session. As a result, there was no learning curve over the sessions, a finding in line with other studies with children with ADHD [14]. There was some variability that may be a result of technical challenges (e.g., dirty electrode later in intervention) or signal noise. Despite this variability, we also found that all children could successfully play the games, making a correlation between learning in NF sessions and behavioral measures inappropriate.

6.3 Future work

For future work with children living in poverty, we would suggest that a study that could include more children, perhaps at two research sites, would lead to larger effect sizes, if positive results were found. We would also suggest including specific transfer tasks that are appropriate to the sample population, and if time permits, using the EEG headset to monitor anxiety and attention levels during these tasks (e.g., timed completion of simple wooden puzzle). However, we caution that with children who are as fragile as our sample was, creating undue stress has ethical implications. Due to lack of resources, we did not explicitly train the teachers to use Mind-Full or coach children using Mind-Full techniques. As a result, none of the teachers reported explicitly supporting the children to self-regulate in the classroom when not using the Mind-Full application. Another approach would be to have a blind rater, perhaps part of the research team, or a counselor from another site, rate the children's behaviors in various blocks of time at pre-test, post-test, and follow-up test points. The downside to this strategy is that it would add considerable time and effort to the assessment process. However, this type of explicit transfer activity has been shown to be important [10]. In future work, we would explicitly train teachers to coach children using Mind-Full techniques (e.g., imagine you are breathing deeply to make the Pinwheel spin, imagine using your eyes to read the instructions like you follow the stones). In this study, we paired counselors and children who already worked together. If an existing relationship does not exist between a facilitator and child, then the facilitator should take care to establish a connection, and the intervention may need one to two more sessions that are dedicated to this as part of the Mind-Full gameplay. We would also recommend having counselors or facilitators take session to session notes to document any unusual events in the child's day/week, note why adjustments were made, if any, to threshold and hold times, and take down general comments about the child's performance. This information would be valuable in exploring within and between session differences, a topic not explored in our study, but mentioned in others (e.g., [13]).

7 Conclusion

In our study, 21 young girls at a school for children living in poverty learned how to self-regulate anxiety and attention in order to play three Mind-Full games. They were able to learn to do this, with coaching, in their first session. They continued to play the games successfully for the full intervention (24 sessions), maintaining relaxation and attention indexes above threshold for at least 70% of their gameplay time over the 24 sessions. Our survey results show that the children were largely able to transfer their self-regulatory behaviors into the classroom and playground, and that these skills were maintained over time (for the intervention groups). Despite our small sample size and non-blind raters, we are cautiously positive about these findings. In particular, this study provides preliminary evidence that outcomes achieved in clinics and well-resourced field studies with children with anxiety and attentional challenges in developed countries may be achieved when basic resources (counselor/teacher, system, quiet space) are available to children living in poverty in the developed and developing worlds. In particular, Mind-Full is an EEG-based NF system influenced by mindfulness practices from the East, implemented using technologies and counseling practices from the West, and then used to help children in living in an Eastern culture, Nepal. Perhaps part of the success of using the Mind-Full system with young children living in poverty was that the mind-body practice they were asked to learn was familiar in that it was grounded in eastern meditative practices. Overall, our study contributes to the growing body of knowledge about using EEG-based NF applications in non-clinical settings worldwide to help young children learn to self-regulate anxiety and attention and to transfer those skills into their everyday lives.

Access to education is not enough to ensure successful outcomes for many children living in poverty. Children who have suffered multiple traumas also need therapeutic interventions. In particular, they need to be able to self-regulate anxiety and attention in order to learn. We designed and deployed an EEG-based NF system that leverages young children's familiarity with everyday activities that they can use to learn and practice self-regulation of anxiety and attention. The main outcome of our research was to help children improve their ability to self-regulate anxiety by calming down in a variety of settings, and to focus their attention at school through repetitive practice with the Mind-Full EEG-based NF system.

With only slight adaptations, our games can be repurposed for other cultures and contexts.[11] Our game design and laddering strategies could enable us to create systems for different populations of children who have suffered trauma in order to help them overcome their challenges. The technical system, at its simplest, combines a simple yet robust commercial-grade EEG headset with an Android tablet and costs about $400 off the shelf—less than many cellular phones or laptops. One system can be used to train 10–15 children at a time with one facilitator. Our longer term goal is to develop a training program that will involve the dissemination of additional systems in order to work with more orphanages and schools throughout Nepal, and eventually with children worldwide who have suffered complex trauma. A successful strategy could be used to translate this experience for individuals with different levels of trauma such as child soldiers or refugees, children with chronic pain or children with attention deficit and hyperactivity disorder (ADHD).

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[11] See www.mindfullapp.ca for two other Mind-Full apps for different populations of children.

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