

# Using Neurofeedback to Teach Self-Regulation to Children Living in Poverty

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## ABSTRACT

In this paper we describe a neuro-feedback system and applications we designed and deployed to help vulnerable children at an NGO-funded school, called Nepal House Kaski, in Pokhara, Nepal. The system, called Mind-Full, enables traumatized children to learn and practice self-regulation by playing simple, culturally appropriate games using an EEG headset connected to an interactive tablet. Children can interact with Mind-Full using body actions that may change their physiology and brain states, which are sensed by the EEG headset and used as input to the games. One of the key challenges was to build an application that the children could immediately understand how to use when they are illiterate, don't speak English and have no computer experience. We describe Mind-Full and highlight the design principles we used to meet these constraints. We report on a subset of findings from a 14-week field experiment in which we use a mixed-methods approach to determine if children improved their ability to self-regulate during gameplay as well as in the classroom, playground and in therapy sessions. Findings from quantitative and qualitative assessment measures suggest that the treatment group significantly improved their ability to calm down and focus in a variety of contexts.

## Categories and Subject Descriptors

H5.2. Information interfaces and presentation: User interfaces.  
K.3.m Computers and education: Miscellaneous.

## General Terms

Design, Human Factors, Measurement

## Keywords

Brain computer interfaces, neurofeedback, self-regulation, children, games for learning, developing countries, evaluation.

## 1. INTRODUCTION

One billion of the world's children live below the poverty level, living on less than \$2.50 a day. The country we worked in is one of the world's poorest countries. Even with access to education many children living in poverty are unable to focus on learning due to multiple traumas they have suffered. Traumas may be layered and include poverty, domestic violence, parental mental illness and addictions, homelessness and civil war. Mind-Full is a

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new research project that arose after the principal investigator (PI) traveled to this country to visit Nepal House Kaski (NHK), a school for girls living in poverty in Pokhara, Nepal. The organization that operates the school is run by local staff and a Canadian NGO called Nepal House Society<sup>1</sup>. The staff work with children at 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 which is 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.

What was needed was a way to motivate and help the children learn and practice self-regulation techniques to improve their ability to regulate anxiety and attention, as well as help the counselors track the children's daily and cumulative progress. Without the ability to self-regulate, children are unlikely to succeed at NHK school, or in local public schools. Without education, these children will likely remain in poverty. The overarching research question that motivated the project was: How can we help some of the world's poorest children succeed at school? Our goal was to create an intervention that motivated repetitive practice, which could change children's brains (think neural plasticity), improve their ability to manage anxiety when stressed and improve attention on educational materials and in therapy sessions.

Current evidence from the fields of pediatric psychotherapy and health science suggests that teaching children mindfulness practices is an effective way to improve executive functioning and help reset the limbic system after trauma [9, 17]. There have been similar findings for adults [15]. The phrase "mindfulness practices" has been used to refer to a variety of techniques including deep breathing, focusing one's attention on inner or outer experiences, as well as different forms of mediation. Approaches utilizing neurofeedback (NF) have been particularly effective and are best practices for adults and children [7,11,14].

<sup>1</sup> [www.nepalhousesociety.org](http://www.nepalhousesociety.org)

NF is a type of biofeedback that uses real-time displays of brain activity (e.g. electroencephalography (EEG)), to teach self-regulation of brain function. Therapy oriented computer games that utilize NF and/or biofeedback have also been effective with child and youth populations [2,7]. Our main research questions were: (R1) Can children living in poverty quickly learn to use neurofeedback-based tablet games? (R2) If so, can children control NF games by learning and practicing to self-relate anxiety and attention? (R3) Can children transfer (i.e. use) their self-regulation skills to other contexts (classroom, playground, and therapy sessions)? (R4) And lastly, can an EEG-based system help counselors help the children (possibly in new ways)? To address these questions we developed and evaluated a series of NF self-regulation games on an Android tablet. In many ways R3 was the most important question. If children could play the games but not transfer learning of self-regulation into their everyday lives, then Mind-Full would not have achieved its main objective as stated in the overarching research question.

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 five to 11; most of the children were seven to eight years old. Compared to children in developed, 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. We designed a series of NF games using a touch tablet. In this paper, we describe how we met the needs of our population through unique design features. We describe a secondary application that runs on a second tablet which enabled counselors to calibrate brainwaves and game difficulty on-the-fly, and monitor the children's brainwave data during gameplay. We summarize the deployment of two identical systems to the school for a 12-week field study. By using a two-group design we controlled for naturally occurring versus treatment-related change in self-regulation. In the study, we investigated if children can use the system and, when they use it consistently, if it improves their ability to calm down (relax) when anxious, focus in the classroom and pay attention as needed. In this paper, we report preliminary results of the field study focusing on changes between the start of the study and the completion of the first treatment group six weeks later.

## 2. BACKGROUND

### 2.1 Therapeutic Interventions for Children

Mindfulness training including breathing, relaxation and attention exercises is beginning to be accepted as a best practice for therapeutic interventions for children and adult issues related to trauma, anxiety and ADHD (attention deficit and hyperactivity disorder). For example, mindfulness-based cognitive therapy for children (MBCT-C) is a 12-week group intervention developed to help children (aged 9-13, n=23) to learn to self-regulate their emotional balance, attention, and flexibility [9,12]. MBCT-C was expected to reduce attention problems, anxiety symptoms and behavioural issues. The MBCT-C included group interaction using games, movement and sensory exercises to increase 'non-judgmental awareness' such as visual, tactile auditory sensations. Feedback was collected from parents, teachers, children and observers. Results suggested that this approach was effective in reducing issues related to attention and anxiety. Mindfulness training was also used in an eight-week program with children (aged 8-12, n=22) with ADHD and in parallel with their parents

[16]. Results from parent reports indicated improvement in ADHD-related behaviours for children and their parents. However, improvements in behaviours related to ADHD were not seen by teachers in the classroom. While three children in the study also received NF, the impact of this was not assessed. NF has not yet been used in conjunction with mindfulness training to help traumatized children (ages 5 and up) learn self-regulation. However, mindfulness techniques have been developed and used in many classrooms (e.g. Mind-up<sup>2</sup>). These approaches have not been studied experimentally (with control groups), and we cannot assume positive outcomes reported by teachers in classrooms will automatically transfer to therapeutic interventions for traumatized children, although they may.

### 2.2 Brain Computer Interfaces using EEG

Brain computer interfaces (BCI) allow for direct communication between people and computers using electrical impulses generated by neurons within the brain. These nerve impulses, which are transmitted and received by cortical neurons, are collected and measured by electroencephalograph (EEG) electrodes. The EEG represents the voltage changes which are measured over time and represented as power spectra, a plot of the squared amplitude of the signals.

There are four primary periodic rhythms recorded in an EEG: alpha, beta, delta, and theta. These rhythms are classified by frequency (Hz or cycles/sec) and amplitude, and correlate with various states [8]. Alpha waves are most prevalent when a person's eyes are closed, and attenuate with focused attention on external stimuli. However, with proper relaxation training it is possible to maintain alpha frequencies with open eyes. Beta rhythms occur during periods of attention to external stimuli or focused mental effort. Both Delta and Theta waves are low-bandwidth EEG patterns associated with stages of sleep. They may also increase during periods of high mental concentration. Theta waves primarily occur in adults during the onset of drowsiness; however, they can also occur during wakeful states as a response to emotionally frustrating situations. Theta wave patterns are also produced during deep meditative states.

The availability of inexpensive consumer-grade EEG systems over the last several years has led to an increase in the development of BCIs. Although these systems are not as robust as medical-grade EEGs, they afford greater comfort and ease of use, making them beneficial for use as BCI controllers [3]. The two most commonly utilized EEG headsets are the Emotive EPOC<sup>3</sup> and the NeuroSky Mindwave<sup>4</sup> with new systems such as the MUSE<sup>5</sup> coming to market over the last year. For this project we selected the Mindwave Mobile, a wireless version of the NeuroSky headset, as our BCI hardware. The NeuroSky headset has been integrated into a number of toys for children including Mattel's MindFlex<sup>6</sup> and the Star Wars Force Trainer<sup>7</sup>. These prior-use scenarios provided evidence of the system's successful use with children.

The NeuroSky Mindwave headset is a single-electrode EEG system that through the use of proprietary algorithms is capable of sensing relative alpha, beta, delta, and theta wave powers. It

<sup>2</sup> <http://thehawnfoundation.org/mindup>

<sup>3</sup> <http://emotiv.com/epoc.php>

<sup>4</sup> <http://store.neurosky.com/products/mindwave-1>

<sup>5</sup> [www.choosemuse.com](http://www.choosemuse.com)

<sup>6</sup> <http://store.neurosky.com/products/mindflex>

<sup>7</sup> [http://starwars.com/shop/toys/the\\_force\\_trainer](http://starwars.com/shop/toys/the_force_trainer)

involves a single dry electrode placed above the left eye, and an ear clip (Figure 1). The system has a built in algorithm (called eSense) that assesses the current meditation (relaxation) and attention levels of the headset wearer. These values are returned as two numbers on a scale from 0-100 with a higher value indicating a greater degree of relaxation or attention. Values of 40-60 indicate moderate degrees of relaxation or attention. Although the NeuroSky system uses proprietary algorithms the system has been assessed by researchers to assure the validity of the EEG wave measurements and the meditation and attention scales. Crowley et al. validated the ability of the NeuroSky system to differentiate between meditation and attention by having participants complete the Stroop test and the Tower of Hanoi puzzle [1]. The attention scale was also validated by another group of researchers using a self-assessment test [13]. Stinson and Arthur's research demonstrated that the data output corresponds with the expected wavelength powers despite some inconsistencies with the relaxation and attention measures [15]. We used this headset in our system, Mind-Full.

### 2.3 EEG-based NF for Children

There have been several EEG-based NF interventions developed for children. EEG data provides a reliable means to measure several brain states (most notably attention and relaxation) in an unobtrusive manner. This data can be then used as input to a computer program which translate data into different forms of feedback which children can use to better understand their current brain state and motivate changes to desired brain states (e.g. calm down, or focus more). There have been several EEG-based NF applications developed and studied specifically for children.

FOCUS is a reading application that claims to increase the engagement in reading by using an EEG-based augmented display over a book [6]. The augmented display changes based on the EEG data related to an attentional engagement index, which is a measure of Beta / (Alpha + Theta). The Emotiv EPOC<sup>8</sup> headset used in the study has 14 electrodes and requires pre-calibration. Children (aged 6-8.5, n=24) were trained in two ways: contextual reading where the augmented display was triggered when the engagement index went below a threshold; and in-order training where training was given after the reading session. Results indicated that the EEG engagement index was significantly higher for contextual reading compared to in-order reading. Teacher feedback on children's reading outcomes was significantly higher for children who did contextual reading than in-order reading. This study shows that EEG-based training can be used to help children stay engaged in their reading sessions. However, in this study, EEG data was taken from the visual cortex and assumes that visual engagement is equivalent to reading engagement.

An EEG-based puzzle was built for children (aged 7-12, n=20) with ADHD in order to improve their attentive state [10]. The system calibrates the attentive and non-attentive states of each child from their EEG for the first two sessions, requiring extensive machine learning. The research grade headset had more than 20 electrodes (making it unsuitable for school settings). The experiment ran for 20 sessions over 10 weeks with ADHD children who were new to medications, and a control group. The sessions involved playing games using attention as input. For example, racing a car where the speed of the car is proportional to attention level. The difficulty level of the games was increased over the sessions by the psychologist. After 5 and 10 weeks, a

questionnaire was filled out by parents and teachers based on their observation of the children at home and in the school. Though there was no significant improvement noticed by parents or teachers, the results indicate that the children underwent the EEG-based NF training with ease.

EEG-based NF was used as a mechanism to improve creativity and well-being of the children (aged 11, n=33) [4]. The experiment involved training children to enhance their theta/alpha states with closed eyes relaxation and with opened eyes relaxation. Children listened to auditory representations of their theta (waves) and alpha (brook) states. They were instructed to relax deeply and listen to pleasant sounds which would occur more frequently as they relaxed more deeply. Results showed that the training improved creativity and musical performance of the children, half of whom rated positive on an index of ADHD. The work also suggested that the students enjoyed the NF training and that it was feasible to employ NF trainings in schools. While this study did involve therapeutic interventions, the findings indicate that it was possible to deploy in school settings.

To date there have been no studies reporting on the use of NF to improve young children's self-regulation around issues of trauma, anxiety and attention. However, therapeutic NF training with adults for anxiety and depression has been shown to be very effective in terms of helping adults purposefully attain alpha brainwave states [5]. NF can be used effectively alongside medications to treat anxiety disorders and depression. NF has also been shown to be effective for improving outcomes related to stroke, aging issues, and head injuries, with fewer side effects than medication [15]. Our work explores the viability of using EEG-based NF to teach children with multiple traumas to self-regulate anxiety and attention.

## 3. THE SYSTEM

### 3.1 Guiding Principles

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 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 spinning the pinwheel. A second design principle was that entire UI had to function so that a child could learn how to interact in a single session (5-10 minutes) with only minor coaching from the school counselors. This included understanding how 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 game play because the children cannot relax or focus or even sit still! To solve this we built an on-the-fly calibration application which enabled us to calibrate while a child was playing games even if unsuccessful (described below). This application also enabled us to make the games easier, because our goal was

<sup>8</sup> <http://emotiv.com/epoc.php>



**Figure 1a. Demo session 1b. Child using system with counselor. 1c. User management interface with three users, one active.**

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.

### 3.2 System Overview

Mind-Full is composed of modules including: user management, user progress (per game, session, study period), on-the-fly calibration 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 pre-processed data streams for either relaxation or attention 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. More information about the design rationale for the Mind-Full system is available through a video presentation<sup>9</sup>.

### 3.3 Games

Mind-Full was composed of three games based on the counselors' goals for the girls. The Pinwheel game was an introductory relaxation game (Figure 2a). It functioned as a warm-up for the user 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 user had to relax their mind and body for five seconds to cause the pinwheel to spin. If they maintained a relaxed state above the default threshold (Relax=40) for five seconds they got a token added to the jar (on the left in figure 2a), and got a new token for every five seconds they could stay relaxed. The threshold and duration was adjusted using the calibration device. The user 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. Breathing was not required to achieve the desired state or to get the pinwheel to spin.

The second game, called Paraglider, was also a relaxation game (Figure 2b). 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 user had to stay in a relaxed state for 11 seconds (default) above a specific threshold (Relax=40). If the user's relaxation measure fell below the threshold then a thermal (gust of wind), pushed the paraglider a little ways back up the mountain. Once the desired state was achieved 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. She moved out of the screen and a paraglider jumped off the hilltop. Reminding the user about sitting back 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 an attention game (Figure 2c). 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 which 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 stone game focused on teaching attentional skills. In this game the user had to focus for eight seconds on 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 (Attn=40) then the stone would move across the screen and place itself onto the stone stack. If the user lost her focus, the stone would fall and roll back into the basket (Figure 2c). The user 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, the user could learn to focus her attention. This game was a bit of a stretch from reality but was none-the-less 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.

### 3.4 User Management

In order for young children who cannot yet read to be able to start their own sessions, we used the camera utility of the tablets. With a single tap, an image of a child was taken and then used to access their account. The user photo page is shown in figure 1c. Basic user management tools were also visual, but were meant for counselors (see Figure 1c). Children started their session by tapping their image. The most recently used accounts were displayed first. Other tools enabled counselors to move users to a different tablet or merge two accounts for the same user on a single or multiple tablets.

<sup>9</sup> <https://www.youtube.com/watch?v=PJ4gfkRUedo>



Figure 2a. Pinwheel game animation. 2b. Paraglider with five tokens. 2c. Stones with signal quality showing green on user photo.

### 3.5 Progress

Progress is represented using jars of tokens for each game. Both counselors and children can see progress in a game (Figures 2a, 2b, 2c), a session (Figure 3b) and/or all sessions (Figure 3c), each represented with jars. Jars were colour coded to match the games (yellow, pink, and blue respectively). If a user (counselor or child) tapped the jar, she was taken to a page that showed all the jars she had filled for any games she had played in that session. On the session progress page jars were displayed on shelves just like in the children's homes (Figure 3b). By tapping any game icon she returned to that game. By tapping any jar on a shelf she went to the progress page for all her sessions (figure 3c). She could return to her current session page by tapping any jar. Tapping the photo of herself at any point returned her to the main page and ended her session.

The counselors could see a girl's progress through the study period from the session progress page (Figure 3c). This page showed all the games played by each user, including each session's date and time, the games played and duration of play. The duration was split to show the time in a relaxed or attentive state using a proportional pie chart. This page was scrollable from left to right to facilitate the viewing of all sessions. Pie charts enabled counselors to visually compare a user's total, relaxed and attentive times over multiple sessions. The pie chart segments were colour-coded to match games (Pinwheel, Paraglider, and Stones).

### 3.6 Calibration Application

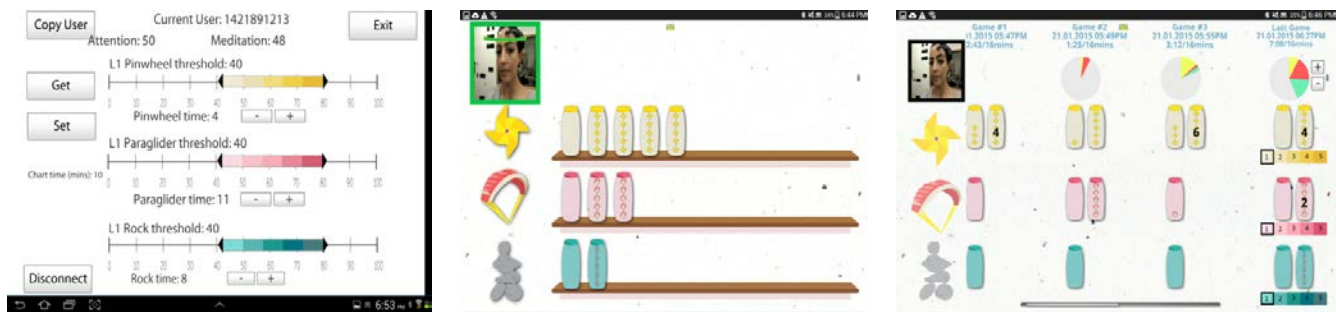
To date, all EEG-based brain computer interfaces require calibration or training prior to using brainwave data in an application. One of the challenges of working with young children suffering from trauma is that we could not calibrate the EEG ahead of usage. The children cannot reliably calm down or focus; therefore we cannot calibrate the application using those states. To solve this issue, we developed a second application running on a second Android device (see technical implementation details below). This application reported the live status from the EEG headset and interacted with the game in real-time (Figure 3a). It enabled a counselor to change any of the default values in the games. For example, the Paraglider game could be made easier by lowering the Relaxation value from 40 to 30, and/or by lowering the time threshold from 11 to eight seconds. In this way, games could also be made more difficult as a girl's skills progressed, and the new default values were stored in her account. This application also showed brainwave data and signal quality, which could help the counselor or a second observer understand how the girl was doing (without looking at her game screen and disturbing her).

### 3.7 Technical Implementation

Mind-Full is composed of the NeuroSky MindWave headset and two Samsung Galaxy 10.1 touch tablets that run the 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 (Figure 2c). 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 or Attention threshold which was set to default values, but could be changed using the Calibrate application (or in user management). 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 token was earned for that game. This process happened once per frame at 60 frames per second, so there were about 16.7 milliseconds 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 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 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 Google Drive at the end of each day by counselors so that little



**Figure 3a. Calibration screen. 3b. Current session progress screen. 3c. All sessions progress screen (swipe L/R to see all).**

data would be lost if a tablet was lost, broken or could not be recharged due to a power outage.

#### 4. FIELD STUDY METHODOLOGY

We conducted a two-group, repeated measures, field experiment at the NHK school. Two equivalent groups of girls used Mind-Full three to five times per week over two six-week periods (total 12 weeks). The study length was based on other successful mindfulness interventions for children (e.g.[17]). The session frequency (3-5/week) meets or exceeds those used in other studies and mirrors that of studies with adults such as Kabat-Zinn's Mindfulness Stress Reduction Program<sup>10</sup>. In this paper, due to space constraints, we only report on the group of girls who used Mind-Full in the first period (weeks 1-6). Repeated measures involved two assessments administered prior to and at the end of six weeks. Other data was collected from counselor and teacher reports, observations by the PI and counselors, feedback from the girls, and log data of gameplay progress, all related to children's improved ability to regulate their relaxation and attention levels. The repeated measures, two-group research design enables us to have a control group to account for developmental and school-related changes.

While it is tempting to have hypotheses for our study there are many factors beyond control in the field, and in particular at a school for children living in poverty. For example, during week five, 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, another researcher worked with teachers during the latter part of this six week period to improve control in the classroom. Events in the children's home lives could also impact results. For these reasons, we state 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.

##### 4.1 Site and Participants

Twenty two girls (aged 5-11) attend the NHK school. All have suffered trauma resulting from violence in home, substance abuse in home, neglect, and/or parental death. There are three classrooms based on age and ability. Children participate in daily classroom work and weekly therapy sessions (.5-1 hours) which include therapeutic art and play therapy. 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. For the study, the 22 girls were split into two groups (treatment/control). The first group used Mind-Full for the first six-week study period. The teachers divided the girls into groups by equivalent pairs based on age, grade, temperament and behavioural issues. Two girls dropped out of the treatment group because they left the school so data is not reported for them. Nine girls completed the treatment during the first six-week period. In this paper, we focus on findings for those nine girls.

##### 4.2 Procedure

In the 10 days before the study, the Western therapist worked with all the teachers and counselors to learn to use Mind-Full. She 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. The PI arrived a week later and worked to iron out technical issues and to re-develop all the assessment instruments in conjunction with the Western therapist and NHK staff.

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. The goal was to reduce researcher and power effects by using someone closer to the children's own age, who had developed proficiency using Mind-Full (Figure 1a). The demonstration also enabled us to get verbal informed consent from the girls who would not have been able to understand what we were asking them without a demonstration. Their parents had all met with the school previously to give their verbal consent after a demonstration by the counselors.

All of the girls were assessed at the beginning of the study. Each assessment was facilitated by a trained Western therapist/researcher, and involved the child's teacher with input from their counselor. During the first week, the treatment group began to use Mind-Full in addition to current (non-system) instruction in breathing practices. Each session involved one child using Mind-Full supervised by one counselor. We deployed two identical systems. Each child used the system with a counselor for about 10 minutes/day three to five times a week for six weeks (see study setup in Figure 2b). The control group only received non-system instruction in breathing practices. At the end of six weeks all of the girls were re-assessed by a western researcher and staff with the same assessment instrument.

##### 4.3 Measures: Assessment Instrument

The assessment instrument was developed by the PI, the Western trauma therapist, three counselors and a teacher from the school. The goal of the assessment was to address the research questions and was modified to include input about what the counselors and teachers considered to be successful outcomes for the study, and for the children. The end result was an instrument with open survey questions, statements rated using an interval five point Likert scale, and space for comments that explained ratings. The

<sup>10</sup> [www.mindfullivingprograms.com/whatMBSR.php](http://www.mindfullivingprograms.com/whatMBSR.php)

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. To ensure consistency of the multiple administrations of the assessment, we iteratively developed standards for administration. We included information on how to focus on observable behaviours (as well as children's emotional states), using consistent terms, checking for consistency between similar questions, using prompts to get more details and using examples. The assessment instrument included two open questions about general issues and learning disabilities: G1. What are the main behavioural issues with this child in the classroom and at school? G2. Do you think this child has a learning disability? If so, explain why you think this? The next section used mixed measures to assess *Calmness*. There were five closed statements with a five-point interval rating system (from 0 to 4) in which the staff rated the child's ability to self-regulate anxiety and their ability to calm themselves down after an upsetting situation. The rating section was followed by an open comment field which was used to explain ratings or add other comments related to calmness. The statements covered contexts including the classroom, playground and therapy sessions. The statements were:

- 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 scale was worded so to represent equal intervals between each of the 5 categories (Table 1).

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.

**Table 1. Five point interval scale for Calmness**

The last section used mixed measures to assess *Attention*. The closed statements, rated with a similar five-point interval scale, were:

- 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 explain ratings about attention and focus.

The PI also observed the first two sessions (to address RQ1 and RQ2), and another session a week later. The PI conducted informal focus groups with staff after each of these sessions. Counselors also sent periodic email updates on progress and issues throughout the six weeks and a written report alongside the second assessment at the end of the first six weeks.

Quantitative data was analyzed using parametric techniques when variances were equal since the rating scale was interval. We analyzed written comments using a bottom up thematic analysis approach to look for common themes, and changes between the first and second assessments. We used our observational notes and email comments from counselors to substantiate findings, provide quotes and examples and report on unexpected benefits.

## 5. PRELIMINARY RESULTS

In this paper we report on the results comparing the treatment and control group using the first and second assessments. We would expect the treatment group to improve across all qualitative and quantitative measures and the control group to possibly improve across some measures due to natural or developmental, and/or counselling and/or educational factors but to improve less than the treatment group. We report results in order of our research questions with quantitative analysis first, followed by a thematic analysis of written responses to G1 (issues), G2 (learning disability) and comments for *calmness* and *attention* for both groups. The qualitative analysis provides details which help explain findings from quantitative ratings. We also include observations from notes of three sessions and quotes from post-session focus groups with staff.

*(R1) Can young children living in poverty quickly learn to use neurofeedback based tablet games?*

Based on observations we determined that all the girls in the treatment group were able to quickly understand how to play the Pinwheel game in the first session. The counselors gave them minimal instructions. For example, saying things like "take a deep breath to make the pinwheel spin" or "remember how the boy took deep breaths to make the pinwheel spin" (from the demo 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 eight to five seconds per stone), all of the girls managed to complete one jar of five tokens for all three games in the first session.

*(R2) If so, can children control neurofeedback-based tablet games by learning and practicing to self-regulation of anxiety and attention?*

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 one to five minutes of each session and hold an alpha state (threshold of 40) for five seconds, 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 on-the-fly calibration to make the Pinwheel game easier by lowering the threshold brainwave value for relaxation value or decreasing the time they had to hold that state. We found that all the girls understood how to play the Paraglider and Stones games, although all of the children found these games harder. Most girls found either one of Paraglider or Stones harder and this tended to be consistent across sessions. Some of the girls needed minor re-calibration and encouragement to successfully achieve tokens. Session lengths ranged from 5 to 15 minutes. The longer sessions typically involved re-calibration or re-starting when the WiFi direct connection was lost, or headset Bluetooth connection was weak (which turned out to be due to dirt on the girls' foreheads).

*(R3) Can children transfer their self-regulation skills to other contexts (classroom, playground, therapy sessions)?*

In order to determine if there was an interaction between groups (treatment, control) and assessment (1/pre, 2/post) we first looked at variance using Levene's test for between subjects (group) and Mauchley's test for within subject (assessment) for all questions

(C1-C5; A1-A3). Results indicated that there was a homogeneity of variance between subjects for all measures except A2 at the  $p > 0.05$  level. The assumption of sphericity was also met for two levels. Since these assumptions were met and our data was interval we used as two way ANOVA for all measures except A2. For A2, we used a Wilcoxon signed-rank test, which is the nonparametric equivalent of a two way ANOVA for correlated measures.

The results for the two way tests indicated that there was a significant interaction between the groups and assessment for all measures except C (stay calm while helping other children) at levels ranging from  $p < 0.01$  to  $p < 0.001$ , with an effect size ranging from moderately large to large ( $\eta^2 = .22$  to  $.58$ ). This means that the children's ability to calm down and pay attention increased from assessment 1 to assessment 2 for the treatment group and stayed the same or actually decreased from assessment 1 to assessment 2 for control group. In order to further explore these findings, we used one way repeated measures ANOVA. We report the significance levels and effect sizes for all measures (except C5 because there was no difference in either group).

For C1 (calm themselves when upset) the results for the treatment group indicate that the rating of calmness by teachers and counselors significantly increased from assessment 1 ( $M = 1.27$ ,  $SD = 0.61$ ,  $N = 9$ ) to assessment 2 ( $M = 2.55$ ,  $SD = 0.88$ ,  $N = 9$ ) with high effect size ( $F(1, 8) = 28.98$ ,  $p = 0.001$ ,  $\eta^2 = 0.78$ ). There was no significant change in the rating of calmness of the children in the control group.

For C2 (calmly talk about past trauma) the results for the treatment group indicate that the ratings of the children's ability to calmly talk about something that had upset them significantly increased from assessment 1 ( $M = 1.5$ ,  $SD = 0.50$ ,  $N = 9$ ) to assessment 2 ( $M = 2.27$ ,  $SD = 0.66$ ,  $N = 9$ ),  $F(1, 8) = 10.74$ ,  $p = 0.011$ ,  $\eta^2 = 0.57$ . There was no significant change in the rating of ability of the children to calmly talk about stressful topics from assessment 1 to assessment 2 for the control group.

For C3 the results for the treatment group indicate that the ratings of children's self-control on the playground significantly increased from assessment 1 ( $M = 1.5$ ,  $SD = 1.3$ ,  $N = 9$ ) to assessment 2 ( $M = 2.77$ ,  $SD = 0.83$ ,  $N = 9$ ),  $F(1, 8) = 7.93$ ,  $p = 0.023$ ,  $\eta^2 = 0.49$ . There was no significant change in the ratings of children's ability to maintain self-control in playground from assessment 1 to assessment 2 for the control group.

For C4 the results for the treatment group indicate that the ratings of children's ability to calm down when they did something wrong significantly increased from assessment 1 ( $M = 1.11$ ,  $SD = 1.26$ ,  $N = 9$ ) to assessment 2 ( $M = 2.66$ ,  $SD = 0.7$ ,  $N = 9$ ),  $F(1, 8) = 7.93$ ,  $p = 0.05$ ,  $\eta^2 = 0.64$ . There was no significant change in the calmness of the children when their mistake was pointed out, from assessment 1 to assessment 2 for the control group.

For A1 the results for the treatment group indicate that the ratings of the children's attention in the class significantly increased from assessment 1 ( $M = 0.94$ ,  $SD = 0.72$ ,  $N = 9$ ) to assessment 2 ( $M = 2.55$ ,  $SD = 0.52$ ,  $N = 9$ ),  $F(1, 8) = 31.73$ ,  $p < 0.001$ ,  $\eta^2 = 0.80$ . The ratings of the children's attention in the class did not change significantly from assessment 1 to assessment 2 for the control group.

For A2, the results for the treatment group indicate that the ratings of the obedience of the children significantly increased from assessment 1 to ( $M = 1.44$ ,  $SD = 0.72$ ,  $N = 9$ ) to assessment 2 ( $M = 2.77$ ,  $SD = 0.44$ ,  $N = 9$ ),  $F(1, 8) = 32$ ,  $p < 0.001$ ,  $\eta^2 = 0.80$ . The ratings of the children's obedience did not significantly change from assessment 1 to assessment 2 for the control group.

For A3 the results for the treatment group indicate that the ratings of the children's ability to concentrate significantly increased from assessment 1 ( $M = 1.61$ ,  $SD = 1.11$ ,  $N = 9$ ) to assessment 2 ( $M = 2.66$ ,  $SD = 0.70$ ,  $N = 9$ ),  $F(1, 8) = 6.5$ ,  $p = 0.034$ ,  $\eta^2 = 0.45$ . The concentration of the children had no significant change from assessment 1 to assessment 2 for the control group.

Our analysis of the qualitative comments for G1, overall calmness and attention resulted in the identification of common themes in both groups.

1. Hyperactive
2. Attention/concentration/loses items
3. Unruly
4. Angry/Aggressive
5. Fear/anxiety/reserved/low self esteem

Overall many of these behaviours that were described for each girl in group 1 in assessment 1 were reduced in assessment 2. For example, four girls were reported to have poor attention and concentration in assessment 1 and only 3 in assessment 2. There was some unruly behaviour reported for girls, such as not listening to teachers, stealing and lying. These were reported for six girls in assessment 1 and no girls in assessment 2. 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 behaviours in assessment 1, and 3 in assessment 2. Five girls in assessment 1 were reported to have emotional issues, such as fear, being reserved with friends and low self-esteem, which was reduced to four girls in assessment 2. These improvements were not mirrored in the control group findings. In the control group, most of the issues mentioned in assessment 1 remained in assessment 2.

In addition to negative behaviors, there were several positive comments from the teachers after assessment 2 for the treatment group. 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.

*(R4) Can an EEG-based system help counselors help the children?*

Based on informal email reports during the six weeks, and a written report at the end of the six weeks, the counselors were mostly positive about how Mind-Full also helped them support the girls and noticed many changes in the treatment groups' girls' behaviors. For example, at the end of the six-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." 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). 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. The counselors also sent these two quotes from the girls, "I like the tablet and after it I feel comfortable and I can draw a picture" and "I practice deep breathing at night" (translated by counselors into English).

There were several important unexpected benefits that counselors pointed out or we 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 attentional issues. For three girls in the treatment 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 a 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 counselling 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 counselling 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's 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.

#### *Limitations and Confounds*

One limitation was that sometimes a headset had poor data quality during a session which took some time to rectify, usually by adjusting the forehead connection, but other times by starting over completely. Later in the study, we discovered that regular cleaning of the headsets and girls' foreheads with alcohol immediately improved the connection; the headset signal quality was much improved and stable from then onwards.

For A1 (paying attention in the classroom) only the treatment group improved. We expected that all children would improve because another researcher was working with the teachers near the end of the period to improve control in the classroom. However, this factor beyond our control did not appear to affect our results. Similarly when three of the girls in the treatment group were given glasses during the first period. Their counselor reported that the glasses improved their vision, which in turned improved their ability to play games using Mind-Full. At least one of the girls was nearsighted, which would not have affected classroom work. Another issue is that the teachers might have been biased because they knew which children had participated in the first treatment group. Having a non-NHK therapist facilitate the second assessment may have helped reduce this effect. It is difficult to control all factors in a field study; however, our effect sizes were large so we could be relatively certain that usage of Mind-Full was an important element in improvements.

## **6. DISCUSSION**

Mind-Full's game design was based on activities that are familiar to the children, combined with therapeutic best practices from the west, some of which are also familiar in concept to these children (e.g. breathing in Buddhist meditation). Mind-Full alongside counselor support provided motivation for the children to repetitively practice, receive visual feedback, and improve their ability to self-regulate in the classroom. More importantly, our findings show that children's abilities to self-regulate anxiety and attention transferred beyond our games into real-world situations that the children face every day. Our experimental design enabled us to make claims about the impact of our intervention compared to naturally occurring changes due to maturation and other interventions. Our preliminary results were overwhelmingly (and surprisingly) positive. With so many factors beyond our control and a population that has never been tested with NF or commercial grade EEG headsets, there were many things that might have gone wrong. Having the PI and/or Western therapist and other researchers on site for the whole field study ensured that we were able to troubleshoot, validate consistent usage and make our own observations. The staff was involved from the very beginning of the project, long before we started to design the system. They were enthusiastic about our ideas, informed our designs (system and assessment instruments), and were willing to take the risk to run the study. A key strategy was to enable the staff at the school to use and technically troubleshoot Mind-Full, and be involved in all aspects of assessment and data collection. Without this type of buy-in and their steadfast commitment to conduct about 20-25 practice sessions with each child, it is doubtful that our results would have been as positive as they were.

At this time we can only make claims about short-term effects. It remains to be seen if improvements will hold, with or without further use of Mind-Full. We will determine this, in part, by re-

assessing the first group after another six weeks in which they did not use Mind-Full. We are also interested in long-term compliance and usage in the school. At this time, there is interest by staff and children in continuing to use Mind-full in weekly practice. This will help us determine if effects will continue to improve, flatline or even drop off due to a novelty effect. It is possible using Mind-Full was a good jump-start for children but will not have a lasting effect. NF studies of adults (including experts in meditation) suggest that NF mindful and/or mediation practice can actually change the brain's neural configuration. For NHK children, this would mean that Mind-Full practice alongside other therapeutic interventions mitigates the effects of trauma on their brain development. Our full field study (12 weeks) and continued longitudinal studies will assess this. This would be the best case outcome, and we are currently analyzing brainwave data to begin to assess this goal as well as organizing a longitudinal study.

## 7. CONCLUSION

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 actions that can be used to support learning and practicing self-regulation of anxiety and attention. The main outcome of our research was to help children improve their ability to regulate anxiety, focus and pay attention through daily practice Mind-Full. With only slight adaptations, our games can be repurposed for other cultures and contexts. Our games and laddering strategy (easy game first, then harder games are released) could enable us to help children with different levels of trauma 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. 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, children with chronic pain or children with ADHD.

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