Evaluating the Impact of a Mobile Neurofeedback App for Young Children at School and Home

Alissa N. Antle
School of Interactive Arts and Technology
Surrey, Canada
aantle@sfu.ca

Elgin-Skye McLaren
School of Interactive Arts and Technology
Surrey, Canada
emclaren@sfu.ca

Holly Fielder
Education Assistant Department
Langara College
Vancouver, Canada
hollyfiedler@gmail.com

Naomi Johnson
Social Work Independent Consultant
Toronto, Canada
naomi.megan.johnson@gmail.com

ABSTRACT

About 18% of children in industrialized countries suffer from anxiety. We designed a mobile neurofeedback app, called Mind-Full, based on existing design guidelines. Our goal was for young children in lower socio-economic status schools to improve their ability to self-regulate anxiety by using Mind-Full. In this paper we report on quantitative outcomes from a sixteen-week field evaluation with 20 young children (aged 5 to 8). Our methodological contribution includes using a control group, validated measures of anxiety and stress, and assessing transfer and maintenance. Results from teacher and parent behavioral surveys indicated gains in children's ability to self-regulate anxiety at school and home; a decrease in anxious behaviors at home; and cortisol tests showed variable improvement in physiological stress levels. We contribute to HCI for mental health with evidence that it is viable to use a mobile app in lower socio-economic status schools to improve children's mental health.

CCS CONCEPTS

• **Human-centered computing → Empirical studies in ubiquitous and mobile computing**.

KEYWORDS

Brain computer interfaces, HCI for mental health; children, self-regulation, field studies, positive computing.

ACM ISBN 978-1-4503-5970-2/19/05…$15.00
https://doi.org/10.1145/3290605.3300266

ACM Reference Format:
Alissa N. Antle, Elgin-Skye McLaren, Holly Fielder, and Naomi Johnson. 2019. Evaluating the Impact of a Mobile Neurofeedback App for Young Children at School and Home. In *CHI Conference on Human Factors in Computing Systems Proceedings (CHI 2019), May 4–9, 2019, Glasgow, Scotland UK*. ACM, New York, NY, USA, 13 pages. https://doi.org/10.1145/3290605.3300266

1 INTRODUCTION

Anxiety disorders are among the most common mental health issues in childhood and the first to emerge — affecting about 18% of children; often lasting into adulthood with devastating social-emotional, health, and economic costs [5, 24]. Children living in lower socio-economic-status (SES) areas are more likely to have severe anxiety, challenges regulating it, and are less likely to be diagnosed or treated [8, 15, 31]. Ongoing, frequent neurobiological stress responses are correlated with increasing risk of both physical and mental health problems [14]. When these responses occur in periods of rapid brain development, such as when young children first enter schooling, they can be particularly harmful. In addition, anxiety negatively affects children's education and career outcomes, feelings of self-esteem and self-efficacy, social competence, and their physical and mental well-being [33, 35]. However, it is often difficult to get help with mental health issues. In a Canadian survey on mental health, 38% of respondents indicated that the time between initial help-seeking and diagnosis exceeded a period of 12 months and only 1 in 5 children who required mental health services received them [29]. Learning to self-regulate anxiety early in life is beneficial and may reduce the negative impact of this mental health challenge on educational, social-emotional, and economic outcomes for children [34, 38].

Clinical research has shown that neurofeedback (NF), a type of brain-computer interface (BCI), can provide lasting results in treating many neurological conditions, including challenges with anxiety and attention [7, 25]. A common form of NF BCI measures, records and provides visual and/or auditory feedback about brain states sensed using an electroencephalography (EEG) headset. However, most systems involve complex and expensive EEG systems only available through clinics. As such this approach is not available to many children, in particular those from lower SES families. Recently, consumer-grade headsets have been introduced to the market. This creates opportunities to design and deploy NF apps that help people learn to self-regulate outside of clinical settings. Despite a recent spike in availability of NF apps for adults and children on smart devices, little is known about viability and effectiveness of these systems in field settings [3]. Yet if beneficial, there may be significant potential for these systems to address disparities of access associated with clinical interventions [38].

Our research addresses the following overarching question: *What is the impact on young children's ability to self-regulate anxiety in schools and homes after using a mobile neurofeedback intervention?* To address this question, we conducted a field investigation of the viability and effectiveness of an intervention using Mind-Full, a NF BCI application, designed based on previous guidelines [2]. Mind-Full is composed of a simple and inexpensive commercial EEG headset and Android tablet. In this paper we describe the methodology for a field study with 20 young children attending two lower SES schools in Canada who were of mixed ethnicities including aboriginal and refugee children. We report on our mixed but encouraging quantitative results of the impact of our intervention on children's ability to self-regulate anxiety, their anxious behaviors and their physiological stress levels both at school and home. We contribute to the fields of HCI for mental health and positive computing (e.g. [6]) in two main ways. Our field methodology utilizes a control group and validated behavioral and physiological measures, addressing prior concerns with rigour. Our results show the viability and effectiveness of the Mind-Full app, serving as a proof of concept for a mobile, low cost approach that can be used in schools to improve the mental health of young children who are often marginalized.

2 BACKGROUND

In clinical settings there has been a growing body of work studying EEG-NF games as a therapeutic treatment to help children with anxiety and/or attentional challenges learn to self-regulate (see [12] for a review). Self-regulation involves learning ways to stay calmly focused and alert, and practicing those techniques until they become automated. EEG-NF training has been suggested as a beneficial technique for teaching children to self-regulate because it makes invisible brain processes visible [2], and may lead to behavioral and neural changes [38, 40]. Training via games provides motivation and has been linked to high training compliance and reduced attrition in clinical studies with children with attentional challenges [10]. While using EEG-NF games to teach children self-regulation seems compelling, it is important to take this work out of clinics and into children's everyday lives if we are to reach some of the children who may benefit the most.

Field-based NF Studies of Children and Anxiety

Very little research exists focusing on non-clinical approaches to teaching children self-regulation of anxiety using NF. In one randomized controlled experiment with an active control group with 136 participants (aged 8-13), children and youth played either MindLight or an alternative video game [33]. Participant and parent ratings of anxiety showed a decrease from pre-test to post-test, and no change at follow-up test points. This methodological design has a large sample size and standardized, reliable and multi-informant behavioral measures. However, the authors suggest that the play context may have impacted results since the children all played in shared rooms (contamination effect). The authors also suggest that positive results might be due to non-specific factors such as being primed to expect an improvement in anxiety. Lastly, they acknowledge that without a control group it was difficult to determine if improvements were greater than without any intervention.

In a randomized controlled experiment with a waitlist control group with 21 girls (aged 5-11), children completed 24 NF sessions over six weeks with their counselor at a school for girls living in poverty in Nepal [3]. Counselor and teacher ratings of behavioral indications of self-regulation of anxiety showed a significant improvement in a variety of contexts for the intervention from pre-test to post-test; the gains were maintained at a follow-up test point. The waitlist group later completed the intervention and pre-post ratings showed a similar pattern. There are no other known field studies of NF-based interventions for children and anxiety challenges.

Field-Based Methodological Challenges

For further methodological guidance we can look to other field-based biofeedback (e.g. heart rate variability) and neurofeedback studies targeting children and self-regulation of other brain processes (e.g. attention, depression) [11, 13, 18, 21, 39]. For example, computer games were turned into biofeedback games for 16 children and youth (aged 8 to 17) with fetal alcohol syndrome [23]. Children showed a significant improvement in pre-post test ability to regulate brain processes associated with inattention. However, the authors state that they could not make claims about efficacy due to study limitations (e.g., no control group, small sample size, large age range of children, un-validated measures). In a similar study, 26 children and youth (aged 9-17) learned relaxation techniques using a biofeedback PC platform [20]. Between group results showed improvement in behavioral measures of anxiety and depression. However, claims were limited by non-random assignment to groups. Analysis of other studies shows similarly that claims are often limited because study designs have involved small sample sizes, non-randomized designs, and inadequate control conditions [11]. However, we note that when working in lower SES contexts, an active (placebo) control group design may be ethically unacceptable [1]. Another issue noted is that some studies do not assess a child's ability to transfer regulation skills into their everyday lives or assess maintenance over time [3, 12, 37]. Lastly, it remains unknown if NF interventions that show behavioral improvements also help children improve regulation of neurological or physiological processes (e.g. stress response) [40]. We suggest that what is needed is a field study design in line with the positive practices noted above but with a randomly assigned control group and measures of transfer and maintenance of self-regulation behaviors and physiological stress response.

3 MIND-FULL SYSTEM AND GAMES

We developed a new version of our EEG-based NF game system, called Mind-Full, using established BCI for children design principles as described in [2]. We created six games. Two of the games closely resemble games used in our Nepal study, described in [3], which was conducted in a school for children living in poverty. The Nepali children share some characteristics with our new population (e.g. lower SES, similar age range). The four other games are new but follow guidelines cited in [2], and require similar interactions as the previous games. For example, a child must breath calmly or relax their body to cause an effect in the game. Since we are replicating and building on previously published research on game designs but evaluating our games with a new population in a new context, we provide only a summary of the games here.

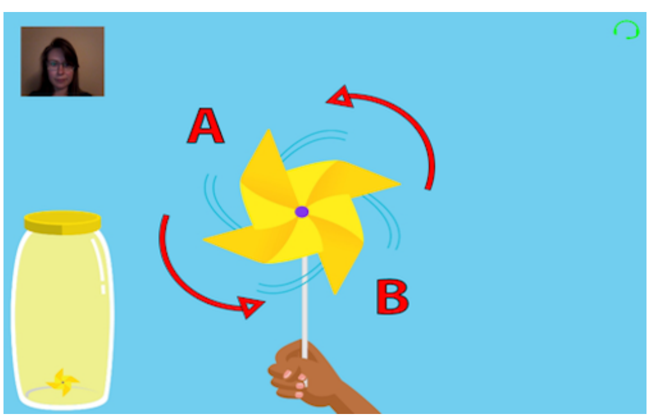

Figure 1: Pinwheel game. Blowing softly on pinwheel calms the brain causing pinwheel to spin counterclockwise A to B.

Our Mind-Full system uses a BrainLink Pro[1] EEG headset to wirelessly transmit brainwave data into a Unity 3D game engine running on an Android tablet. BrainLink is a commercially available EEG headset that uses the Neurosky chip and only one dry electrode to record electrical activity in the left pre-frontal cortex. Compared to most EEG units, it is robust, non-invasive, adjustable, and easy to wear due to the single dry electrode. It is inexpensive ($99 USD) compared to clinical EEG headsets. A predecessor of the system was validated in terms of its ability to reliably measure attentional states using a proprietary algorithm [30]. Our own tests have shown that the headset can differentiate between anxiety and attention in young adults. The headset sends processed and raw brainwave data via Bluetooth to the Unity application, where it is analyzed and used to control game mechanics, and interface and output elements.

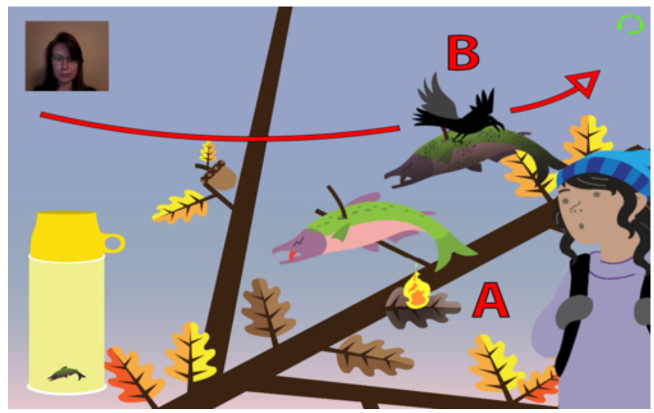

Figure 2: Salmon game. Blowing softly on the ember (A) creates a flame and smokes the salmon, which is then stolen by the raven (B).

There were two types of games to help children learn how to self-regulate anxiety by calming their body and brain. One type of game helps children learn to relax a little by breathing. We refer to the three variations of this breathing-relaxation game as Pinwheel, Salmon, and Squirrel. In the Pinwheel game, we represent relaxation using a familiar metaphor — a pinwheel (Figure 1). The child user sees an animation of a girl softly blowing on a pinwheel, which spins. Next, it is the child's turn. Like the animated girl, the child softly blows on pinwheel image, which relaxes her body, thus shifting her brain state toward a relaxed state (lower alpha brainwave frequency). The EEG sensor uses a proprietary algorithm to determine a "relax" index. When the index passes a threshold, the game triggers an animation of the pinwheel spinning. If the threshold is maintained for a set amount of time, the child earns a token. In the Salmon game, the child must blow

[1] http://store.neurosky.com/collections/brainlink-pro

on an ember to start a fire to smoke a salmon, which a pesky raven steals (Figure 2). The child must enact the same slow breathing but in a different context.

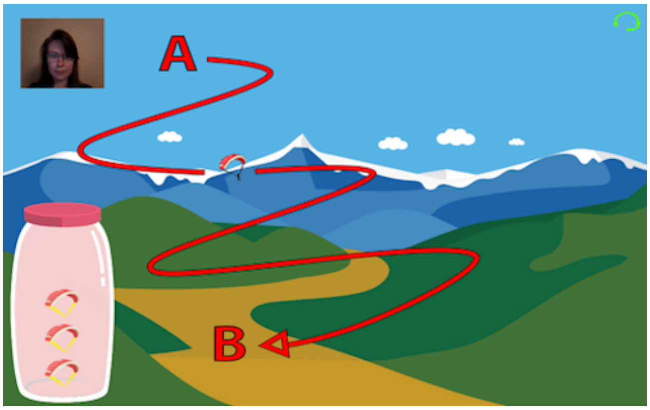

Figure 3: Paraglider game. Relaxing whole body as if lying in the field calms the brain, landing paraglider from A to B.

The other type of game teaches children how to use their body to sustain a relaxed brain state by becoming and then remaining relaxed in their body. We refer to the three variations of this sustained relaxation game as Paraglider, Bear, and Sasquatch. In the Paraglider game the child must relax their body and stay calm to land the paraglider (Figure 3). In the Bear game, the child must stay relaxed and calm to stay hidden so they can take a photograph of a bear who cautiously approaches, drawn by the scent of the salmon carried by the raven (Figure 4). All together our system contains six games (three of each type) that help children learn self-regulation of anxiety by learning to calm themselves. We created six games to address concerns of reduced engagement and enjoyment cited in [19].

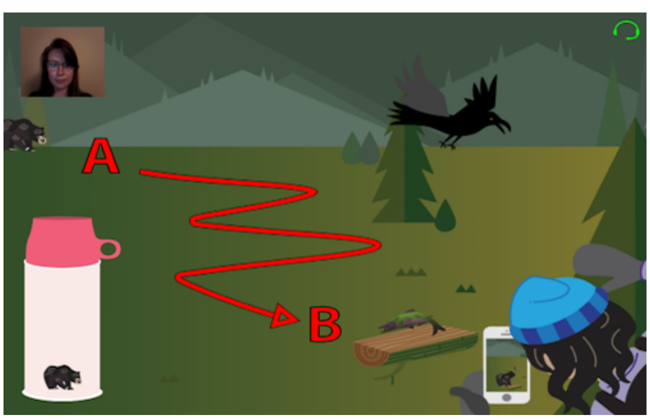

Figure 4: Bear game. Staying calm hides the user so bear advances from A to B where it is captured on phone.

The key characteristics of each game follow design principles from [2]. For example, each game uses a form of embodied metaphor that relates body and brain states (source domain) to a familiar activity for this population (target domain). In this way children can learn how to use their body to regulate their mind and receive positive or corrective feedback through the simple animated game responses (e.g. pinwheel spins or stops, ember turns to flame or goes out, bear advances or recedes).

4 METHODOLOGY

We conducted a 2x3 randomized controlled experiment with 20 young (aged 5 to 8 years) children, split into two groups, to determine the impact of the Mind-Full intervention on young children's anxiety and stress levels. The children were recruited from two lower SES schools that served diverse and multi-ethnic populations, including aboriginal children, recent immigrant and refugee children. Many of the children had suffered from trauma due to family dysfunction, refugee status, marital break-ups and/or other factors related to living in lower SES situations. Children were drawn from Kindergarten, grade one or two classrooms, representing the span of the target age for our system. Half the children participated in 18 individual, facilitated sessions with Mind-Full over seven weeks during school hours.

There are two independent variables: group (intervention, control) and assessment time (pre-test, post-test, follow-up test). Assessment time is named relative to the intervention group, however all the children were assessed at pre and post-test points. We also report data for the intervention group (only) at nine week follow-up. For ethical reasons (for example, see [1]), the control group was later able to do the intervention but we do not report that data here. The control group provided a comparative group to account for children's social-emotional learning in the classroom and/or at home and other maturation or developmental effects. Ethics approval to conduct this research was obtained from Simon Fraser University (Burnaby, Canada) and the Burnaby School District.

Research Questions and Hypotheses

We investigated two constructs: **viability**, which we defined as the ability to *self-regulate during gameplay*, and to *complete* the intervention at school; and **effectiveness**, which was the impact of the intervention on anxiety (see Table 1). We operationalized effectiveness in three ways: 1) behaviors related to the use of *self-regulation skills related to anxiety* in situations at school and home; 2) levels of *anxious behaviors* at school and home; and 3) physiological measures of *stress* at school only. We provide details of measurement below under data collection and analysis.

We measured viability to ensure children in the intervention group could use our system to learn to self-regulate during gameplay and complete the intervention. We also observed early sessions, and analyzed facilitator's observation notes to look for any usability or usage issues. We measured effectiveness to understand the impact of the intervention, which addresses our overarching research question. Effectiveness was measured to determine how well children could use self-regulation skills during stressful events at school and home. An assumption here is that if children in the intervention group are better at using self-regulating skills after the intervention (i.e. at post-test) compared to the control group, then they learned that from the intervention and were able to transfer this learning into other situations. Any other self-regulation learning that occurred would have randomly occurred in classrooms or homes; and groups were chosen to have equal numbers of children from different classrooms.

We also measured all children's anxious behaviors at school and home and stress levels at school because for children who have suffered trauma or live in lower SES situations, it was possible that children in the intervention group might get better at self-regulating during stressful events but that their overall levels of anxiety and stress would not change. We did not measure stress level at home because we use salivary cortisol tests (details below), which we were not able to administer in a home setting. Our specific research questions and directional hypotheses, where appropriate, follow:

RQ1. *Is our system a viable neurofeedback intervention that can help children learn to self-regulate anxiety during gameplay?*

H1.1 Children in the intervention group will be able to successfully self-regulate anxiety to play the games over the course of their intervention.

H1.2 Children in the intervention group will be able to complete the intervention (i.e. receive five tokens per each game in 18 sessions over seven weeks).

RQ2. *Can children effectively transfer their ability to self-regulate anxiety learned during the intervention to other contexts where they are anxious (school, home)?*

H2.1 There is no significant difference *between* the intervention and control groups on behavioral measures of their ability to self-regulate anxiety at pre-test (i.e. groups are equivalent before the intervention starts).

H2.2 There is a significant difference *between* the intervention and control groups on behavioral measures of their ability to self-regulate anxiety at post-test.

H2.3 There is a significant improvement *within* the intervention group on behavioral measures of ability to self-regulate anxiety from pre-test to post-test.

H2.4 Any improvement *within* the intervention group on behavioral measures of ability to self-regulate anxiety from pre-test to post-test will be maintained at follow-up test.

RQ3. *Are children's anxious behaviors reduced after the intervention (school, home) compared to the control group?* We expect that children in the intervention group will improve their ability to self-regulate anxiety at school and at home (H2.2-2.3). However, we cannot necessarily expect that they will experience fewer episodes of anxiety. There are many events in each child's life that contribute to their experiences of anxiety. The intervention does not impact the causes of anxiety, nor do we have control over these events. For RQ3, our expectation is that children's behaviors that indicate they are experiencing anxiety, in both groups, will fluctuate over the course of the intervention. It is possible that a child's improved ability to self-regulate will mean that a parent or teacher may not notice behaviors related to anxiety as often. That is, the anxiety is still present, but the child can deal with it more effectively and as a result show less behavioral evidence of anxiety.

RQ4. *Are children's physiological levels of stress reduced after the intervention at school compared to the control group?* As a result of being better able to self-regulate anxiety, we might expect that children's overall stress levels would decrease. However, they may still have events in their lives that cause elevated stress levels. As a result, we have no directional hypotheses for this research question.

Participants

Thirty-two children were identified by school principals, counselors and teachers at two elementary schools in a lower SES urban area of Canada. The primary criterion for initial selection was qualitative identification of severe challenges with anxiety and/or attention, since these are often correlated. Of the 32 children identified, 30 children and their parents provided assent/consent to participate. We screened the children in two ways. At pre-test, the teachers were interviewed about the nature of each child's learning and anxiety challanges, other challenges, and personal characteristics. We also administered the teacher Self-Regulation of Anxiety survey (described below). Of the 32 children, 20 met the criteria for severe challenges with anxiety and age appropriate cognitive functioning, resulting in a sample size of 20 children with severe anxiety.

Children's teachers and parents also had to provide consent as they participated in classroom coaching activities (teachers) and assessment (teachers and parents) as described below. Based on the results of pre-test teacher interviews, we formed 10 matched pairs of children based on school, grade, gender, anxiety challenges, and personal characteristics. One child from each pair was randomly assigned to the intervention group and one to the control group. The end result was 14 males, 6 females split evenly across the two schools and groups. Six children were in kindergarten, four children were in grade one and eight children were in grade two. The children's ages ranged from 5 to 8 years old and changed over the study duration. All children had good verbal mastery of the English language.

Figure 5: Child using the Mind-Full system in study setting.

Procedure

The Mind-Full intervention was delivered to the intervention group in 15-20 minute pull-out sessions in a quiet counseling room at each school (Figure 5). They were facilitated by a recently graduated social worker. Sessions were delivered over seven weeks with a frequency of three times per week, and a final week for make-up sessions. The length, frequency and number of sessions was based on other successful NF studies with children (e.g. [10, 13, 19, 33]) and determined based on the constraints of each school's classroom schedules. Children played one relaxation and one sustained relaxation game in each session, switching to new games every 6 sessions, for a total of 18 sessions. All children played the same games in the same order. Make-up sessions (e.g. due to illness) were facilitated by the social worker or an educational assistant (EA) trainee who had a relationship with all the children. Both the social worker and EA trainee were trained by the PI (Antle) on the project.

Each child was introduced to the Mind-Full system using a scripted protocol. In each session, children were instructed on how to use breathing or body relaxation to change their brain state and cause game effects (e.g. pinwheel spin, bear approach) and earn tokens in the games. Session coaching involved helping children understand the relationship between their body and brain (e.g. breathing calms the brain, relaxing the body from feet all the way up to head helps body stay relaxed). Note that all children in the study had previously been exposed to these practices in other classroom interventions. Each session was also facilitated with a scripted protocol designed to build rapport, identify daily stresses, and encourage the children to focus on practicing rather than succeeding at playing the games. Sessions began and ended by asking/reminding children to use self-regulating strategies outside of the intervention.

The PI monitored early and intermittent sessions and reviewed detailed facilitator observation notes to ensure protocol compliance. Teachers were also trained to use small laminated posters, containing simple images and phrases taken from the intervention, to support children to transfer self-regulation from the games into the classroom. For example, one poster was an image from the Pinwheel game showing an illustration of a girl blowing on a pinwheel and included text for the teacher to read, "Calming down…imagine blowing on a pinwheel — slow deep breaths." All classrooms in both schools with students in the study were given posters. Teachers were asked to explain these materials to all the students in their classes, relating them to other mindfulness practices they used. This ensured that both intervention and control students were exposed to the classroom materials.

Data Collection

We addressed RQ1 (**viable**) with structured observational notes taken by the facilitator for every session, which enabled us to determine the number and duration of sessions for each child in the intervention group. We also determined if each child, in each session could successfully complete each of the two games by receiving five tokens (i.e. play successfully five times).

In order to address RQ2 (**effective**), we assessed each child's ability to self-regulate anxiety (*SRAnx*), that is to calm down in a variety of situations at school and home. We used a teacher version of a short survey that was used in a previous study [3]. In previous work, the survey was shown to be reliable (Cronbach's $\alpha > 0.70$) and sensitive to change over time. The construct *SRAnx* was measured with five statements, each related to the child's ability to calm themselves down in different situations at school (teacher) or home (parent), and a five point rating scale ranging from "Can do this mostly by themselves" (5) to "Cannot do this at all even with support" (1). The main difference in the survey we used in this study compared to [3] is that we removed one question that was not found to be sensitive to change and replaced it with a question that was contextually relevant for the current study. Sample questions include: *Child can calm down when they are having difficulty with some schoolwork* and *Child can calm down after a stressful event in the playground.* We also adapted the teacher version to create a parent version that assessed the same behaviors but in a home setting. Sample questions include: *Child can* *calm down when they are having difficulty with a task at home* and *Child can calm down after a stressful event at home*.

We assessed all the children at pre-test, post-test and the intervention group at follow-up test with the *SRAnx* surveys. Translators were assigned to parents who were not fluent in English. Teachers were given dedicated time to administer the surveys while substitute teachers taught their classes. There was likely bias in the teacher and parent survey assessments since they were not blind to condition. However, in line with other studies and recommendations [12], children's teachers and parents are best suited to assess children's ability to self-regulate anxiety at school and at home. We interpret results with caution and used multiple measures to improve validity.

In order to address RQ3, children's levels of anxious behaviors, we used the Behavior Assessment System for Children (BASC-3) Survey, subscale: anxiety for teachers and for parents [32] at the same test points as *SRAnx*. The BASC-3 teacher rating scales are a comprehensive measure of problem behaviors in school settings. We used the survey for ages 6 through 11. The survey contains statements with descriptors of 16 behaviors relaxed to anxiety and a 4 point rating scale related to frequency of observed behavior, ranging from never (1); sometimes (2); often (3); and almost always (4). Sample statements include: *Has panic attacks*; *Appears tense*; and *Overreacts to stressful situations*. The BASC-3 has excellent test score reliability (i.e., mid-.80s or higher) [32]. Parents also filled out the BASC-3 anxiety subscale, which was comprised of 21 questions and the same 4 point scale. In cases where a parent or primary caregiver was not fluent in English we assigned a translator to work with the parent and translate the survey.

We addressed RQ4, stress level, by measuring salivary cortisol levels, which provide an objective, biological indicator of stress and have been validated with young children (e.g. [22, 26]). Salivary cortisol is increasingly being used as an indicator of children's stress related experience in the classroom. For example research with preschoolers found that higher levels of teacher-child conflict were associated with increased levels ofchildren's cortisol during interactions with teachers [22]. Higher cortisol levels in 5^{th} grade students may be linked to mental health issues [28].

A normal pattern for cortisol in typical children is that levels rise within 20 to 45 minutes after waking and then gradually decline throughout the day. Abnormally high, low, or flat levels of cortisol throughout the day may indicate dysregulation associated with high stress levels. We took salivary cortisol swabs at pre-test and post-test following standard procedures for testing with children (e.g. [16, 17]). For example, we collected samples at set times of day (9:15 am, 11:30 am, 2:30 pm) and had children avoid vigorous exercise or food intake prior to sampling. The session facilitators and researchers worked with the children in small groups to take the swabs at the set times at the two schools over two adjacent days. We created a 60 second song about delicious foods to help the children salivate (an issue reported in [17]) and also so they would keep the swabs in their mouth for the full 60 seconds. We also encourage children to remain calm during the testing. Samples were kept cold and picked up at the end of each day by courier. They were shipped to the Clemens Kirschbaum laboratory at the Dresden University of Technology in Germany for analysis. The lab uses a standard procedure as reported in [28]. Based on the data received from the lab, we calculated three cortisol measures per child: morning level, and average and decline (slope) during the school day. We also determined if the daily pattern was irregular.

Table 1: Constructs, dependent variables and measures.

Construct	Operational Definition	Variable Name	Measurement Instrument
1 Viable (intervention group only)	SR in games	SRGame	Structured obs (facilitator)
	completion of sessions	Completion	Structured obs (facilitator)
2 Effective (both groups at pre & post, intervention only at f-up)	Use/Transfer of anxiety SR behaviors to non-gameplay contexts	SRAnx-S (school)	Calm survey (teacher)
		SRAnx-H (home)	Calm survey (parent)
3 Effective (both groups at pre & post, intervention only at f-up)	Anxious behavior levels	Anxiety-S (school)	BASC-3 survey (teacher)
		Anxiety-H (home)	BASC-3 survey (parent)
4 Effective (both groups at pre & post)	Physiological stress levels	Cortisol (school)	Salivary cortisol tests (researchers)

Data Analysis

RQ1: We used facilitator's detailed session notes to calculate the number and duration of sessions for each child in the intervention group. We also determined if each child, in each session could successfully collect five tokens in each game, and made notes of usability or learning challenges.

RQ2: Since the survey for the RQ2 construct self-regulation of anxiety (*SRAnx*) was a variation of a previously published instrument, we assessed its reliability using Cronbach's alpha, which is a measure of the internal consistency or the extent to which all the items in a survey measure the same construct. There is different advice about the satisfactory level of reliability, ranging from 0.7 to 0.9 [9]. We used SPSS to run reliability analysis. For Cronbach's alpha values of 0.8 and above, we included all questions. When values were less than 0.8, if deleting any items could increase the overall reliability above 0.8 we removed them to improve the reliability of the construct measure as is standard practice in survey development [9]. The RQ3 BASC-3 *Anxiety* measure has already been shown to be valid and reliable so we included all questions for the *Anxiety* construct [32].

For all survey data we used SPSS to check for assumptions of normality (Shapiro-Wilks' test) and equal variance (Levene's test) and examined frequency distributions to explore deviations. We generated descriptive statistics (mean, standard deviation) and ran mixed 2x2 (repeated measures) ANOVAs for each dependent variable to determine the impact of group and test point (pre and post). We ran repeated measures t-tests on intervention group data from post to follow-up. We used an alpha level of .05 for all statistical tests. ANOVAs are robust to violations of normality. Where there were violations in assumptions we state results with caution.

RQ4: Results from cortisol tests indicated that there were missing values (either no test or empty vial), significant events that impacted results (e.g. crying, sick), and cases where the test protocol had not been followed (e.g. child had just exercised, consumed orange juice, taken asthma or cold medication). These values were excluded. Exploration of remaining values for morning, average and slope of cortisol levels showed high individual variability, which has been found to be the case for children in other studies [36]. In addition, the covariate of school was found to affect cortisol measures. Due to high variability and low sample size, we chose to conduct a frequency analysis of individual cases. Previous research has established norms for cortisol levels for 5 to 10 year olds throughout the day in the 5th, 50th and 95th percentiles [27]. Interpolation between the 50th and 95th percentiles is nonlinear and would require complex modeling, so we chose the 50th percentile norms. Using this data we calculated thresholds for morning, average daily and daily decline based on our sample times. For each child and test point we determined if their cortisol variables were above the 50th percentile and noted irregular patterns. We then compared all counts across groups and test points.

5 RESULTS

RQ1. Viability of Intervention

All children were able to learn to use their bodies to change their brain states enough to play the games and receive tokens. With coaching and patience, children were able to complete 18 sessions, receiving five tokens in each of the two games per session. Each session included, on average, about 10 minutes of gameplay. A technical challenge was that the headset occasionally disconnected from the tablet, requiring restarting.

RQ2. Self-Regulation of Anxiety

The *SRAnx* survey measures children's ability to self-regulate their anxiety, as rated by either their teacher or parent. The Cronbach's alpha at each test point then ranged from α = 0.81 to 0.89, which is within an acceptable range [9]. Distributions were not normal for the intervention group at post and follow-up test points (positive skew, which is typical of Likert data). All datasets had equal variances. Descriptive statistics comparing teachers' ratings for *SRAnx* for each group at each test point are shown in Table 2. We ran a two-way mixed ANOVA on a sample of 19 participants (one child moved before post-test survey) to examine the effect of group and test point on average *SRAnx* score. Results indicated a significant interaction between the effects of group and test points on *SRAnx* score, $F(2,18) = 4.868$, p =.041 with a small effect size (η_p^2 = .222). As hypothesized (H2.1) simple main effects analysis showed no significant difference (p = .525) at pre-test between the intervention and control groups. Contrary to our hypothesis (H2.2) there was no significant difference (p = .390) at post-test between the groups. In alignment with our hypothesis (H2.3) the within group analysis results indicated that the intervention group improved significantly (p = .010), from pre-test to post-test. As hypothesized (H2.4), a t-test showed that this improvement was maintained (p = 1.00) at the follow-up test.

Table 2: Teacher rating (5-1) ability to self-regulate anxiety.

Measure	Group	Mean	Std. Dev.	N	*p*
Teacher	Interv'n	2.88	.945	10	n.s
SRAnx @ Pre-test	Control	3.11	.574	9	
Teacher	Interv'n	3.43†	.834	10	n.s
SRAnx @ Post-test	Control	3.06	.990	9	
Teacher	Interv'n	3.43††	.858	10	N/A
SRAnx @ Follow-up	Control	N/A	N/A	0	

†within intervention group difference p =.10;
††gain maintained p = 1.00.

For the parent ratings on *SRAnx* we assessed the internal-consistency reliability of our five items using Cronbach's alpha at each test point. The reliability was improved by removing Q4 (Child can calm down after a transition). The resulting Cronbach's alpha at each test point then ranged from α = 0.80 to 0.93. All datasets had equal variances and normal distribution. Descriptive statistics comparing parents' ratings for *SRAnx* for each group at each test point are shown in Table 3. We ran a two-way mixed ANOVA on a sample of 16 participants (4 parents did not return surveys) to examine the effect of group and assessment period on average *SRAnx* score. Main effects analysis showed that test period was approaching significance (p = .058) and group had a significant impact, $F(1,15)$ = 4.761, p = .047) on *SRAnx* with small to medium effect size (η_p^2 = .254). Post-hoc analysis showed that contrary to our hypothesis (H2.1) there was a significant difference at pre-test (p = .014) between the two groups. Also contrary to our hypothesis (H2.2) there was no significant difference (p = .277) at post-test between the groups, largely because the intervention group improved to the level of the control group. In alignment with our hypothesis (H2.3) the within group analysis results indicated that the intervention group showed significant improvement (p = .014) from pre-test to post-test. As hypothesized (H2.4), a t-test showed that this improvement was maintained (p = .395) at the follow-up test.

In summary, we have evidence that teachers rated groups equivalent at pre-test but not parents (H2.1); no evidence for between group effects at post-test at school or home (H2.2); positive evidence for within group gains in the intervention group at both school and home (H2.3), which were maintained at follow-up at school and home (H2.4). We interpret these results with caution due to the small sample size and since some of the data was not normally distributed.

Table 3: Parent rating (5-1) ability to self-regulate anxiety.

Measure	Group	Mean	Std. Dev.	N	*p*
Parent *SRAnx* @ Pre-test	Interv'n	2.91	.667	8	***p*=.014***
	Control	4.02	.898	8	
Parent *SRAnx* @ Post-test	Interv'n	3.59†	.865	8	n.s
	Control	4.05	.732	8	
Parent *SRAnx* @ Follow-up	Interv'n	4.02††	.694	7	N/A
	Control	N/A	N/A	0	

*between group significant difference at pre-test at p < .05 level

†within intervention group pre to post difference p = .014.

††gain maintained p = .395.

RQ3. Anxious Behavior

The *BASC-3 Anxiety* subscale survey measures children's behaviors that indicate anxiety, as rated by either their teacher or parent. For the teacher survey, Cronbach's alpha at each test point then ranged from α = 0.70 to 0.89. Distributions were normal and all datasets had equal variances. Descriptive statistics comparing teacher ratings of *Anxiety* for each group at each test point are shown Table 4. We ran a two-way mixed ANOVA on a sample of 19 participants to examine the effect of group and test point on average *Anxiety* score. Results showed no significant effect of group on *Anxiety* at either pre-test or post-test. There was no significant difference within the intervention group between post-test and follow-up. The groups were equivalent at pre-test as expected, but teachers did not see a change in the numbers or kinds of anxious behaviors over the course of the study between or within groups.

Table 4: Teacher BASC-3 rating (1-4) anxious behaviors.

Measure	Group	Mean	Std. Dev.	N	*p*
Teacher *Anxiety* @ Pre-test	Interv'n	2.05	.272	10	n.s.
	Control	2.00	.601	9	
Teacher *Anxiety* @ Post-test	Interv'n	1.99	.301	10	n.s
	Control	2.06	.571	9	
Teacher *Anxiety* @ Follow-up	Interv'n	2.05	.319	10	N/A
	Control	N/A	N/A	0	

For the parent *Anxiety* survey Cronbach's alpha at each test point then ranged from α = 0.80 to 0.91. Distributions were normal and all datasets had equal variances. Descriptive statistics comparing parents' ratings for *Anxiety* for each group at each test point are shown in Table 5. We ran a two-way mixed ANOVA on a sample of 16 participants. Results indicated a significant interaction between the effects of group and test points on *Anxiety* scores, $F(2,15)$ = 6.988, p =.019 with a medium effect size (η_p^2 = .333). Simple main effects analysis showed a significant difference (p < .001) at pre-test between the intervention and control groups, that is parent's rating indicated that the groups were non-equivalent at pre-test. There was no significant difference at post-test between the groups, largely because the intervention group improved and the control group's behavior deteriorated. The within group analysis results indicated that the intervention group improved significantly (p = .012), from pre-test to post-test and a t-test showed that this improvement was maintained (p = .742) at the follow-up test.

RQ4. Stress Levels (Salivary Cortisol)

Our viability analysis of samples showed that in the intervention group of the 60 samples (ten children x three daily samples x two test points) there were 15 protocol issues,

Table 5: Parent BASC-3 rating (1-4) anxious behaviors.

Measure	Group	Mean	Std. Dev.	N	*p*
Parent *Anxiety* @ Pre-test	Interv'n	2.66	.476	8	***p*<.001***
	Control	1.76	.274	8	
Parent *Anxiety* @ Post-test	Interv'n	2.17†	.471	8	n.s
	Control	1.91	.402	8	
Parent *Anxiety* @ Follow-up	Interv'n	2.12††	.274	7	N/A
	Control	N/A	N/A	0	

*between group significant difference at pre-test at $p < .001$ level
†within intervention group pre to post difference $p = .012$.
††gain maintained $p = .742$.

Table 6: Count of cortisol variables above 50^{th} percentile.

Group	Morning		Daily Ave		No Decline		Irregular	
	pre	post	pre	post	pre	post	pre	post
Interv'n	6/9	4/10	7/8	4/4	7/8	3/7	9/9	4/8
Control	5/7	8/10	8/8	8/8	8/8	8/9	6/7	5/9

one empty sample and one major event resulting in 43 viable samples. In the control group there were nine protocol issues, one empty and six missing samples, resulting in 45 viable samples. At pre-test morning cortisol levels were above the 50^{th} percentile for over half the children in both groups (Table 6). At post-test this count dropped for the intervention group and increased for the control group. Almost all the children had average daily cortisol above the 50^{th} percentile, and this did not change over the course of the study. At pre-test the expected decline in cortisol level over the day was seen for only one child. However, at post-test just over half the children in the intervention group had the expected decline and only one in the control group. Most children had an irregular cortisol pattern at pre-test and this dropped for both groups at post-test.

Methodological Limitations

Despite the strengths of our random assignment, control group and mixed measures experimental design, there are many limitations working in the field with children with behavioral problems. The small number of children in our sample and small effect sizes of some of our results reduce the strength of claims that we can make about effectiveness. However, working with a larger sample was not possible without introducing more facilitators, which would introduce another variable. The ability of a facilitator to build rapport with a child and coach them successfully is required for any successful intervention. Mind-Full is simply a tool, which must be used in competent hands. Our study design does not disambiguate the impact of facilitator from tool in causing positive outcomes.

Our assessors for survey measures and interviews were not blind to condition, since teachers had to coordinate session schedules and we assumed that these young children spoke about doing the intervention with their teachers and parents. Both self-regulation and anxiety are internal states, and any behavioral measures are proxies at best. Self-reports might address this and are often used in studies with older children. We did collect this data but realized quickly that it was completely unreliable (e.g. children not wanting to admit anxiety, children wanting to please facilitator, children over dramatizing etc.). Only 16/20 parents returned the surveys, despite our many efforts to administer and collect them. It is possible that this introduces a bias to our parent results. Parents that did not return surveys might have been higher on measures of adverse child-rearing practices, which may further heighten behavioral and neurophysiological impacts of stress. However, for this demographic, 80% return rate is substantial, perhaps indicating parents who were committed to their child's well-being. It is difficult to know. We could explore the correlation between missing parental surveys and a child's cortisol levels, however, there are likely many factors at play.

While testing cortisol levels adds an objective measure, we were not clear if our intervention would significantly impact irregular patterns, which are manifestations of dysregulation associated with high stress levels over time. In addition, testing cortisol levels has challenges due to the nature of pulling children from class, taking them to a sampling room, and conducting tests with peers nearby. All of these factors may have contributed to variable or heightened cortisol, although it takes roughly 20 minutes for raises in cortisol levels (e.g. from running down the hall) to impact salivary levels. There were numerous protocol issues and adverse effects that impacted results, which could have been avoided if it was possible to test cortisol across several days.

6 DISCUSSION

In this research we investigated if a mobile, low-cost EEG-NF app, designed using existing guidelines and readily available technology, was viable when used in one-on-one pull-out sessions with highly anxious young children in lower SES schools. Our proof of concept suggests that this approach warrants attention as a way to address the growing gap between mental health challenges and support services for children, especially those who have behavioral issues and are difficult to access.

This is the first study to show that it is viable for a novice but trained facilitator to use an EEG-NF app in a school setting with young highly anxious children. After 18 sessions teachers and parents saw a noticeable within intervention group difference in most children's ability to self-regulate their anxiety in the classroom and at home. We tentatively suggest that this was a result of their ability to transfer, with teacher supports, self-regulation learning from the games into other contexts. We also assessed maintenance and saw that self-regulation gains were maintained over nine weeks. Parents but not teachers of the intervention group also saw a decrease in anxious behaviors at home, an effect also seen in [19]. This warrants further investigation. Between group effects at post-test were not significant and may have been impacted by high individual differences (between and within children) leading to variable data, as well as small sample sizes and having non-equivalent groups at pre-test for some measures (except the measure we used to create the groups). In summary, our findings are in line with studies that show improvement on behavioral measures of anxiety (e.g. [4, 19, 32]). However, we did not see between group effects cited in these papers.

Our methodological contribution included the use of a randomized (waitlist) control design, addressing concerns cited in [3, 11, 38]. However we were still limited to small sample sizes due to scheduling three sessions per week per child with a single facilitator (to control for facilitator-based differences). Another key contribution of our methodology was the development and reliability assessment of the *SRAnx* survey for teachers and parents, which measured children's ability to self-regulate anxiety rather than only looking at levels of anxious behaviors. We know of no other studies that have included a similar measure. Our measure enabled us to provide an indicator of *transfer* of learning from self-regulation in the intervention games to everyday life in the school and home, an issue raised in previous research (e.g. [4, 12, 36]) as well as maintenance of self-regulation ability.

Another challenge with existing studies is the reliance on non-blind assessments of behavior [12]. We think that parents and teachers are well suited to assess behaviors related to children's anxiety. However, to improve rigor we added an objective measure of stress; salivary cortisol tests. The test was difficult to administer in a school setting, but provided some evidence of the baseline stress level of our sample, and showed some positive change for the intervention group. Overall, we have contributed a detailed description and suggestions for improvement of our methodology, which can support other researchers working in mental health app development to understand the ways in which they can rigorously evaluate effectiveness in the field.

In future work, we will analyze data from this study for children who had attentional challenges, focusing on self-regulation of attention, and including the waitlist control group's post-intervention data to improve sample size. Results will reveal if the gains seen for self-regulation of anxiety reported in this paper are also found for self-regulation of attention, as was seen in previous work [3]. We are also interested in determining if our approach and design guidelines result in effective EEG-NF apps for other emotion regulation areas such as pain, fear, sadness and anger. We have begun work on conceptual designs for these areas.

In addition, we are currently seeking funding to conduct a larger research project in which we will investigate if we can more directly impact clinical practice and/or mental health services. For example, we are planning to work with an anxiety clinic at a local children's hospital, which would enable us to have a greater sample size, a longer study duration and to understand how to adapt our intervention to a clinical setting. In addition, we need to determine how to better support and assess transfer and if additional coaching or sessions are needed, and at what frequency, to extend maintenance gains. To address individual differences seen in this study, we may adopt a mixed methods case-by-case analysis approach. This approach may also reveal socio-technological factors of importance (in addition to those reported in [4]), which would contribute to understanding how to deploy such interventions more broadly. In this case, we might include data collection and analysis investigating mediating factors such facilitator, family dynamics (as suggested in [38]), teacher and school; the impact of teacher stress levels and practices (as discussed in [28]); individual characteristics such as self-efficacy and perceived competence; and contextual factors at schools including children's feelings and opinions of safety and belonging (as suggested in [28]). Lastly, we would like to see future studies in which investigators measure the impact of long term NF interventions on brain structure and activity directly, which would address concerns that NF may only impact behavior (e.g. [40]).

7 CONCLUSION

Our research contributes to HCI for mental health by showing the viability of an anxiety intervention using a low-cost, mobile EEG-NF system with a marginalized, hard to reach population of young children. We hope our work contributes to the uptake of a research agenda in Positive Computing focusing on emotion regulation and socio-emotional learning for young children. We see NF apps like ours as a tool — one of many — needed through children's lives to help them overcome the negative impacts of poverty and trauma on brain development, and subsequent education and personal development. Our results are promising and we urge other researchers to explore how digital mental health applications can be used to support children and their caregivers from marginalized populations.

ACKNOWLEDGMENTS

Thanks to NSERC, Leslie Chesick, the Mind-Full development team, the Burnaby School District, Mia Cole for wrangling cortisol samples, and as always, special thanks to all children and their teachers for taking a risk.

REFERENCES

[1] Alissa N. Antle. 2017. The ethics of doing research with vulnerable populations. *ACM Interactions* 24, 6 (Oct. 2017), 74–77.

[2] Alissa N. Antle, Leslie Chesick, and Elgin-Skye McLaren. 2018. Opening up the design space of neurofeedback brain-computer interfaces for children. *ACM Transactions on Computer-Human Interaction* 24, 6 (Jan. 2018), 1–38.

[3] Alissa N. Antle, Leslie Chesick, Srilekha Kirshnamachari Sridharan, and Emily Cramer. 2018. East meets west: A mobile brain-computer system that helps children living in poverty learn to self-regulate. *Personal and Ubiquitous Computing* (June 2018), 1–28. https://doi.org/10.1007/s00779-018-1166-x

[4] Alissa N. Antle, Elgin-Skye McLaren, Holly Fiedler, and Naomi Johnston. 2019. Design for mental health: How socio-technological processes mediate outcome measures in a field study of a wearable anxiety app. *Proceedings of Conference on Tangible, Embedded and Embodied Interaction (TEI '19)*, in press.

[5] Katja Beesdo, Susanne Knappe, and Daniel S. Pine. 2009. Anxiety and anxiety disorders in children and adolescents: developmental issues and implications for DSM-V. *Psychiatric Clinics of North America* 32, 3 (Sept. 2009), 483–524.

[6] Rafael A. Calvo and Dorian Peters. 2014. *Positive Computing: Technology for Well-Being and Human Potential.* The MIT Press.

[7] Robert Coben, Emma Kate Wright, Scott L. Decker, and Tina Morgan. 2015. The Impact of Coherence Neurofeedback on Reading Delays in Learning Disabled Children: A Randomized Controlled Study. *NeuroRegulation* 2, 4 (Dec. 2015), 168. https://doi.org/10.15540/nr.2.4.168

[8] Adele Diamond, W. Steven Barnett, Jessica Thomas, and Sarah Munro. 2007. Preschool Program Improves Cognitive Control. *Science (New York, N.Y.)* 318, 5855 (Nov. 2007), 1387–1388. https://doi.org/10.1126/science.1151148

[9] Ellen A. Drost. 2011. Validity and reliability in social science research. *Education Research & Perspectives* 38, 1 (June 2011), 105–123.

[10] Holger Gevensleben, Birgit Holl, Björn Albrecht, Claudia Vogel, Dieter Schlamp, Oliver Kratz, Petra Studer, Aribert Rothenberger, Gunther H. Moll, and Hartmut Heinrich. 2009. Is neurofeedback an efficacious treatment for ADHD? A randomised controlled clinical trial. *Journal of Child Psychology and Psychiatry* 50, 7 (July 2009), 780–789. https://doi.org/10.1111/j.1469-7610.2008.02033.x

[11] Holger Gevensleben, Maike Kleemeyer, Lillian Geza Rothenberger, Petra Studer, Andrea Flaig-Röhr, Gunther H. Moll, Aribert Rothenberger, and Hartmut Heinrich. 2014. Neurofeedback in ADHD: Further pieces of the puzzle. *Brain Topography* 27, 1 (Jan. 2014), 20–32. https://doi.org/10.1007/s10548-013-0285-y

[12] John H. Gruzelier. 2014. EEG-neurofeedback for optimising performance. III: A review of methodological and theoretical considerations. *Neuroscience & Biobehavioral Reviews* 44 (July 2014), 159–182. https://doi.org/10.1016/j.neubiorev.2014.03.015

[13] John H. Gruzelier, Melissa Foks, Tony Steffert, Jeanlon Chen, and Tomas Ros. 2014. Beneficial outcome from EEG-neurofeedback on creative music performance, attention and well-being in school children. *Biological Psychology* 95 (Jan. 2014), 86–95. https://doi.org/10.1016/j.biopsycho.2013.04.005

[14] Megan Gunnar and Karina Quevedo. 2007. The neurobiology of stress and development. *Annual Review of Psychology* 58, 1 (Jan. 2007), 145–173. https://doi.org/10.1146/annurev.psych.58.110405.085605

[15] Daniel A. Hackman, Martha J. Farah, and Michael J. Meaney. 2010. Socioeconomic status and the brain: Mechanistic insights from human and animal research. *Nature Reviews Neuroscience* 11, 9 (Sept. 2010), 651–659. https://doi.org/10.1038/nrn2897

[16] Kirsten Hanrahan, Ann Marie McCarthy, Charmaine Kleiber, Susan Lutgendorf, and Eva Tsalikian. 2006. Strategies for salivary cortisol collection and analysis in research with children. *Applied Nursing Research* 19, 2 (May 2006), 95–101. https://doi.org/10.1016/j.apnr.2006.02.001

[17] Amanda G. Harmon, Leah C. Hibel, Olga Rumyantseva, and Douglas A. Granger. 2007. Measuring salivary cortisol in studies of child development: Watch out–what goes in may not come out of saliva collection devices. *Developmental Psychobiology* 49, 5 (June 2007), 495–500. https://doi.org/10.1002/dev.20231

[18] Jin Huang, Chun Yu, Yuntao Wang, Yuhang Zhao, Siqi Liu, Chou Mo, Jie Liu, Lie Zhang, and Yuanchun Shi. 2014. FOCUS: Enhancing children's engagement in reading by using contextual BCI training sessions. *Proceedings of the Conference on Human Factors in Computing Systems (CHI '14)*, 1905–1908. https://doi.org/10.1145/2556288.2557339

[19] Stuart J. Johnstone, Steven J. Roodenrys, Kirsten Johnson, Rebecca Bonfield, and Susan J. Bennett. 2017. Game-based combined cognitive and neurofeedback training using Focus Pocus reduces symptom severity in children with diagnosed AD/HD and subclinical AD/HD. *International Journal of Psychophysiology* 116 (June 2017), 32–44. https://doi.org/10.1016/j.ijpsycho.2017.02.015

[20] Michele Knox, J. Lentini, T.S. Cummings, A. McGrady, K. Whearty, and L. Sancrant. 2011. Game-based biofeedback for paediatric anxiety and depression. *Mental Health in Family Medicine* 8, 3 (Sept. 2011), 195.

[21] Choon Guan Lim, Tih-Shih Lee, Cuntai Guan, Sheng Fung DS, Yin Bun Cheung, S. S. Teng, Haihong Zhang, and K. Ranga Krishnan. 2017. Effectiveness of a brain-computer interface based programme for the treatment of ADHD: a pilot study. *Psychopharmcol. Bull* 43, 1 (June 2017), 73–82.

[22] Jared A. Lisonbee, Jacquelyn Mize, Amie Lapp Payne, and Douglas A. Granger. 2008. Children's cortisol and the quality of teacher–child relationships in child care. *Child Development* 79, 6 (Nov. 2008), 1818–1832. https://doi.org/10.1111/j.1467-8624.2008.01228.x

[23] Regan L. Mandryk, Shane Dielschneider, Michael R. Kalyn, Christopher P. Bertram, Michael Gaetz, Andre Doucette, Brett A. Taylor, Alison Pritchard Orr, and Kathy Keiver. 2013. Games As Neurofeedback Training for Children with FASD. *Proceedings of the 12th International Conference on Interaction Design and Children (IDC '13)*, 165–172. https://doi.org/10.1145/2485760.2485762

[24] John S. March. 2011. Looking to the future of research in pediatric anxiety disorders. *Depression and Anxiety* 28, 1 (Jan. 2011), 88–98. https://doi.org/10.1002/da.20754

[25] Anna-Maria Marx, Ann-Christine Ehlis, Adrian Furdea, Martin Holtmann, Tobias Banaschewski, Daniel Brandeis, Aribert Rothenberger, Holger Gevensleben, Christine M. Freitag, Yvonne Fuchsenberger, Andreas J. Fallgatter, and Ute Strehl. 2015. Near-infrared spectroscopy (NIRS) neurofeedback as a treatment for children with attention deficit hyperactivity disorder (ADHD)–a pilot study. *Frontiers in Human Neuroscience* 8 (Jan. 2015), 1038. https://doi.org/10.3389/fnhum.2014.01038

[26] Ann Marie McCarthy, Kirsten Hanrahan, Charmaine Kleiber, M. Bridget Zimmerman, Susan Lutgendorf, and Eva Tsalikian. 2009. Normative salivary cortisol values and responsivity in children. *Applied Nursing Research : ANR* 22, 1 (Feb. 2009), 54. https://doi.org/10.1016/j.apnr.2007.04.009

[27] Robert Miller, Tobias Stalder, Marc Jarczok, David M. Almeida, Ellena Badrick, Meike Bartels, Dorret I. Boomsma, Christopher L. Coe, Marieke C. J. Dekker, Bonny Donzella, Joachim E. Fischer, Megan R. Gunnar, Meena Kumari, Florian Lederbogen, Christine Power, Carol D. Ryff, S. V. Subramanian, Henning Tiemeier, Sarah E. Watamura, and Clemens Kirschbaum. 2016. The CIRCORT database: Reference ranges and seasonal changes in diurnal salivary cortisol derived from a meta-dataset comprised of 15 field studies. *Psychoneuroendocrinology* 73 (Nov. 2016), 16–23. https://doi.org/10.1016/j.psyneuen.2016.07.201

[28] Eva Oberle and Kimberly A. Schonert-Reichl. 2016. Stress contagion in the classroom? The link between classroom teacher burnout and morning cortisol in elementary school students. *Social Science & Medicine* 159 (2016), 30–37.

[29] Ken Porter. 2016. 2015 Mental Health Care System Survey Results. https://mdsc.ca/research/2015-mental-health-care-system-survey-results/ [Online; accessed 2018-12-30].

[30] Genaro Rebolledo-Mendez, Ian Dunwell, Erika A. Martínez-Mirón, María Dolores Vargas-Cerdán, de Sara Freitas, Fotis Liarokapis, and Alma R. García-Gaona. 2009. Assessing NeuroSky's Usability to Detect Attention Levels in an Assessment Exercise. In *Human-Computer Interaction. New Trends*, Julie A. Jacko (Ed.). Springer Berlin Heidelberg, 149–158. https://doi.org/10.1007/978-3-642-02574-7_17

[31] Franziska Reiss. 2013. Socioeconomic inequalities and mental health problems in children and adolescents: a systematic review. *Social Science & Medicine* 90 (Aug. 2013), 24–31. https://doi.org/10.1016/j.socscimed.2013.04.026

[32] Cecil R. Reynolds, Randy W. Kamphaus, and Kimberly J. Vannest. 2011. Behavior Assessment System for Children (BASC). In *Encyclopedia of Clinical Neuropsychology*. Springer, New York, NY, 366–371. https://doi.org/10.1007/978-0-387-79948-3_1524

[33] Elke A. Schoneveld, Monique Malmberg, Anna Lichtwarck-Aschoff, Geert P. Verheijen, Rutger C. M. E. Engels, and Isabela Granic. 2016. A neurofeedback video game (MindLight) to prevent anxiety in children: A randomized controlled trial. *Computers in Human Behavior* 63 (Oct. 2016), 321–333. https://doi.org/10.1016/j.chb.2016.05.005

[34] Stuart Shanker. 2010. Self-regulation: calm, alert and learning. *Education Canada* 50, 3 (2010), 105–138.

[35] Stuart Shanker. 2013. *Calm, alert, and learning: Classroom strategies for self-regulation.* Pearson.

[36] Elizabeth A. Shirtcliff, Amber L. Allison, Jeffrey M. Armstrong, Marcia J. Slattery, Ned H. Kalin, and Marilyn J. Essex. 2012. Longitudinal stability and developmental properties of salivary cortisol levels and circadian rhythms from childhood to adolescence. *Developmental Psychobiology* 54, 5 (July 2012), 493–502. https://doi.org/10.1002/dev.20607

[37] Petr Slovàk and Geraldine Fitzpatrick. 2015. Teaching and developing social and emotional skills with technology. *ACM Trans. Comput.-Hum. Interact.* 22, 4 (June 2015), 1–19. https://doi.org/10.1145/2744195

[38] Petr Slovàk, Nikki Theofanopoulou, Alessia Cecchet, Peter Cottrell, Altarriba Bertran, Ella Dagan, Julian Childs, and Katherine Isbister. 2018. "I Just Let Him Cry. . . ": Designing socio-technical interventions in families to prevent mental health disorders. *International Conference on Computer Supported Collaborative Work and Social Computing (CSCW'18)*, 160.

[39] Naomi J. Steiner, Elizabeth C. Frenette, Kirsten M. Rene, Robert T. Brennan, and Ellen C. Perrin. 2014. Neurofeedback and cognitive attention training for children with attention-deficit hyperactivity disorder in schools. *Journal of Developmental & Behavioral Pediatrics* 35, 1 (Jan. 2014), 18–27. https://doi.org/10.1097/DBP.0000000000000009

[40] Madelon A. Vollebregt, Martine van Dongen-Boomsma, Dorine Slaats-Willemse, and Jan K. Buitelaar. 2014. What future research should bring to help resolving the debate about the efficacy of EEG-neurofeedback in children with ADHD. *Frontiers in Human Neuroscience* 8 (May 2014). https://doi.org/10.3389/fnhum.2014.00321

[41] Peter A Wyman, Wendi Cross, C Hendricks Brown, Qin Yu, Xin Tu, and Shirley Eberly. 2010. Intervention to strengthen emotional self-regulation in children with emerging mental health problems: Proximal impact on school behavior. *Journal of Abnormal Child Psychology* 38, 5 (May 2010), 707–720. https://doi.org/10.1007/s10802-010-9398-x