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A Pilot Feasibility Study of Neurofeedback for Children with Autism

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Abstract Neurofeedback (NFB) is an emerging treatment for children with autism spectrum disorder (ASD). This pilot study examined the feasibility of NFB for children with ASD. Ten children ages 7–12 with high functioning ASD and attention difficulties received a NFB attention training intervention. A standardized checklist captured feasibility, including focus during exercises and academic tasks, as well as off-task behaviors. Active behaviors and vocalizations were the most frequent off-task behaviors. Positive reinforcement and breaks including calm breathing exercises were the most common supports. Low motivation was associated with higher feasibility challenges, yet parental involvement and accommodations were helpful. This pilot study shows that it is feasible to conduct NFB sessions with children with high functioning autism and attention difficulties.

Keywords Biofeedback · Autism spectrum disorder · Neurofeedback

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Introduction

Autism spectrum disorder (ASD) is a heterogeneous group of neurodevelopmental disorders that typically affects communication, social interaction, and restricted, repetitive or stereotyped behaviors (Johnson et al. 2007). Applied behavior analysis (ABA) has been shown to lead to both language and behavioral progress (Anderson and Romanczyk 1999; Harris and Delmolino 2002). Other types of behavioral interventions are available depending on age of child and state recommendations or educational preferences of school systems, but have not been subjected to adequate trials (Palmen et al. 2012). Pharmacological treatments are frequently used in children with ASD to attenuate symptoms of anxiety (SSRIs), to support focus (stimulant medication), or to decrease challenging behaviors (neuroleptics) (Langworthy-Lam et al. 2002). These pharmacological treatments aim to treat some symptoms of ASD, but are not cures.

Considering the high prevalence of attention difficulties in children with ASD, researchers, clinicians, and educators have an increased interest in studying specific forms of neurofeedback (NFB) that train attention for this population. Different NFB protocols such as brainwave case studies on Mu training (Pineda et al. 2008), Sensorimotor Rhythm (SMR) training (Sichel et al. 1995; Jarusiewicz 2002) and Beta training (Kouijzer et al. 2009) have been used and reported to treat children with ASD (Thompson

et al. 2010). A recent meta-analysis for children with ASD suggests that NFB is possibly efficacious (Coben et al. 2010). These study protocols use individualized assessment-based NFB training versus one standardized protocol for all children included in the study.

The behavioral characteristics of children with ASD can make it difficult for children with this disorder to adapt to stringent NFB protocols. Therefore children with ASD are often excluded from larger attention training studies. The current study assessed the feasibility of administering NFB attention training to children who have ASD and attention difficulties, looking specifically at adaptability to sessions and required modifications for support. In addition, unlike previous NFB studies using individualized protocols, the current study used a single standardized attention training protocol and a commercially available NFB system for all participants. This decision enabled researchers to examine a specific NFB training protocol that has the potential to be implemented on a larger scale.

Methods

Participants

Parents of children with ASD were informed of the research intervention through local ASD support listservs. Interested parents responded to the announcements. Boys and girls, 7 to 12 years of age, were recruited and enrolled to participate in the NFB intervention to take place daily, Monday through Friday, over a 6 week time period from mid-June until August 2011. Clinician and neuropsychological reports of the children were reviewed to establish confirmation of ASD diagnosis and significant attention difficulties. Children were eligible to enroll if: (1) their ASD diagnosis and attention difficulties were reported (see above), (2) they had an intelligence quotient (IQ) higher than 80, due to the cognitive demands of the NFB, as related studies have associated low IQ with diminished treatment effects (Owens et al. 2003), and (3) they had sufficient English ability to complete assessments and intervention protocols. The principal investigator (PI), a Developmental and Behavioral Pediatrician, read over all incoming clinician reports as well as individual education plans (IEPs) and latest school special education evaluations (which is repeated every 3 years in Massachusetts) to evaluate the level of functioning of the participants, the presence and severity of behavioral concerns, and possible classroom supports. She then decided whether or not to include the child in the study. Decisions were made independent of medication use. Medication use was tracked before and after the intervention. However, children were excluded if they had a coexisting diagnosis of another serious mental illness (e.g., psychosis). The study was approved by the Tufts Medical Center Institutional Review Board. Informed consent forms were obtained from parents, and participants provided informed assent.

Enrollment

If participants did not have documentation of IQ testing, the Kaufman Brief Intelligence Test-Second Edition (KBIT-2), a standardized and validated screening test of cognitive ability that takes approximately 20 min (Bain and Jaspers 2010), was administered. The KBIT-2 yields standard scores and percentile ranks by age for Verbal, Nonverbal and IQ composites. Background information consisting of demographic characteristics and treatment history was obtained.

Procedure

Families of 22 children initially requested additional information following the listserv announcements. Ten families ultimately chose not to participate due to logistical reasons related to the timing of the intervention during 6 weeks of the summer vacation or the difficulty in dropping off and/or picking up every day at the intervention location. Another two children were not eligible because they had an IQ below 80. In order to accommodate participants, researchers chose two convenient locations to conduct the sessions: at a public school that held a summer camp and at the local public library. All participating families were informed to continue attending regular appointments with their physicians and to continue ongoing treatments during the intervention.

Intervention

The specific NFB system used (Play Attention®) detects two frequency ranges, one in the low frequency theta brainwave range that has been associated with drowsiness (4–8 Hz), and another in the high-frequency beta brainwave range that has been associated with attention and concentration (12–15 Hz) (Unique Logic and Technology©, 2011). The brainwaves are measured by an EEG sensor centrally embedded in a standard bicycle helmet on the top of the skull. Two other EEG sensors are on the chin straps, located bilaterally on the mastoids. One of these is a grounding electrode and the other is the reference.

The system uses an algorithm that monitors theta and beta brainwaves and recalibrates every few seconds in order to challenge the student to progress on the cognitive exercises and raises the students' theta/beta ratio. The algorithm recalibrates should the theta/beta ratio become too difficult so that the interactive feedback remains

feasible yet challenging. Time on Task (TOT) is the percentage of time the student is able to meet and sustain this challenge requirement. An example of one exercise involves a dolphin swimming in the sea. As the child's focus increases, the prevalence of theta waves decrease relative to beta waves, and the dolphin swims towards the bottom of the ocean and collects coins (points) from a treasure chest. As the child becomes distracted or decreases focus and theta waves increase relative to beta waves, the dolphin swims towards the surface of the sea and no points are collected. As the children progress, through trial and error they learn to produce the desired outcome and reach higher, more challenging, levels. The computer interface provides children with constant and immediate auditory and visual feedback about their success in paying attention.

Research Assistants (RAs) completed a standardized training protocol, developed by the research team for a larger randomized control trial (RCT), so that all participants received the same intervention. Participants received sessions either alone or in pairs depending on scheduling logistics. Each session included 25–30 min of NFB, a break, 25 more minutes of NFB and a small prize for successful sessions. After the first week of the intervention, academic work (e.g., reading, math and writing) was incorporated into the sessions. The software measured brainwave activity as the child completed his/her academic work. As this was a feasibility study and children with ASD often have great difficulties with transitions, participants completed 3 min of relaxation breathing using a small biofeedback device (Helicor Inc. 2012) that measures heart rate variability to enable transitions into the sessions. Participants place their finger into a slot at the top of the device. While breathing deeply and calmly, activating their parasympathetic nervous system, participants can see their breathing patterns on a mini-LCD screen. This device is particularly appealing to children as they receive "points" for greater relaxation.

Primary Outcome Measures to Assess Feasibility

Fidelity to Intervention

Fidelity to the protocol was ensured in several ways. RAs received standardized training following a written protocol on how to administer the intervention to participants. This protocol has been used successfully in past and ongoing studies (Steiner et al. 2011). During the sessions, RAs prompted children if they became distracted, helped them set both behavior-related and exercise-related goals and evaluated their daily progress. If the participant was progressing successfully, the RA did not intervene. The PI observed each RA's sessions weekly, reviewed their Session Checklists to ensure persistent adherence to the protocol, facilitated weekly meetings to discuss progress of each of the participants in the program and gave feedback suggestions to RAs on how to make amendments.

Documentation of Intervention Implementation

Session Checklists were completed by RAs during each session with each participant, which documented fidelity to intervention, progress on the NFB exercises, maladaptive behaviors, and supports given by the RAs if required. See Table 1 for descriptions of maladaptive behavior. Progress on the NFB exercises was represented by the TOT percent, which was recorded after each exercise on the Session Checklists as an indicator of progress. These Session Checklists were used as a primary outcome measure for determining feasibility of this intervention.

Motivation Questionnaire

The Motivation Questionnaire was administered to participants at the end of each week (six times in the duration of the study). It consists of seven questions, designed specifically by the current research group to measure participant motivation level. The response categories ranged from (1-very untrue for you) to (5-very true for you). This tool, along with the Session Checklists and Feedback of Intervention questionnaires, has been used successfully in previous studies (Steiner et al. 2011). A total score of 26 or higher is considered motivated or highly motivated and a score of 25 or lower represents low motivation.

Feedback of Intervention Questionnaire

The Feedback of Intervention Questionnaire assesses parents' and participants' satisfaction with all aspects of the intervention. This questionnaire includes both open-ended and likert-scale format responses to rate specific aspects of the intervention, such as how helpful the intervention was

Table 1 Maladaptive behaviors

Type of behavior	Description
Active behavior	Moves on chair, fidgets, eyes off screen, repetitive movements/tics such as biting nails or tapping hands or feet
Makes noises	Vocalizations, talks (also to self), whistles
Upset/ frustrated	Grunts, screams, is loud, has temper tantrums
Impulsive	Acts or clicks mouse out of turn
Compliance	Refuses to follow directions, oppositional
Instructional issues	Does not understand or remember instructions well, requires additional support to complete task

in helping their child learn to concentrate better. If at least 2/3 of the responses were supportive of the intervention, the questionnaire feedback was considered positive. Parents reported on how helpful the NFB intervention was in helping their child concentrate and finish their homework.

Secondary Outcome Measures

Permanent Product Measure of Performance (PERMP)

The PERMP is a 10 min math test for children as young as 6 years of age (Wigal and Wigal 2006). It is used to obtain an objective measure of academic performance as well as the child's ability to pay attention and stay on task. Both the number of questions attempted and the number of questions answered correctly within 10 min are scored. For the purpose of the current study, the percentage of correct responses (# answered correctly/# attempted) was analyzed. The PERMP is an outcome measure often used to evaluate response to stimulant medication intervention for children with ADHD (Wilens et al. 2008).

Continuous Performance Test (CPT)

The CPT is a behavioral test of vigilance, impulsivity and response inhibition. The CPT provides an objective measure of visual and auditory attention skills (Pan et al. 2007). The specific CPT used is called the Integrated Visual and Auditory Test Plus (IVA + Plus). The IVA + Plus consists of Warm-Up, Practice, Main Test (13 min), and Cool-Down periods. The output of the IVA + Plus are quotient scores with a mean of one hundred and a standard deviation of fifteen.

Conners Rating Scale-Parent (CRS 3-P)

The CRS 3-P assesses ADHD-related symptomatology. All subscales display acceptable internal consistency, retest reliability, and factor structure (Conners et al. 1997, 1998; Collett et al. 2003; Kumar and Steer 2003). For the purpose of this study, ADHD specific (Hyperactive-Impulsive and Inattentive) subscales as well as the Global Index were analyzed.

Autism Spectrum Rating Scale (ASRS)

The ASRS is for 6–18 year olds, consists of 71 items that assess symptoms of ASD, and takes around 15–20 min for parents to complete. The response categories are: (0-never), (1-rarely), (2-occasionally), (3-frequently), and (4-very frequently). Conversion tables are used to convert raw scores to T-scores and percentile ranks. The ASRS has been validated against the CARS, the GARS and the GADS (Goldstein and Naglieri 2011). Percentiles from the DSM-IV, social/communication and sensory/sensitivity domains were analyzed, as these are the areas trained in this intervention.

Childhood Autism Rating Scale (CARS)

The CARS identifies the diagnosis of autism in individuals 3–22 years of age and estimates the severity of ASD. Standardized scores were used to calculate percentiles and a table for determining the likelihood that a child is autistic and the severity of the disorder if present are provided (Schopler et al. 1980). Fifteen criteria are rated on a scale from one to four with (1-normal for child's age), (2-mildly abnormal), (3-moderately abnormal), and (4-severely abnormal). The CARS has demonstrated adequate validity and reliability (Russell et al. 2010). Total scores are used to analyze this scale.

Statistical Analysis

For primary outcome measures, summary statistics for demographic information were reported as mean (SD). Time on Task during academic work was assessed for each participant by plotting the computer software output during academic work over time. Positive trend lines were indicators of improvement. The maladaptive behaviors in Fig. 1 are an average of the overall participant group over time. The number of participants changed over time as they varied in the total number of sessions they each completed. Participants ranked their motivation regarding the NFB program each week by answering the seven questions on a scale of one to five (low to high). Any total score less than 25 was classified as low motivation. For secondary outcome measures, statistical analyses were performed using SYSTAT (version 13, Systat Software, Inc. Chicago, IL). Parent questionnaires and child assessments were collected for baseline (week 0) and conclusion of intervention (week 6). Due to the small sample size, no control group, and paired nature of the data, the non-parametric Wilcoxon Signed Rank Test was used to assess changes over time and is reported using z-scores and p-values.

Results

Ten children (nine boys), 7–11 years of age with ASD and attention difficulties were enrolled. Nine of the children had one additional co-morbid psychiatric diagnosis or a developmental delay. See Table 2 for participant characteristics.

Primary Outcome Measures

Review of the RA's Session Checklists revealed that the NFB intervention was implemented successfully with

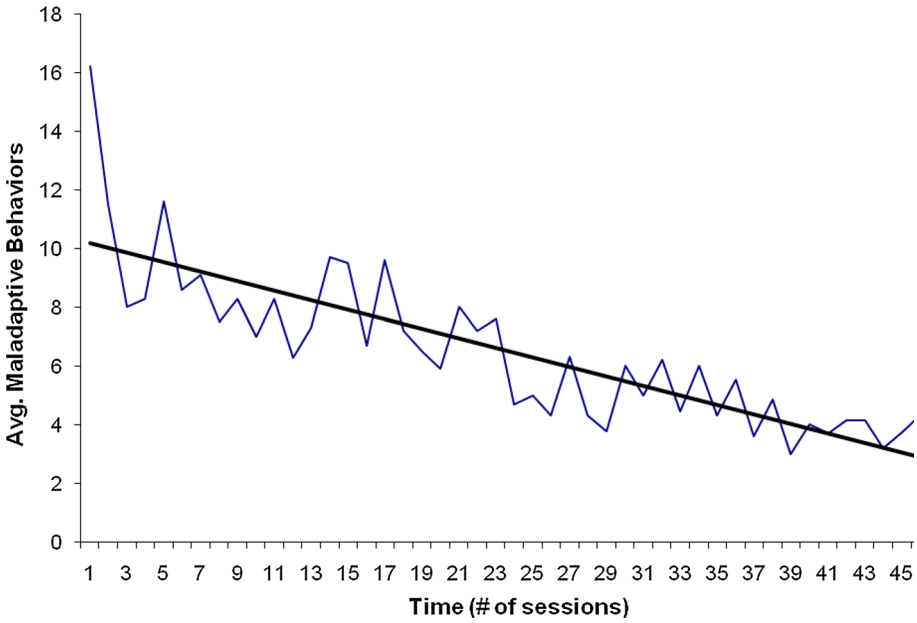

Fig. 1 Maladaptive behavior over time. The average of maladaptive behaviors for all participants at each session is depicted over the intervention period. A trend line was included to show change over time

Table 2 Participant characteristics

Child	Age	Gender	IEP status	Medication Usage	Co-morbidities
1	10	Male	Yes	No	Language delay
2	8	Male	Yes	Adderall	Speech delay
3	7	Female	No	No	Mitochondrial disorder, OCD
4	7	Male	Yes	No	Receptive and expressive language delay
5	9	Male	Yes	No	Sensory integration disorder, developmental coordination disorder, speech delay
6	9	Male	Yes	Adderall	Allergies, non-verbal learning disorder
7	11	Male	Yes	Strattera, risperidone, fluoxetine	Asthma, allergies, depression
8	11	Male	Yes	Concerta, methylphenidate, clonidine, trazodone	Anxiety
9	8	Male	Yes	No	Severe nut allergies
10	8	Male	Yes	Adderall	Allergies, asthma, language delay

fidelity to the protocol. Session Checklists showed that active behaviors and vocalizations were the most frequent maladaptive behaviors that affected participants' abilities to concentrate and remain focused. Positive reinforcement and breaks that incorporated breathing exercises were the most common supports given by the RAs. All participants decreased their maladaptive behaviors (e.g., active behaviors, vocalizations) over time, as recorded on the Session Checklists by the RAs throughout the course of the intervention. The Session Checklists documented that seven of the ten participants improved their TOT percent during academic work. Five of the ten participants improved their scores on TOT percent during the NFB exercises. See Fig. 1 for average maladaptive behaviors over time. See Table 3 for feasibility outcome data. No adverse side effects were observed.

All children were able to understand and follow the NFB procedures, including the ability to transition from summer camp, home, or a previous activity to sitting down in a quiet classroom or study room at a public school or library and begin the session. Eight out of the ten children completed an average of 46 NFB sessions. One of the children (ID# 5) was unable to complete all of the sessions due logistical conflicts unrelated to the project. The other child (ID # 8) did not complete all of his scheduled sessions secondary to behavior challenges. He presented with high anxiety which escalated during transition time (from the house to the treatment room). However when this participant was able to transition into the treatment room, the NFB sessions were successful. In addition, despite these challenges to adapt, this participant did not drop out and was able to participate in 23 sessions. True to the intent to

Table 3 Feasibility outcomes

Child ID	Total number of completed sessions	Motivation Score	Improvement on TOT during academic work	Maladaptive		Feedback	
				Total	Resulting in missed sessions	Parent	Child
1	44	34	No	0	0	Positive	Positive
2	50	31	Yes	1	0	Positive	Positive
3	42	30	Yes	6	0	Positive	Positive
4	55	35	No	74	0	Positive	Positive
5	36	28	Yes	13	0	Positive	Positive
6	45	35	No	10	0	Positive	Positive
7	40	28	Yes	0	0	Positive	Positive
8	23	21	Yes	13	10	Positive	Positive
9	48	22	Yes	207	0	Positive	Positive
10	46	12	Yes	22	0	Positive	Positive

treat model, the data from both of these participants were included in the statistical analyses evaluating the secondary outcome measures.

Progress on the NFB exercises was measured by the increase in TOT percent during academic work and seven out of the ten participants improved on this measure (see Table 3 feasibility outcomes).

The Motivation Questionnaires revealed that three participants (ID # 8, 9, 10) had low motivation scores. ID #8 showed high anxiety and resistance transitioning to the sessions, resulting in missed sessions. The Session Checklists showed that ID# 9 had significantly more maladaptive behaviors than any other participant. All of these participants required increased parental involvement and accommodations to complete the project. See Table 3 feasibility outcomes.

On the Feedback of Intervention Questionnaire completed by parents, 90 % reported that the intervention was helpful in teaching their child to concentrate.

On the Feedback of Intervention Questionnaire completed by participants, all children reported that the intervention was easy to understand and follow. All of the participants thought that the RAs were helpful and that the sessions helped them concentrate. Five of the participants reported that they found the sessions "Boring." However, one participant who reported this also wrote that "It made me concentrate more." All participants commented that they found the relaxation breathing using the hand-held biofeedback device to help transition to the NFB sessions, and between the NFB exercises if needed.

Secondary Outcome Measures

On the participant assessments, statistically significant change was found on the Full Scale Response Control Quotient ($p < 0.05$) from the IVA continuous performance test. Participants also significantly improved on the percent of correct answers on the PERMP ($p < 0.05$). See Table 4 Wilcoxon signed-rank tests for child outcome measures. Means and standard deviations are reported for descriptive purposes.

Table 4 Wilcoxon signed-rank tests for child outcome measures

Measure	Mean(SD)		z	p
	Pre	Post		
PERMP				
Percent correct	84.4(24.1)	97.7(2.8)	2.38	0.02*
IVA-CPT				
Full Scale Response Control Quotient	68.3(38.0)	97.2(17.7)	2.08	0.04*
Full Scale Attention Quotient	63.1(37.5)	78.5(27.4)	1.33	0.19

* $p \leq 0.05$

On the parent questionnaires, mothers reported significant positive change on two out of the three ASRS subscales analyzed ($p < 0.05$); the DSM-IV and the Social/Communication subscales. Although mean scores improved on the CARS Total score and three out of the four subscales of the CRS 3-P, these changes were not statistically significant. See Table 5 Wilcoxon signed-rank tests for parent outcome measures.

Medication was tracked and all participants retained the same medications and dosages at the post-testing period as they reported at the pre-testing period. Five of the participants were on psychotropic medication.

Discussion

This pilot study demonstrated that children with ASD were able to participate in this structured NFB intervention. The

Table 5 Wilcoxon signed-rank tests for parent outcome measures

Measure	Mean(SD)		*z*	*p*
	Pre	Post		
CRS 3-P				
DSM IV-ADHD Hyperactive-Impulsive	63.0(7.8)	58.5(11.8)	−1.61	0.11
DSM IV-ADHD Inattentive	68.8(9.1)	69.2(8.9)	−0.52	0.60
Global Index Total	89.7(8.7)	86.3(9.8)	−1.16	0.25
Global Index: Emotional Lability	78.3(28.7)	67.2(28.0)	−0.85	0.40
ASRS				
DSM-IV	50.0(11.9)	43.7(14.2)	−2.45	0.01*
Social/Communication	27.7(11.5)	21.1(8.8)	−2.20	0.03*
Sensory/Sensitivity	3.2(2.0)	4.0(2.4)	1.19	0.24
CARS				
Total score	23.5(4.5)	22.1(3.9)	−1.13	0.26

Negative z-scores on the CRS-R, CARS, and ASRS indicate a decrease of symptoms over time

* $p \leq 0.05$

participants were able to adapt to the NFB protocol even though it required following a strict procedure in order to be successful. NFB requires continuous adaptation to ongoing feedback. However, all ten children participated in this intensive, time consuming intervention, and progressed. There were no drop-outs, even though one participant completed only 23 sessions over the full 6 weeks. Close review of the Session Checklists reveals that in the first five sessions, participants displayed more behavioral issues, requiring RAs to set expectations, develop a routine, and redirect the participants in order to enable adaptation.

Higher motivated participants showed higher success in adapting to and completing sessions. Mothers were very helpful in supporting their children towards a successful intervention. According to the National Research Council (2001), parent involvement is critical and constitutes an essential 'best practice' in the education of young children with ASD (National Research Council 2001). The result that seven out of ten of the participants improved in their TOT percentages during academic tasks over time is important. It is indicative that participants learned how to be successful in the NFB training and further that this success translated to a reduction in their theta/beta ratio over the duration of the intervention.

A notable aspect of this study was the implementation of a commercially available NFB system using one protocol for all participants. By contrast, an individualized NFB protocol can be expensive and limits the feasibility of a large scale intervention that could be administered to many children. This is the first study to our knowledge that used a standardized NFB protocol to train attention in children with ASD.

Due to the small sample size of this study, it was more difficult to obtain statistically significant findings that can be interpreted as meaningful. Most measures reported by mothers showed pre- to post-intervention improvements. However, results from the PERMP math test indicate that participants achieved significantly higher scores despite the well documented trend of decreased academic performance of children during summer vacation (Cooper et al. 1996). Participants showed statistically significant change ($p < 0.05$) on the Full Scale Response Control Quotient from the IVA continuous performance test. They also showed significant improvement on two out of the three subscales analyzed on the ASRS. Participants showed mean improvements, but not significant improvements on three out of the four subscales of the Conners Parent Questionnaire.

This intervention is unique, as it was found to help children with ASD to focus using external feedback, which can be challenging for children with ASD. Adaptation to a new system is often difficult for children with ASD as well. The computer interface was a very positive attribute of this therapy as children became fixated on achieving higher scores. There is potential for a surprising yet important impact of this intervention as it might have an effect not only on attention, but on broader autism symptoms as well, with the possibility that the program is teaching and training skills that alter children's thought processes and behaviors.

There were some important limitations to this study that should be considered. A convenience sample was used and there was no control group. Parent report measures were not blinded and have a potential for bias. It is important to note that ASD has inherent qualities that make it difficult to assess efficacy of a given intervention. Children often have highly variable symptoms and develop skills unevenly (Marcus et al. 2005; Lord et al. 2005). As there is currently no standard treatment of care, many children may be using any number of treatments at any given time. Although the results of this pilot study are positive, future RCTs investigating the efficacy of NFB training in children with Autism are warranted.

Conclusions

These results support the need for a larger study evaluating a NFB intervention for children with ASD and attention difficulties. In order to assess the true efficacy of this

treatment, a control group is needed and other factors such as biases, family socio-economic status, medication usage, age, gender, and geographic location should be taken into consideration. Unlike many other NFB studies that have individualized training protocols, this work is standardized, inherently controlling for more variables and easier to compare across individuals. Implementation in a school setting would assure that all eligible children in a given school would have equal access to treatment and the school setting would include a larger, more diverse sample. We are currently pilot testing the feasibility of training school staff to implement NFB sessions in the school setting. Careful assessment of intervention effects on classroom behavior and academic performance should be measured as well. Teacher involvement could be extremely helpful in the implementation of a scaled-up version of this intervention. Long-term follow-up is essential in order to assess whether gains attributable to treatment are sustained over time.

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Conflict of interest None of the authors have any financial relationships or conflicts to resolve with the manufacturers of commercial products used in this study.

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