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ORIGINAL PAPER

Facilitating Neurofeedback in Children with Autism and Intellectual Impairments Using TAGteach

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Abstract

Individuals with autism and intellectual impairments tend to be excluded from research due to their difficulties with methodological compliance. This study focuses on using Teaching with Acoustic Guidance—TAGteach—to behaviorally prepare children with autism and a IQ ≤ 80 to participate in a study on neurofeedback training (NFT). Seven children (ages 6–8) learned the prerequisite skills identified in a task analysis in an average of 5 h of TAGteach training, indicating that this is a feasible method of preparing intellectually-impaired children with autism to participate in NFT and task-dependent electroencephalography measures. TAGteach may thus have the potential to augment this population's ability to participate in less accessible treatments and behavioral neuroscientific studies.

Keywords Autism · Low-functioning · Intellectual impairment · TAGteach · Conditioned reinforcement · Auditory secondary reinforcement · Mirror neurons · Mu rhythms · Neurofeedback

Introduction

Autism Spectrum Disorder (ASD)—a neurodevelopmental condition characterized by social-communication deficits, and restrictive or repetitive behaviors (American Psychiatric Association 2013)—is currently estimated to affect 15 per 1000 children (Christensen et al. 2016). The highly heterogeneous nature of impairments and range of severity, along with an elevated rate of comorbidities (Hofvander et al. 2009; Lugnegard et al. 2011; Simonoff et al. 2008), complicate the understanding, treatment, and study of the disorder. While the standard behavioral interventions for autism show improvements in psychosocial outcomes, they tend to be costly, time-consuming, and limited in efficacy (Krebs-Seida 2009). Prognosis is generally poor in terms of social, occupational, and independent functioning later in life. This is particularly true for those who have more intellectual or language deficits (Ben-Itzchak and Zachor 2011; Howlin et al. 2013; Levy and Perry 2011; Matson and Shoemaker 2009).

Numerous neurobiological anomalies in ASD have been identified (Anagnostou and Taylor 2011; Parellada et al. 2013) though the cause remains unknown. The disorder is thought to arise from a wide variety of genetic and environmental factors that play a role in the diverse expression of phenotypic traits (Hall and Kelley 2013). Converging findings from brain imaging research have given rise to theories on the neuroetiology of ASD. Studies on functional communication across brain networks have been reporting patterns of hypo-coherence in long-range default mode networks, inter- and intra- hemispheric hypo-connectivity, and hyperconnectivity in local and long-distance networks (Kahn et al. 2015; Mohammad-Rezazadeh et al. 2016; Müller et al. 2011; Rane et al. 2015), although the methodologies applied and results reported have been inconsistent. Moreover, the manner in which dysfunctional connectivity specifically impacts core ASD symptoms or the degree of severity has not been clearly delineated thus far.

This manuscript is based on the doctoral dissertation of the first author. Preliminary data from this study was included in the publication, Pineda et al. (2014b).

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An alternate framework has linked ASD social impairments with abnormal activation during action observation of the mirror neuron system (MNS) and 8–12 Hz electroencephalographic (EEG) frequency band (mu) over the sensorimotor cortex, which is proposed to index MNS activity (see Pineda et al. 2012, 2014b). While research on the MNS and mu suppression has garnered support generally and as related to ASD deficits (Arnstein et al. 2011; Bernier et al. 2007; Dapretto et al. 2006; di Pellegrino et al. 1992; Fox et al. 2016; Iacoboni and Dapretto 2006; Mukamel et al. 2010; Perkins et al. 2010; Oberman et al. 2005, 2013; Pineda 2005a, b; Williams et al. 2001), it has also been a prominent subject of scientific debate with a number of researchers providing contradictory evidence and alternative viewpoints (Enticott et al. 2013; Dinstein et al. 2010; Hamilton 2013; Hickock 2009; Hobson and Bishop 2016; Mostofsky et al. 2006; Stiegliz Ham et al. 2011).

Limitations to traditional behavioral therapies and emerging neuroetiological theories have led researchers to explore if neurofeedback training (NFT) can normalize the electrophysiological profiles of individuals with ASD, thereby reducing core symptomology. NFT uses a brain-computer interface system to display real-time electrophysiological signals to users—usually in the form of a game—to facilitate the self-regulation of EEG through operant learning (Marzbani et al. 2016). The applications of NFT are widespread, and efficacy evidence is available for a variety of disorders associated with abnormal electrophysiology (LaVaque and Moss 2003), such as epilepsy (Tan et al. 2009; Walker 2008) and attention deficit-hyperactivity disorder (Cortese et al. 2016; Mayer and Arns 2016).

Several NFT studies of individuals with ASD have shown positive changes in social behavior, attention, and connectivity using various protocols guided by clinical symptoms or individualized based on a quantitative EEG assessment (For a review, see Coben et al. 2010, 2014; or; Pineda et al. 2012). NFT research from our laboratory, reviewed in more detail by Pineda et al. (2014a), has targeted mu waves by up-training 8–12 Hz rhythms over the central motor strip while inhibiting beta and theta waves (which are associated with general movement and eye blinks, respectively). Results suggest that learning to control mu-related oscillations though NFT can normalize mu suppression during action observation tasks and improve behavior in individuals with ASD and an IQ > 80 (Datko et al. 2017; Pineda et al. 2008; Pineda et al. 2014a; Friedrich et al. 2015). Relevant criticisms of these studies have highlighted potential confounds, such as the control of attentional factors, highly localized evidence of the effect NFT on neurophysiology, and the overlap of occipital alpha with the mu frequency band. Additional, contrasting views on connectivity and mu-based NFT paradigms in ASD are discussed by Holtmann et al. (2011). Although there is a need for clearer theoretical and empirical alignment between the electrophysiological targets of NFT and core symptoms, NFT for ASD overall (whether the protocol targets mu activity or other local or more broadly distributed functional networks) appears to be a promising, noninvasive means of clinically intervening at the neurobiological level as opposed to solely focusing on the behavioral manifestations of the disorder.

Nevertheless, many individuals with ASD may not have the prerequisite behavioral, language or cognitive skills necessary to participate in therapies that might improve their symptoms or condition. While those with a higher degree of severity have the greatest need for effective treatments, these individuals tend to be understudied due to their difficulties with methodological compliance and ability to provide useful data. Thus, the literature on ASD overall, and as related to NFT, is more inclusive of high functioning individuals rather than those described as low functioning, often defined by investigators as an IQ below 70 or 80. There is a strong need to develop novel, empirically-based methods for behaviorally preparing intellectually-impaired individuals with ASD to participate in more experimental research and improve their ability to engage in less accessible clinical interventions, such as NFT.

Teaching with Acoustic Guidance (TAGteach) is a novel teaching tool that is simple to learn and implement, and appears to have the potential to facilitate lower-functioning children's participation in more treatment and research studies. The method is based on the classical and operant principles that have been central to autism treatment for decades (Granpeesheh et al. 2009; Skinner 1953), and uses conditioned auditory markers to shape complex behavioral sequences in successive approximations (http://www.TAGteach.com). The auditory marker is optimal for a population with the social-communication impairments inherent in autism because it removes the social and language features of verbal praise. The sound marker is also more distinct and temporally precise in reinforcing target behaviors than verbal communication (Vargas 2009).

TAGteach interventions are structured to be flexible, individualized, and arranged for high success rates (Vargas 2009). Caregiver involvement is encouraged in the conceptual teaching of a *tag point*, which is defined as the single, observable action currently being trained. Trainers generally abide by the *three-try rule*, meaning that if the learner fails to perform an action three times, then the trainer can return to a *point of success* by choosing a more achievable tag point. Tag points are described in five words or less and attempts are made to devise tag points that resolve more than one problematic behavior, known as *value-added tag points*; for instance, the tag point of "put hands in pockets" could potentially resolve a multitude of behaviors, such as nail biting or hand flapping. TAGteach invites participants to be involved in the naming of tag points, and also emphasizes the offering of behavioral choices to learners to improve their participation in performing tasks. Training sessions should be shorter in duration to avoid *focus fatigue*, which occurs when the learner's ability to focus on task-learning deteriorates because the duration of a training session is too long.

Through an AB design, Barbera (2010) showed it was possible to teach a 14 year-old with moderate to severe autism who had been unable to learn to tie his shoes to do so after 90 min of TAGteach. Morien and Eshelman (2010) examined sign-language behaviors and the number of prompts required during signing trials in three nonverbal children with autism (ages 6–9) across three communication training conditions that included access to primary reinforcers and verbal praise (1) at fixed intervals (Non-Contingent Reinforcement; NCR), (2) immediately following a correct response (Contingent Reinforcement; CR), and (3) after auditory marking of a target behavior (TAGteach). With ratings of treatment integrity and interobserver agreement all above 97%, their results showed that TAGteach was more effective at eliciting sign-language than the CR or NCR conditions, and required prompting as much as the CR condition did and at a lower rate than the NCR condition. For a review of other case reports that support TAGteach in autism populations, see Pineda et al. (2014a).

In the present study, we sought to evaluate the feasibility of using TAGteach to quickly prepare children with ASD and an IQ ≤ 80 to perform skills required to participate in a neurofeedback intervention (as discussed in Pineda et al. 2008, 2014a) and the corresponding behavioral tasks of an encephalographic (EEG) imaging test, the mu suppression index[1] (MSI; see Oberman et al. 2005).

Methods

Design and Participants

We employed a case-series design that used TAGteach to train participants to perform prerequisite skills of NFT and the MSI in 6 h or less. Participants were seven boys and one girl, ages 6–8 ($M = 6.9 \pm .8$ years) that met DSM-IV-TR criteria for Autistic Disorder (American Psychiatric Association 2013). Diagnoses were based on the judgement of an expert clinician and met cut-off criteria for autism using standard diagnostic tests—the Autism Diagnostic Interview Revised (ADI-R; Lord et al. 1994) and Autism Diagnostic Observation Schedule (ADOS; Lord et al. 2002). Full scale IQ scores, according to the Wechsler Abbreviated Scale of Intelligence (WASI; Wechsler 1999), ranged from 58 to 80 ($M = 69 \pm 8$) while verbal IQ and performance IQ ranged from 58 to 76 ($M = 66 \pm 6$) and 63 to 99 ($M = 78 \pm 14$), respectively. One participant was dropped from the study after beginning TAGteach due to a medical problem. Table 1 provides descriptive data on individual cases.

Participants were recruited through a private San Diego agency and a local autism e-newsletter. Each individual was required to show an inability or unwillingness to perform all prerequisite behaviors volitionally or with incentives. The Institutional Review Board of Alliant International University, San Diego approved the study.

Procedures

TAGteach-Assisted Behavioral Preparation

We used TAGteach to train four core skills (see below) that were required to participate in a subsequent study on mu rhythm neurofeedback training (NFT). These prerequisite skills were broken down into 26 discrete behaviors in a task analysis. The prerequisite skills had to be sustained for 120 s for the participant to meet behavioral criteria, and were defined as follows:

1. Participant sits still and quietly in a chair.
2. Participant tolerates electrodes and skin preparation procedures.
3. Participant performs a motor task of slowly opening and closing the right hand.
4. Participant visually attends to a display screen with video stimuli.

During the baseline assessment of participants' ability to perform prerequisite skills, we used verbal praise to promote compliance, and if unsuccessful, parents offered primary reinforcers (e.g., food and access to toys) as incentives. Participants were offered up to three trials to demonstrate a requested behavior.

We next introduced TAGteach, and structured sessions to last an hour or less. After each session, participants received a score of 1 or 0 for each of the 26-items of the task analysis to indicate if they did or did not demonstrate a behavioral criterion. We trained attention to visual stimuli using a video of a circle shape oscillating from left to right. When participants met all task analysis criteria at least one time, they underwent NFT and MSI testing as part of another study (LaMarca et al. 2013).

[1] The Mu Suppression Index (MSI; Oberman et al. 2005) assesses changes in EEG mu power in response to observing four 120 s videos of different types of movement: non-biological, biological, goal-direction, and social. A ratio of power is calculated for the four motion observation conditions relevant to a resting baseline, and an action execution condition. Ratio data are transformed with a log algorithm, such that positive and negative values indicated mu enhancement and suppression, respectively.

Table 1 Descriptive characteristics of individual cases

Case	Age, sex	WASI IQ [95% CI]	ADI-R algorithm	ADOS module/algorithm
RC	7 years, male	FS: 73 [68, 80] V: 72 [67, 82] P: 79 [73, 87]	S: 24 C: 21 (V) R: 11 (NV) Onset: 3	Module 3 C: 5 S: 14 I: 2 R: 6
CR	6 years, male	FS: 80 [75, 86] V: 68 [63, 77] P: 99 [92, 106]	S: 30 C: 19 (V) 11 (NV) R: 11 Onset: 4	Module 2 C: 7 S: 11 I: 0 R: 2
ZB	7 years, male	FS: 73 [68, 80] V: 76 [70, 85] P: 74 [69, 82]	S: 21 C: 20 (V) 11 (NV) R: 11 Onset: 2	Module 3 C: 8 S: 14 I: 2 R: 7
SR	7 years, female	FS: 63 [59, 70] V: 61 [56, 71] P: 70 [65, 79]	S: 26 C: 20 (V) 13 (NV) Onset: 4	Module 1 C: 7 S: 10 P: 1 R: 4
XD	8 years, male	FS: 58 [54, 65] V: 58 [54, 68] P: 64 [59–73]	S: 29 C: 20 (V) 11 (NV) R: 10 Onset: 5	Module 1 C: 5 S: 9 I: 0 R: 4
SK	6 years, male	FS: 72 [67, 79] V: 67 [62, 67] P: 83 [77, 91]	S: 27 C: 22 (V) 14 (NV) R: 13 Onset: 3	Module 1 C: 4 S: 9 P: 2 R: 4
TT	6 years, male	FS: 75 [70, 82] V: 64 [59–74] P: 93 [87, 100]	S: 27 C: 22 (V) 13 (NV) R: 8 Onset: 4	Module 1 C: 8 S: 10 P: 0 R: 2
ET	8 years, male	FS: 59 [55, 66] V: 59 [55, 69] P: 65 [60, 74]	S: 28 C: 18 (V) 14 (NV) R: 8 Onset: 4	Module 2 C: 7 S: 14 I: 2 R: 6

WASI Wechsler abbreviated scale of intelligence, *FS* full scale, *V* verbal, *P* performance, *ADI-R* autism diagnostic interview—revised, *ADOS* autism diagnostic observation schedule, *S* social, *C* communication, *NV* nonverbal, *R* restricted, repetitive, stereotyped behavior or interests, *I* imagination/creativity, *P* play

TAGteach-Assisted Mu Suppression Testing

During MSI testing, participants earned tag points by observing or executing specific motions, and by completing a resting baseline. Each participant had a single attempt to maintain his/her visual attention when action observation stimuli were presented, though the resting baseline and the action execution tasks were conducted more than once if needed since these tasks were not impacted by habituation to stimuli. We used TAGteach to facilitate MSI testing three times (pre-test, post-test, and follow-up) to assess mu rhythm changes from NFT in the subsequent study.

TAGteach-Assisted Neurofeedback

To participate in the NFT intervention, participants were to complete a total of 30 min of NFT twice per week for approximately 20 weeks. Participants earned tag points for completing a resting baseline at the start of each NFT session, and for completing an NFT segment, each of which ranged from 2.5 to 10 min. Participants were rewarded for

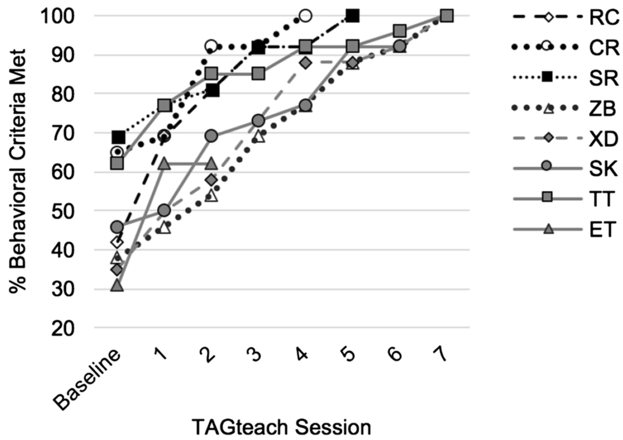

Fig. 1 Percent behavioral criteria met across TAGteach sessions relative to baseline

modulating EEG mu rhythms by the progression of video games or by an increase in the size of the display screen playing preferred DVD movies. The acoustic marker was also incorporated into the neurofeedback software and was heard when thresholds were met.

Results

General Feasibility of TAGteach

Results are summarized for all seven cases regarding the use of TAGteach to train prerequisite skills, and facilitate MSI testing and NFT. Individual case details are presented thereafter.

TAGteach-Assisted Behavioral Preparation

At baseline, participants met behavioral criteria for an average of 12.6 (± 3.8) items, or 49%, of the 26-item task analysis; all cases had difficulty tolerating the skin preparation procedures and/or electrode placements, and all were unable to sustain the prerequisite skills for their required durations of 120 s. Following an average of 5.0 (± 1.0) h of TAGteach intervention over 5.9 (± 1.2) training sessions, six participants demonstrated 100% and one demonstrated 92% of behavioral criteria identified in the task analysis (see Fig. 1).

Learning was initially facilitated by tagging parents or a toy doll, or by first using a dry swab or water instead of the skin preparation gel. We used the value-added tag point to "Dry off" the preparation gel. During training, three cases had more difficulty progressing in visually attending to the non-biological motion video of an oscillating shape of a circle, presumably because of a lack of interest in the content. Adding another video stimulus of more interesting content, a train moving along a railroad, was successful in facilitating progress. All cases needed an occasional verbal prompt in one or more of their discrete trials when learning to sustain behaviors for 120 s.

TAGteach-Assisted Mu Suppression Testing

TAGteach facilitated the participation in MSI testing for all seven cases. Each case demonstrated artifact-creating behaviors during part of one or more MSI testing tasks, for instance, speech, noncommunicative vocalizations, fidgeting, or biting or licking the chin rest. During the action execution task, two participants executed the hand motion with a notably variable pace and size of the grasping compared to learning trials, two exhibited some unusual hand or finger mannerisms, and one ceased the motion entirely without resuming after verbal prompts. Five cases had difficulty attending to the action observation videos, and verbal prompts were provided at the clinician's discretion; one case peered out of the corner of her eye. Three cases commented on or imitated the actions observed in the videos upon stimulus presentation, potentially related to the novelty of video stimuli presented during MSI testing relative to the stimuli used to train visual attention, a feature that was not considered when creating the task analysis of prerequisite skills. At post- and follow-up testing, it was necessary to reshape the self-generated hand motion using TAGteach for four cases.

TAGteach-Assisted Neurofeedback

TAGteach facilitated participation in NFT for all seven cases. Over 23 (± 4) weeks, participants completed a mean of 17.5 (± 3.4) h of NFT over 36.3 (± 7.0) sessions. Neurofeedback training segments were kept shorter at first, then gradually lengthened up to 10 min. Upon the introduction of NFT, four cases seamlessly and immediately engaged in NFT. Three cases had difficulty engaging in NFT upon treatment introduction for the required 30 min per session, but TAGteach was successfully used to assist these individuals to engage in NFT in gradually increasing durations (see Fig. 2).

RC

RC is a 7 year-old male with a history of seizures and significant difficulties with aggression, anxiety, and inattention. Though he was able to demonstrate sitting still and quietly, he made odd facial expressions at times so he earned tag points for relaxing his muscles. He was observed to engage in increasing hand-flapping behavior while learning the self-performed hand motion, presumably due to focus fatigue; thus, we ended this session at

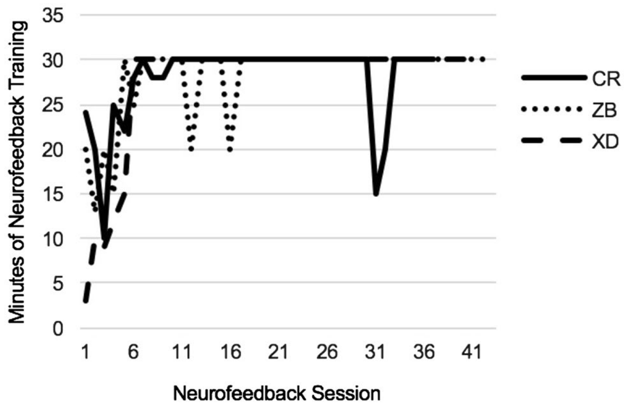

Fig. 2 Minutes of neurofeedback completed per session. Note the reduction in minutes of neurofeedback completed for session 31–32 of case CR was due to equipment

a point of success and hand-flapping was not problematic when he resumed training in his next session.

CR

CR is a 6 year-old male with a history of marked hyperactivity and disruptive behavior, and a tendency to be oppositional, noncompliant, and destructive. Other challenging behaviors included frequent screaming; crying; repetitive vocalizations; aggressive outbursts; and compulsive or stereotyped behaviors. He made frequent demands to alter the behavior of the experimenter or the environment, and when reasonable, his preferences were accommodated. Though CR already demonstrated tolerance of sensor placement at baseline, he was unwilling to do so after commencing TAGteach training. He had difficulty performing the hand-movement, preferring to use his left or both hands. His willingness to perform the hand movement correctly was contingent on being allowed to earn tag points for performing it with his other hand. In accord with TAGteach philosophy, we strongly emphasized the offering of choice to CR to help address his tendency to demand control and compulsively complete specific behavioral sequences.

During NFT, disruptive behaviors included unplugging electrodes and equipment power cords, removing sensors, and expressing displeasure for sounds or elements within NFT scripts. After minimizing access to lab equipment and environmental distractions, TAGteach was used to shape his ability to engage in NFT in increasingly longer training segments. We also individualized some NFT scripts, and made more neurofeedback games available to increase his interest.

SR

SR is a 7 year old female who has shown limited response to traditional behavioral therapies. She is suspected to have a seizure disorder which has never been confirmed due to her inability to tolerate EEG testing. She is known to display trichotillomania behaviors when under increasing stress; thus, her sessions were kept short to avoid focus fatigue and discontinued if she displayed any signs of hair-pulling. She named the tag point for performing the skill of quietly sitting motionless, “Sit like a statue.” Despite past intolerance of EEG testing, SR learned all required behaviors after 4 h of TAGteach training.

ZB

ZB is a 7 year-old male whose challenging behaviors include tantrums and aggressive outbursts. His willingness to tolerate sensor placements was at times dependent on earning tag points for attaching the electrodes himself. The experimenter also assigned a tag point to “leave wires on” to fade ZB’s behavior of removing sensors between each trial. When training the hand movement, ZB required the experimenter to verbally count down till the task was completed. The use of an audio/visual timer ameliorated this by gradually moving it out of view across discrete trials.

XD

XD is an 8 year-old male who presented with avoidant and self-injurious behaviors, hyperacusis, tantrums, sensory hypersensitivities, and frequent insistence on sameness. He often avoided sitting down or the experimenter by leaving the room or building. After noting that avoidant behaviors increased following approximately 40 min of TAGteach, we structured sessions to be shorter. When training to sustain visual attention to stimuli while wearing sensors, he first tagged his doll to do so, then he tagged himself, and subsequently allowed his mother and then the experimenter to tag him. XD had difficulty engaging in NFT upon introduction as evidenced by removing electrodes. TAGteach facilitated his ability to engage in NFT in increasingly longer durations.

SK

SK is a 6 year-old male whose challenging behaviors included hyperactivity, hyperacusis, inattention, anxiety and obsessive–compulsive symptoms. SK learned to perform 92% of behavioral criteria following 6 h of TAGteach over six sessions. He learned sufficient skills to participate in NFT through TAGteach but was unable to adequately sustain all behaviors for the full 120 s, though an attempt was nonetheless made to administer MSI testing by offering verbal reminders of the current tag point as needed.

TT

TT is a 6 year-old male with anxiety, frequent tantrum behavior, and small bowel disease who tends to communicate nonverbally before resorting to verbal communication. His mother was heavily involved in skill teaching. Reinforcement items that were highly desirable to TT were distracting to his learning, and his selection of primary reinforcers was limited by dietary restrictions. Individualized phrasing of tag points was necessary for him to cooperate, for instance, he refused to execute the hand motion with the phrasing, "Open close hand," but agreed after he suggested the modification, "Open shut hand." His ability to perform the hand motion deteriorated mid-training and he was reshaped to execute the movement through the use of physical aid first, through imitation next, and ultimately, independently. One session was terminated early due to TT becoming so distressed due to difficulty communicating a choice preference. We also removed the auditory marker from NFT scripts, which resolved avoidant behaviors (e.g. covering his ears or humming) likely related to hyperacusis. TT lost his ability to execute the hand movement task at post- and follow-up MSI tests so the behavior was reshaped via TAGteach.

ET

ET was an 8 year old male who, similar to his brother TT, had an extremely restrictive diet, small bowel disease, and anxiety that required close involvement of his mother during TAGteach training. He was withdrawn from the study due to an exacerbation in gastrointestinal symptoms after two TAGteach sessions. Relative to baseline, he showed progress in learning to tolerate all skin preparation procedures and sensor placements, cease vocalizations, and quietly sit still for 30 s. Sessions lasted 30 min since his interest in primary reinforcers after this amount of time declined. Though ET was withdrawn early from the study, he did show learning during TAGteach training and his case contributes to highlighting the difficulties in studying and treating children with autism and more severe functional deficits.

Discussion

Investigating the feasibility of using TAGteach methodology to behaviorally prepare intellectually-impaired children with autism to undergo MSI testing and NFT resulted in three main findings. TAGteach was a viable method for (1) training behavioral criteria identified in a task analysis as required to participate in NFT and MSI testing, (2) facilitating task performance during the MSI, and (3) facilitating participant engagement in NFT.

Findings suggest that applied behavioral analytic methodology that uses conditioned auditory reinforcers, or TAGteach, is a feasible method for preparing children with autism who lack skills necessary for a particular research or clinical intervention to successfully participate. Our results converge with the literature on classical and operant learning in animals (McSweeney and Murphy 2014; Neuringer 2002) and a small body of case report research on TAGteach with humans and those with autism (see Pineda et al. 2014a)—albeit accelerated learning was not examined in this study. Theoretically, the use of conditioned reinforcement is consistent with learning paradigms as simple as Pavlovian conditioning or a rat in a Skinner box, and the widely accepted effects of auditory reinforcers on animal learning and behavior could feasibly be extended to facilitate learning in children with greater autism severity. TAGteach may serve as a practical tool for clinicians, researchers, parents and teachers for enhancing independent functioning and access to promising treatments. Rates of research study participation for individuals in the lower functioning range of the autism spectrum also have the potential to be enhanced by TAGteach.

Since commencing our study, Persicke et al. (2014) used a modified TAGteach procedure to correct toe-walking in a 4 year-old male with autism. Using an ABAB design, they examined: (a) Correction alone (i.e. gently pushing downward on the child's shoulders), and (b) Correction + TAGteach (reinforcing correct steps). Correct footsteps were observed at a mean rate of 24.6% at baseline, 63.6% in the Correction Alone phase, and 90.5% in the Correction + TAGteach phase. A visual inspection showed that correct steps clearly reduced in the reversal phases, and were maintained above a rate of 73% in the fading and generalization phases. Although promising, more research is needed to determine if TAGteach can assist other children with autism to reduce toe-walking behavior or other impairments. This peer-reviewed case study is congruent with our results that show TAGteach facilitates learning and provides additional support by showing a powerful reversal effect.

Even though our participants demonstrated the ability to sustain the four core skills during shaping procedures, our results indicate that this requirement was not sufficient to procure the level of mastery needed for reliable skill demonstration during MSI testing, as several artifact-creating behaviors were documented in multiple recording trials. This was more problematic for action observation trials, which could only be administered a single time whereas we restarted EEG recording trials during resting baselines and motor tasks if necessary. Herein, we discuss possibilities to address limitations related to training this population through a combination of TAGteach and more advanced methods of artifact-identification and technology usage, principally biofeedback.

Limitations and Future Directions

Future researchers using TAGteach ought to consider developing a sham or replica protocol of actual outcome testing tasks and stimuli for assessing participant readiness to undergo actual testing, identifying probable artifact-creating behaviors that may need to be (re)targeted with TAGteach, and identifying an acceptable level of behavioral and electrophysiological artifact in data samples. For example, it is more likely we would have pre-identified the problematic effect of novelty in stimulus presentation had we performed mock testing of the MSI, preempting the inclusion of a wider variety of visual content when training subjects to complete action observation trials. Mock testing conditions would also aid future investigators in developing a thorough task analysis prior to commencing shaping procedures.

One limitation of this study was the poor means of training sustained visual attention, which was subject to clinical judgement. In future studies, stimuli content of a moderate interest level should be elected for optimum results, as too low a level of interest appeared to disengage participants, and content with too high of a reinforcement value was distracting. Another means of verifying visual attention may be to include an attention or counting task (see Pineda et al. 2008), albeit developing a uniform attention task that is appropriate to all participants may be challenging given the heterogeneity in cognitive and language abilities typical of children who are low-to-mid range functioning. Nevertheless, the creative flexibility inherent in the TAGteach methodology may allow the successful shaping of participant ability to count and communicate the events of an attention task, whether verbally or through a picture-communication or computer-based program, or some other means. What is more important is that more advanced software integrations have the potential to not only help improve participant communication through game-like user interfaces, but also to enhance interest and motivation levels by rewarding their cooperation, and perchance successively, their accuracy. TAGteach may be a viable candidate to facilitate this sort of research in lower functioning populations, ideally, in conjunction with gaze tracking technology or other means of enhanced artifact rejection.

Duffy and Als (2012) reported that they facilitated compliance with EEG protocols in a group of children with low functioning autism by using technologists experienced in the special management of pediatric populations. Their study posits that more sophisticated artifact-rejection and unspecified behavior management techniques coupled with relaxation breaks is sufficient to maintain a relatively low level of EEG artifact in children with autism who are less than high functioning—highlighting that conditioned auditory reinforcers may not be a requirement. Alternatively, the comparability of their study population to the present one is weakened since they did not clarify their criteria for low functioning autism or use standardized diagnostic or IQ assessments, and instead relied on subjective diagnoses of independent clinicians.

TAGteach may be able to assist in other methods for compensating for group-specific artifact or skill deficits during outcome testing, for instance, training participants to tolerate additional sensors. Technological advances in equipment that minimize the participant or instructor demands and the behavioral criteria needed for task compliance are also recommended, such as using a cap with dry leads or wireless sensors. Lastly, as some cases had difficulty sustaining or entirely ceased skill demonstration during some of the task-related EEG trials, researchers may consider developing formal criteria to determine when or if a discrete trial may be restarted or if a uniform reminder of the present tag point can be given and then sourced out during data analyses.

A more innovative extension of this study would be to integrate biofeedback into TAGteach procedures for shaping prerequisite skills, which could be useful for training actions with greater specificity or for sustaining skill demonstrations. For instance, a learner could receive real-time auditory feedback about their muscle movement or visual attention, which must be maintained above a predetermined, cumulative threshold in order to earn a tag point at the end of a discrete trial. A biofeedback-assisted TAGteach approach such as this for shaping sustained skill demonstrations would help resolve problems associated with depending on a single auditory marker to mark the completion of performing the skill at the end of a discrete trial, which unintentionally reinforces behaviors that increase artifact even if they only occur to a minor degree. Furthermore, customizable software with multimedia capabilities, with which participants can interact, may be useful in enhancing their communication about events and choosing preferred rewards, increasing their interest and motivation to comply with task requirements. The feasibility of integrating biofeedback approaches into TAGteach for shaping skills, particularly prolonged skill demonstrations, is encouraged to continue carving a path toward including more lower functioning children with autism in more rigorous neuroscientific studies or behavioral interventions.

Lastly, we recommend starting neurofeedback treatment with lower functioning autism populations by selecting shorter NFT segments (i.e. an estimate of 2–5 min) interspersed with breaks to improve the generalization of skills from TAGteach training to NFT. Practitioners may opt to use novel NFT games or movies rather than participants' preferred DVD movies to minimize the chance that they will disengage due to psychological distress about familiar movie content functioning in a different way than it has in their other environments. More broadly, TAGteach could be of use to some laboratories studying low- and high-functioning children that are designing interactive environments (e.g. video-games, e-learning applications, virtual realities) with neurofeedback-integration capabilites to optimize electrophysiological activity and reward desired behavior in direct correspondence with the underlying significance of perceived stimuli (for instance, see Friedrich et al. 2014).

Regarding the aforementioned suggestions, TAGteach appears worthy of further exploration to determine if it can prepare more highly-impaired individuals with sufficient skills to comply with treatment and research tasks, and if the method can be supplemented in research studies by more sophisticated means of electrophysiological measurement, computational, or artifact rejection techniques; technological advances in human–computer interfaces; or other individualized, teaching adaptations. Findings from the present case series begin to impart support for TAGteach as a means of exploring whether the prerequisite skills of such adaptations to research and teaching methods can be successfully incorporated into TAGteach training.

As in all single-subject research, the effects of TAGteach cannot be causally determined from the present design. Without independent raters, TAGteach findings were bound to the sole judgment of the experimenter. Additionally, the nonrepresentative sample used in the current case series restricts the external generalizability of case results.

Conclusions

This case series shows that it is feasible to use conditioned auditory reinforcers to teach intellectually-impaired children with autism to cooperate with a neurofeedback study and task-dependent EEG outcome tests. However, research is still needed to determine (a) if TAGteach is preferable to other teaching methods, (b) if TAGteach can facilitate improved skill performance during EEG outcome testing or NFT, and (c) whether incorporating skills required of more demanding or rigorous research methods into TAGteach training is a viable means of improving skill generalization to treatment and outcome measure tasks. Unquestionably, intellectually-impaired children with autism are deserving of a greater rate of inclusion in treatment and other studies by developing empirically-supported, skill-teaching methods to improve their participation. TAGteach appears to be a candidate to help amend this problem—warranting further study.

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Compliance with Ethical Standards

Conflict of interest The authors disclose no conflicts of interest.

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