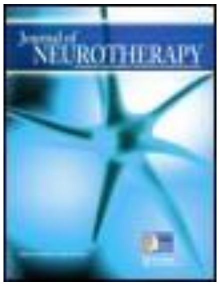

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Pilot Project to Ascertain the Utility of Tower of London Test to Assess Outcomes of Neurofeedback in Clients with Asperger's Syndrome

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SCIENTIFIC FEATURE

Pilot Project to Ascertain the Utility of Tower of London Test to Assess Outcomes of Neurofeedback in Clients with Asperger's Syndrome

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ABSTRACT. *Introduction.* Behavioral and cognitive improvements in clients with Asperger's Syndrome (AS), employing continuous performance tests (CPTs), intelligence and academic measures, and electroencephalographic data, have been reported following 40 sessions of neurofeedback (NFB) training combined with coaching in metacognitive strategies. However, measures of executive functions (EFs) in this population have not been commonly employed and NFB is still not commonly used as a treatment for AS. Therefore, this pilot project used Tower of London – Drexel University (ToL^{DX}), an individually administered test of EFs, in addition to the previously mentioned measures. The goal of the current study was to investigate the utility of ToL^{DX} as an assessment tool for clients with AS as well as further study the effects of NFB and training in metacognitive strategies on executive functioning in clients with AS.

Method. Nineteen consecutive clients at the ADD Centre, Toronto, Canada (M age = 12 years 0 months) recruited over a 2½-year period all had full clinical assessment, completed age appropriate questionnaires, and were tested pre- and post-40 NFB sessions.

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Results. Following the training, clients with AS were able to plan more efficiently, inhibit premature responses, and shift set with greater ease, as well as solve problems more quickly as measured by their ToL^{DX} scores. On CPTs, clients with AS showed a trend toward less impulsivity. Finally, improvement in their scores on ToL^{DX} was not affected by age or IQ.

Conclusion. These data are important because they provide an extension of results of previous studies (Reid, 2005), demonstrate the utility of tests of executive functions in a clinical setting with clients with AS, and suggest directions for further controlled research in this area.

KEYWORDS. Asperger's Syndrome, executive function, frontal lobes, neurofeedback, Tower of London

Asperger's Syndrome (AS) is a chronic developmental disorder that is considered one of the Pervasive Developmental Disorders commonly referred to as autism spectrum disorders (ASDs; Klin, McPartland, & Volkmar, 2005). It is characterized by difficulties in correctly interpreting social innuendo, either verbal or nonverbal (sensory aprosodia), an inability to use emotionally appropriate vocal intonation and volume control in conversation (motor aprosodia), and by stereotyped, rigid, and repetitive patterns of behavior, activities, and interests (Ross, 1981; Wing, 2001). Lack of general delay in language or cognitive development is what distinguishes AS from the other ASDs. Although not mentioned in the standard diagnostic criteria, motor clumsiness and atypical use of language have also been reported (McPartland & Klin, 2006). Inappropriate friendliness and openness with strangers are some of the examples of problems with social boundaries children with AS tend to experience. Due to their social naivety and immaturity these individuals tend to be teased and rejected by peers and consequently socially withdraw once they reach adolescence and adulthood (L. Thompson & Thompson, 2007).

Viennese paediatrician Hans Asperger was the first to describe the collection of symptoms of AS using the term "*autistischen psychopathen*" (austisitic psychopathology). He described a group of boys with severely limited social skills and relationships, inappropriate eye contact, motor clumsiness, behavioral problems such as aggression, and limited facial or gestural expressiveness, who were often teased by their peers. Although these boys would often present with obscure use of language and unusual prosody, they had excellent language skills in general. Furthermore, they had areas of intense, special interests with extremely high expertise (Wing, 1981). His paper was finally translated into English in 1991, and AS was included in the 1994 *Diagnostic and Statistical Manual of Mental Disorders* (4th ed. [*DSM*–IV]; American Psychiatric Association, 1994) from the American Psychiatric Association (*DSM–IV* code number 299.80). As a result of numerous controversial issues regarding AS, such as the distinction between AS and high-functioning autism, prevalence of AS is still not firmly established. Nevertheless, it has been found that AS is much more frequent in boys. Asperger offered an extreme male analogy as a way of characterizing this syndrome; that is, boys, when contrasted with girls, tend to be more interested in figuring out how systems work rather than how people feel (Lawson, Baron-Cohen, & Wheelwright, 2004). Furthermore, brain imaging techniques have not yet identified a clear common pathology. Although research supports the likelihood of a genetic basis, an exact cause of AS remains unknown (McPartland & Klin, 2006).

On the Wechsler Intelligence Scales (Wechsler Intelligence Scale for Children [WISC] and Wechsler Adult Intelligence Scale [WAIS]), most AS clients obtain high IQ scores with significantly better Verbal IQ than Performance IQ (Alvarez, 2004). To explain these results, researchers have proposed that these individuals can successfully use their excellent verbal and logical left hemisphere skills to score well (Alvarez, 2004). Although Attwood (2007) cited a review of the cases seen over a 30-year period by Asperger and his colleagues showing that 18% actually had higher Performance IQ, the majority (48%) of AS clients presented with the more typical IQ pattern (verbal greater than performance IQ). Therefore, most of the clients with AS have difficulty with spatial reasoning and mathematics but tend to excel in language-based areas. In addition, AS clients may have poor emotional regulation as well as anxiety difficulties that become most apparent with any transition or change. For example, they could go from placid to tears, or even extreme anger, in a very short period (L. Thompson & Thompson, 2007).

Portway and Johnson (2005) reported that these people just "don't fit in" within the general population. This may be a result of their social and cognitive deficits. Research thus far has demonstrated that AS clients vary wildly with regards to deficits in social-emotional information processing (Emerich, Creaghead, Grether, Murray, & Grasha, 2003; Kaland et al., 2005; Laurent & Rubin, 2004). Specifically, they cannot correctly understand inferences from stories that include information that requires interpretation such as pretence, figures of speech, and irony (Kaland et al., 2005). Furthermore, they may have problems understanding humorous material (Emerich et al., 2003; Kaland et al., 2005) as well as difficulties verbalizing emotions and interpreting intentions (Laurent & Rubin, 2004). In addition to these difficulties, clients with AS have been found to present with cognitive difficulties such as cognitive switching, word retrieval strategies (Kleinhans, Akshoomoff, & Delis, 2005), and free but not cued recall (Bowler, Gardiner, & Berthollier, 2004). Finally, deficits in face-processing strategies have also been shown (Deruelle, Rondan, Gepner, & Tardif, 2004).

Clinically, there is overlap in symptoms with a few other diagnoses. For example, attention deficit/hyperactivity disorder (ADHD) and AS tend to share numerous behavioral features (Klin, Volkmar, & Sparrow, 2000). Also, children are frequently incorrectly diagnosed with ADHD prior to being diagnosed with AS at age 11 (Fitzgerald & Kewley, 2005). Furthermore, researchers noted comorbidity with learning disabilities involving difficulty with organization, mathematics, and physical and social limitations (Klin & Miller, 2004). Rourke and Tsatsanis (2000) postulated white matter damage in the brain and a smaller corpus callosum. To better understand inability of clients with AS to comprehend social innuendo, numerous studies have been conducted that examined the symptoms of damage to the right hemisphere (Edwards-Lee & Saul, 1999; Grattan, Bloomer, Archambault, & Eslinger, 1994; Ross, 1981). Ross reviewed sensory aprosodia that results from neurological damage such as infarct to the right temporal-parietal area and noted that these individuals cannot understand emotional tones of sadness or happiness in another person's voice. Edwards-Lee and Saul demonstrated that damage to the right hemisphere also frequently causes impairment in processing of emotional and social information. When damage is right frontal, people show motor aprosodia. Similarly, those with AS often speak in a monotone voice or they may use a loud voice, especially when feeling stressed (L. Thompson & Thompson, 2007). Furthermore, Grattan and colleagues (1994) failed to find specific lesions in the prefrontal cortex that result in impairment in cognitive flexibility (found to correlate with cognitive empathic ability) mediated by prefrontal cortex. Therefore, they concluded that several circuits may be involved in modulating cognitive flexibility found to be impaired in AS clients. Taken together, these findings indicate that although studies have shown significant right hemisphere dysfunction in AS, answers regarding the pathways involved and exact location of dysfunction remain far from unequivocal.

The literature on approaches to intervention is still sparse and there is a significant lack of outcome data (L. Thompson & Thompson, 2007). Overall, psychotherapy, behavior therapy, social training, group therapy, and medications in addition to speech therapy are commonly tried interventions for ASDs (Green et al., 2006). According to Bashe and Kirby (2005), ASD in some individuals may involve the digestive system;

therefore, diet should be considered as one of the approaches to intervention. Although a variety of medication is used to treat symptoms of AS, such as Ritalin for hyperactivity, Risperdal for anger and temper tantrums, and serotonin re-uptake inhibitors for anxiety and panic, there is still no specific pharmacological intervention for AS (Sloman, 2005). Furthermore, most of these medications used in children have not gone through the evaluation necessary to establish their safety, tolerability, and efficacy, nor they are able to ameliorate the basic deficits in social interaction and communication (Sloman, 2005). From their clinical experience, L. Thompson and Thompson (2007) reported that results of medications, used with children with AS, are often not favorable. Stimulant medication may increase focus, just like in clients with ADHD, but there may be an increase in anxiety as well when beta spindling is present (L. Thompson & Thompson, 2007). Consequently, focus on an inner worry may be increased, potentially causing the client's behavior to worsen (L. Thompson & Thompson, 2007).

A few papers and presentations have emerged and reported favorable clinical outcomes using neurofeedback (NFB) for clients with AS over the past 12 years (Coben, 2005, 2007; Jarusiewicz, 2002; Reid, 2005; Solnick, 2005; L. Thompson & Thompson, 1995, 2007; M. Thompson & Thompson, 2003). NFB training is based on the premise that normalizing the electroencephalographic (EEG) activity could ameliorate some of the core symptoms of AS (Reid, 2005). Specifically, Sterman (2000) proposed that increasing sensorimotor rhythm (SMR) using neurofeedback at the central location (CZ) may have a stabilizing effect on a cortex that is unstable and easily kindled. Reid (2005) reported amelioration of AS symptoms, based on single-channel EEG assessments, when NFB was applied at CZ or FCZ to train down frequencies that were high in amplitude as compared to the rest of the client's EEG (theta 3–7 Hz or low alpha 8–10 Hz, and/or high frequency beta 20–35 HZ) and to train up SMR (12–15 Hz). In addition, these clients were introduced to metacognitive strategies tailored to suit their areas of difficulties (how to approach problems in order to solve them and monitor success).

The current study uses Tower of London (ToL) test as a primary measure of changes in clients with AS after 40 NFB sessions combined with metacognitive strategies. Tower of London–Drexel University (ToL^{DX}) is an individually administered neuropsychological instrument designed to assess higher-order problem solving—specifically executive planning abilities—in children and adults (Culbertson & Zillmer, 2001). Executive planning involves choosing strategies, organizing them, and then incorporating them as needed to achieve a goal. One must be able to look ahead, respond impartially, generate and select alternative options, and sustain attention (Lezak, 1995). The prefrontal lobes, although interacting with other cortical and subcortical regions, are centrally involved in executive planning. Injuries to these areas and/or deficits can have profound effects on behavior (Cummings, 1993; Grattan & Eslinger, 1991; Shallice & Burgess, 1991). Owen (1997), in a review of a series of neuroimaging studies, has identified the neurosubstrates that potentially support ToL performance such as the mid-dorsolateral frontal cortex (Brodmann areas 9 and 46) and ventrolateral frontal cortex (Brodmann areas 45 and 47). In general, the dorsolateral executive system appears to be related to cognitive planning and the mid-dorsolateral frontal cortex has been implicated in the information monitoring and manipulation within working memory (Petrides, 1998). The ventrolateral frontal cortex has been found to interact with regions related to retrieval of information and volitional encoding such as the posterior temporal and parietal cortex (Petrides, 1998). In more recent publications, M. Thompson and Thompson (2005) have identified increased slow wave activity in these regions in children with AS. Specifically, these authors noted high amplitude slow waves (3–10 Hz) and/or very low amplitude beta (13–18 Hz) and/or high amplitude beta spindling in the medial frontal, orbital and/or prefrontal cortex. These findings, together with right temporal-parietal cortex inactivity (high bursts of slow wave activity, 3–10 Hz, relative to beta activity, 13–18 Hz), suggest dysfunctional networks (M. Thompson & Thompson, 2009). In addition, Hughes, Russell, and Robbins (1994) found that autistic children execute extra moves (indicating impairment) on ToL test as compared to the ability-matched learning disabled and normal controls. Overall, current empirical investigations show that the ToL test assesses a strategic component of cognitive planning and therefore can measure dysfunction in individuals with AS (Kouijzer, de Moor, Gerrits, Congedo, & van Schie, 2009). Despite the importance of executive planning and flexibility in adaptive functioning, there is little research exploring these skills.

Because increasing SMR (12–15 Hz) using NFB appears to have a stabilizing effect on a cortex that is not functioning properly, NFB has already been established as an efficacious intervention for seizure disorders (Sterman, 2000) and ADHD (Beauregard & Levesque, 2006; L. Thompson & Thompson, 1998). Subsequent research has suggested that increasing SMR causes improvement in EEG ratios and social behaviors in cases of ASDs, in particular AS, but further research is essential (Sterman, 2000; M. Thompson & Thompson, 2005). Welsh, Pennington, and Grossier (1991) have indicated that executive planning represents a unique executive function separate from nonexecutive functions such as intelligence and memory. In view of the fact that observed dysfunction in clients with AS corresponds to the brain regions involved in executive functioning and planning, areas that in turn can be influenced by NFB training, it is posited that NFB might improve these frontal lobe/executive functions. The utility of ToL as an assessment measure could also be investigated.

The goal of the current study was thus to investigate the utility of ToL as an assessment tool for clients with AS as well as to further study the effects of NFB and training in metacognitive strategies on executive functioning in clients with AS. Clinical experience spanning more than 12 years at the ADD Centre/Biofeedback Institute of Toronto suggested that such cognitive behavioral intervention produces positive changes in clients presenting with ASDs such as AS (M. Thompson & Thompson, 2005). Changes in clients' frontal lobe functioning, especially regarding cognitive planning and flexibility, as measured by improved performance on ToL, was hypothesized to be the expected outcome after NFB training.

METHODS

Participants

The participants for this pilot project were 19 consecutive clients (16 male and 3 female) at the ADD Centre, Toronto, Canada, recruited over a 2½-year period. All had a full clinical assessment and completed age-appropriate questionnaires: SNAP version of *DSM–IV*, Conners' Global Index for Parents, the ADD-Q (Sears & Thompson, 1998), and the Australian Scale for Asperger's Syndrome (Attwood, 1998). They were included if they met the *DSM–IV* (American Psychiatric Association, 2000) criteria for Asperger's Disorder. Previous research has indicated that single-channel assessment at the vertex (CZ) would reveal patterns similar to those found in clients with ADHD (L. Thompson & Thompson, 2007), and these participants typically demonstrated an EEG power spectrum of increased 4–8 Hz theta at the central location when compared with 13–21 Hz beta activity (Mann, Lubar, Zimmerman, Miller, & Muenche, 1992). Participants varied in age from 7 years 6 months to 21 years 5 months (M age = 12 years 0 months) and were mixed in terms of ethnicity and socioeconomic status. All participants who were taking stimulant medication were off their medication for at least 24 hr prior to testing. Of the 38 clients who were assessed as having AS and were deemed candidates for NFB training, 19 completed at least 40 sessions of training. Results are reported for those 19 participants.

Procedures

A complete clinical assessment done by a psychologist (LT) included history taking, Test of Variables of Attention (TOVA), Integrated Visual Auditory (IVA) continuous performance test, parent behavior rating scales, and the WISC–IV or, for those 17 or older, the WAIS–III. Tests were administered pre- and post-NFB. In addition, EEGs were recorded, with active electrode placement at CZ, reference electrode on the left earlobe, and ground electrode on the right earlobe. Diagnosis was established once all the data were obtained by the clinical psychologist. If the client presented with AS and was determined to be a good candidate for NFB, then additional arrangements were made for further testing. With signed parental consent (or with client's signed consent if the client was 18 years or older), performance on the ToL^{DX} test was additionally assessed pre- and post-NFB by the researcher (BK), who was trained to administer and score ToL under the supervision of the licensed clinical psychologist.

Neurofeedback. The NFB was introduced as a computer game in which one could obtain points by maintaining a focused and relaxed mental state as indicated by brainwave patterns. To achieve as many points as possible, clients were directed to attend to visual and auditory feedback and to find the most successful approach in order to remain alert. They were told to use their own mind to find these strategies, and no further specific instructions were given. Participants were placed approximately 40 in. from the computer screen and presented with gamelike images and sounds during 3- or 4-min training intervals. Each session lasted 50 min during which 10 to 15 min were spent introducing new strategies tailored to the client's needs while still paying attention to auditory feedback to maintain that alert and focused state. The active electrode was placed at the central location (CZ), reference electrode on the right earlobe, and ground electrode on the left earlobe. The actual NFB component of the session taught the child how to maintain an alert and relaxed mental state by focusing on the computer screen. Two different bar graphs were used, one from 12–15 Hz and the second from 15–18 Hz. The feedback screen with 12–15 Hz enhance was used first with those children who show hyperactivity or impulsivity. It is also was used with all clients who had a seizure disorder. Next, all of the clients were trained in metacognitive learning strategies for part of each session. During this part of the training they were required to increase 15–18 Hz just before and during the cognitive task(s) (M. Thompson & Thompson, 2003). The child was rewarded by auditory and visual feedback once he or she increased SMR (12–15 Hz) and/or problem-solving beta (15–18 Hz; M. Thompson & Thompson, 2003, 2006, 2007), depending if the child showed a deficit in one or both, and decreased slow brain wave activity such as theta (4–8 Hz) or thalpha (3–10 Hz), whichever band width showed the most excessive magnitude of slow wave activity. If 12 Hz was not too low on the EEG profile, as was often the case in older clients, then 13–-15 Hz was the SMR range. Training in metacognition, "thinking about thinking," provided executive functioning strategies that allowed the child to go beyond regular thinking and become aware of the learning and remembering processes (M. Thompson & Thompson, 2003). These strategies were taught while the child was in a focused and alert state, as indicated by computerized feedback.

Tower of London. ToL was originally developed by Shallice (1982) as a standardized test of executive functioning in children. Since then it has been revised and standardized by Culbertson and Zillmer (2001) to measure planning, working memory, and forethought in children and adults (Welsh & Pennington, 1988). It comprises a wooden board with three pegs of increasing heights. There are also three plastic beads, each of a different color (blue, red, and green). Following two practice trials, the experimenter demonstrates 10 different patterns of beads that the participant must re-create in the fewest number of moves. The beads are in the same initial position before each of the trials.

Clients were evaluated on six quantitative dependent variable scores of executive function assessed by the ToL: (a) total move score, (b) total correct score, (c) total rule violation score, (d), total time violation score, (e) total initiation time score, and (f) total execution time score. Each raw score was converted to a standard score for statistical analysis. A move is recorded when a client completely takes a bead off a peg and then either places it on another peg or replaces it onto the same peg (if the client only slides the bead up and down the move is not recorded; Culberston & Zillmer, 2001). To calculate the total move score, the ToL's recommended number of moves is subtracted from the number of moves it takes the child to solve the problem, resulting in the total move score that measures the executive functions of inhibition, planning, and problem solving (Barkley, 1998; Culberston & Zillmer, 2001; Pennington, Bennetto, McAleer, & Roberts, 1996). Total correct score is the number of test items solved with the minimum number of moves. Previous research indicates it reflects the client's planning efforts, specifically the efficiency of working memory (Culberston & Zillmer, 2001). Total rule violation score consists of the sum of any violations of Rule Type I and Rule Type II. When the client places more beads on a peg than it can hold, a Rule Type I has been violated. A Rule Type II violation has been committed when a client removes two or more beads from a peg simultaneously. When a rule was violated, the bead was quickly placed back to the previous position and the client was prompted to continue. Furthermore, a time violation was recorded for each item the client needed more than 60 sec to complete. Clinical findings have indicated that clients who exhibit a poor total move score and violate rules numerous times may have difficulties with self-regulation of behavior and working memory (Culberston & Zillmer, 2001). Furthermore, the number of rules broken has been found to relate to executive planning, inhibition, and use of internal speech to guide behavior (Culberston & Zillmer, 1998a, 1998b, 2001). Total initiation time is the amount of planning time between the moment the problem is presented to the client and when they actually touch the first bead (Culberston & Zillmer, 2001). It represents the time the client looks ahead and plans his or her moves (Baker et al., 1996) and is an additional measure of impulsivity in terms of being able to think before they act (Levin et al., 1996; Murji & DeLuca, 1998). Finally, total execution time is the amount of time the client needs to solve the problem from the point when he or she removes the first bead from a peg. Execution times for all 10 items are summoned to obtain the total execution time. Poor score may indicate inefficient planning, difficulties with cognitive flexibility such as shifting set, and/or slow style due to a perfectionistic and excessively cautious nature (Culberston & Zillmer, 2001).

Following completion of all 10 items, clients were rated by the experimenter on a 5-point Likert scale with respect to their problem-solving approach, attention and activity, and personal-emotional-social regulation. Examples of the characteristics that were evaluated were whether the client was systematic or disorganized, alert and attentive, cooperative or resistant, able to tolerate frustration or easily upset, whether frequent prompting and encouragement were needed, and so on. These values were recorded at the end of the test according to experimenter's opinion of the client's performance. Client data were compared pre and post 40 NFB sessions.

RESULTS

Table 1 shows the descriptive statistics for age and IQ and the six measures of executive functioning (EF). The clients' performance ranged from impaired to average prior to NFB. This suggests that there were large individual differences in EF abilities within the age group studied. Some children demonstrated only limited planning, inhibitory, and working memory skills, whereas others had well-developed skills for their age. Scores indicate that the majority of clients with AS had below-average skills prior to neurofeedback.

Data Analytic Procedures

Paired-samples t tests were used to compare clients' scores pre- and post 40 NFB sessions on the measures on ToL^{DX}, TOVA,

TABLE 1. Descriptive statistics for demographics and executive functions initial standard scores.

Variable	(N)	Minimum	Maximum	Mean (M)	Standard Deviation (SD)
Age	19	7.50	21.50	11.97	3.67
IQ	18	82.00	124.00	105.72	13.75
ToL^{DX}					
TMS	19	60.00	108.00	85.37	12.22
TCS	19	74.00	108.00	90.74	9.64
TRV	19	60.00	104.00	72.63	19.69
TTV	19	60.00	114.00	96.95	12.69
TIT	19	80.00	108.00	90.21	6.63
TET	19	60.00	110.00	88.42	15.12

Note. ToL^{DX} – Tower of London – Drexel University.

and IVA. An analysis of variance (ANOVA) was employed to determine whether there were any differences in performance on the measures of EF as a result of age and IQ. Finally, standard linear regression procedure was used to assess the relationship between the amount of improvement on measures of inhibition on these three assessment tools. Specifically, changes in impulsivity were investigated by looking at relationship between the difference in pre- and post-total rule violations on ToL and TOVA commission errors, IVA auditory prudence, and IVA visual prudence.

Tower of London

Quantitative measures. Table 2 reveals the results of paired-samples t tests conducted to assess the changes in EF pre and post 40 NFB sessions. Examination of individual scores found that clients with AS significantly improved on three out of six measures. Specifically, there was a significant difference in scores for total moves ($M = 6.79$, $SD = 12.29$), $t(18) = 2.408$, $p < .05$; total rule violations ($M = 3.58$, $SD = 5.10$), $t(18) = 3.057$, $p < .05$; as well as total execution time ($M = 72.32$, $SD = 86.36$), $t(18) = 3.650$, $p < .05$. Total initiation time measure indicated a trend toward a significant difference in pre and post scores. Following Bonferroni adjustment, difference in scores remained significant for two measures, total rule violations and total execution time.

Qualitative measures. Each client's performance was rated at the end of the test according to the researcher's opinion on 12 qualitative scales that comprised three groups: problem-solving approach, attention and activity, and personal-emotional-social. Paired-samples t-test analysis was employed to compare clients' ratings pre and post 40 NFB sessions. Table 3 provides the results of this analysis. In general, according to qualitative observations clients' performance significantly improved on 11 out of 12 measures. Specifically, their problem-

TABLE 2. Quantitative ToL^{DX} mean standard scores pre- and post-40 neurofeedback sessions.

Variable	Pre	Post	p value
Total Move (TMS)	85.37	94.11	.027
Total Correct (TCS)	90.74	93.89	.392
Total Rule Violations (TRV)	72.63	92.74	.007
Total Time Violations (TTV)	96.95	101.89	.331
Total Initiation Time (TIT)	90.21	95.68	.066
Total Execution Time (TET)	88.42	99.68	.002

Note. ToL^{DX} – Tower of London – Drexel University.

TABLE 3. Qualitative ToL^{DX} mean raw scores pre- and post-40 neurofeedback sessions.

Variable	Pre	Post	*p* value
Systematic	3.32	2.26	.003
Deliberate	4.00	2.63	.002
Persistent	2.47	1.42	.000
Flexible	3.84	2.42	.000
Alert	3.58	1.79	.000
Attentive	3.42	1.63	.000
Motor	1.05	1.00	.331
Cooperative	2.21	1.16	.000
Confident	3.63	2.11	.000
Relaxed	4.00	2.26	.000
Frustration	3.42	1.74	.000
Support	3.52	1.58	.000

Note. ToL^{DX} – Tower of London – Drexel University.

solving approach appeared to become more systematic, $t(18) = 3.499$, $p < .01$; deliberate, $t(18) = 3.714$, $p < .01$; persistent, $t(18) = 6.508$, $p < .001$; and flexible, $t(18) = 5.786$, $p < .001$. They seemed to be more alert, $t(18) = 6.129$, $p < .001$, and task-oriented, $t(18) = 7.195$, $p < .001$. Finally, while working on the task, ratings showed they were more cooperative, $t(18) = 4.729$, $p < .001$; confident, $t(18) = 6.198$, $p < .001$; relaxed, $t(18) = 7.240$, $p < .001$; better able to tolerate frustration, $t(18) = 7.761$, $p < .001$; and needed less support, $t(18) = 8.748$, $p < .001$, subsequent to 40 NFB sessions. Following Bonferroni adjustment, improvement in performance observed post 40 NFB sessions remained significant.

TOVA and IVA

The next set of analyses examined the changes in four TOVA and six IVA variables pre and post 40 NFB sessions in clients with AS. TOVA scores are (a) omission errors (inattention), (b) commission errors (impulsivity), (c) reaction time, and (d) variability of reaction time. IVA scores are (a) auditory prudence, (b) visual prudence, (c) auditory vigilance, (d) visual vigilance, (e) auditory speed, and (f) visual speed. Because some of the clients performed well on TOVA and IVA measures prior to NFB (probably because those with AS are anxious and try to follow rules), we decided to only measure changes in clients who initially scored below mid-average (standard score lower than 100). Thus, only the people who needed to improve were assessed. This criterion however further reduced our already small sample size. Future studies might use more stringent criteria, such as one or two standard deviations below the mean on the initial scores, to measure changes on TOVA and IVA. Tables 4 and 5 reveal results from the analysis of paired-samples *t* tests for TOVA and IVA variables, respectively. Overall, no participants did worse at posttest, and results revealed a trend toward improvement with respect to the number of commission errors made. Examination of the IVA variables indicated that clients significantly improved on two out of six variables and there was a trend toward improvement on auditory vigilance measure. Specifically, there was a significant difference in the scores for auditory prudence ($M = 19.55$, $SD = 11.99$), $t(10) = 5.404$, $p < .001$, and visual prudence ($M = 17.38$, $SD = 16.82$), $t(7) = 2.922$, $p < .05$. Prudence scores were based on the percentage of correct responses to nontargets, that is, inhibiting a response when the number 2 was presented. Following Bonferroni adjustment, difference in scores remained significant for the auditory prudence measure.

TABLE 4. TOVA standard scores pre- and post-40 neurofeedback sessions.

Variable	(N)	Pre	Post	*p* value
Omission errors	12	80.17	87.33	.091
Commission errors	9	66.89	88.56	.066
Response Time	12	73.25	79.83	.189
Response Time Variability	15	70.60	76.07	.142

Note. TOVA – Test of Variables of Attention; clients were excluded if their initial standard score was 100 or greater.

TABLE 5. IVA standard scores pre- and post-40 neurofeedback sessions.

Variable	(N)	Pre	Post	*p* value
Auditory Prudence	11	76.18	95.73	.000
Visual Prudence	8	61.63	79.00	.022
Auditory Vigilance	12	59.67	75.75	.063
Visual Vigilance	8	72.88	73.25	.970
Auditory Speed	10	79.70	82.80	.303
Visual Speed	6	86.00	89.50	.512

Note. IVA – Integrated Visual and Auditory Continuous Performance Test; clients were excluded if their initial standard score was 100 or greater.

Effects of Age and IQ

An ANOVA performed on the initial ToL^{DX} scores and ToL^{DX} difference scores (postscore – prescore), did not demonstrate a significant effect of age and IQ. Therefore, tables and graphs were not produced. First, the participants were divided into two groups according to their age: 10 years of age or younger, and older than 10 years old. There are numerous studies indicating a sequential development of executive functions (in frontal lobes) through childhood (Luciana & Nelson, 1998) that may be associated with gradual emergence of other cognitive skills (Halperin, Healey, Zeitchik, Ludman, & Weinstein, 1989). Consequently, children 10 years of age would have undergone a sufficient amount of neurological development required to complete a ToL test as compared to a group younger than 10 years of age. The results did not indicate a significant difference in performance among these two groups. Given that ToL^{DX} is standardized for age, such findings are to be expected. Therefore, this test is a good measure of clients' performance at all ages. Subsequent analysis divided the participants into two groups based on their IQ score prior to NFB: IQ score of 100 or less, and IQ score higher than 100. As with the previous analysis, results of an ANOVA did not indicate a significant difference in performance between these two groups. Specifically, participants with higher IQ score prior to NFB did not make significantly greater gains than the group with lower average IQ.

Impulse Control

Finally, linear regression analysis was conducted to assess the relationship between the improvement on impulse control measures on the three tests; ToL^{DX}, TOVA, and IVA. As mentioned earlier, the total rule violations score on ToL^{DX} (TRV) relates to inhibition and self-regulation as well as other cognitive skills such as working memory, executive planning, and the use of internal speech to guide behavior (Culberston & Zillmer, 1998a, 1998b, 2001). TOVA commissions score (how many times the nontarget is pressed) and IVA prudence score (one of three measures of response control) also assess one's impulsivity and response inhibition abilities (Strauss, Sherman, & Spreen, 2006). Statistical analysis did not indicate a significant relationship between the improvement on TRV on ToL^{DX} and the impulse measures on TOVA and IVA. Therefore, tables and graphs were not produced. It is important to note that there was improvement on each one of the measures of impulsivity and that clients' initial scores were already elevated prior to training leaving little room for improvement.

DISCUSSION

This clinical outcome study of consecutive clients trained in a private educational setting extends our understanding of executive functioning in clients with AS. It also addresses the utility of the ToL^{DX} in a clinical setting with this population. It partially replicates previous studies that provided evidence that NFB and training in metacognitive strategies produce positive clinical outcomes and demonstrates the utility of ToL^{DX} to aid in diagnosis of AS and treatment planning for individuals with AS. Furthermore, it reveals that systematic data collection can be carried out in a private educational setting. In addition to these general findings, there are a number of specific conclusions that can be drawn from the data.

First, skills such as planning, working memory, cognitive flexibility, and inhibition can be measured in clients with AS using ToL^{DX} and improvement in these areas following 40 NFB sessions was observed. Significant improvements in executive planning, inhibition, cognitive flexibility, and planning efficiency were measured. After NFB training, clients worked more quickly and violated fewer rules. As such, these findings suggest an improved ability to shift set and inhibit a response until they have thought it through. In addition, qualitative observations of client performance after 40 sessions of neurofeedback indicated that clients took a more systematic and organized problem-solving approach, remained more attentive during the task, and showed increased self-confidence. Given that previous imaging studies have postulated that participants with AS do not show typical activation in the left medial prefrontal cortex during mind-reading tasks as compared to controls (Wing, 2001) and that lesions in the left anterior frontal lobe produce real-life problem-solving difficulties (Channon, 2004), our results are not surprising, because NFB utilizes normal plasticity and produces changes in networks in the brain. Training at CZ and FCZ, as was done with these clients, is postulated to affect not only thalamus-cortical loops that stabilize the cortical functioning (Sterman, 2000) but also the anterior cingulate and its links to the limbic system (emotional brain) and mirror neuron areas (Reid, 2005). Recent research has found differences in frontal, temporal, and temporal-parietal mirror neuron areas (Dapretto et al., 2006; Wing, 2001) as well as hypocoherence patterns in the frontal lobe in clients with AS, as compared to a normative database (Neuroguide; Kaiser, 2006; L. Thompson & Thompson, 2007). It is likely that frontal lobe dysfunction is one of the major contributors to this syndrome, particularly with respect to the symptoms that overlap with ADHD. Although the exact cognitive processes that underline ToL^{DX} remain equivocal, numerous theoretical and empirical studies support the involvement of frontal lobe executive functioning such as planning, organizing, and executing goal-directed behavior (Fuster, 1989, 1997). Neuroimaging studies have indicated that ToL performance involves the ventrolateral frontal cortex (Brodmann areas 45 and 47) and mid-dorsolateral frontal cortex (Brodmann areas 9 and 46; Owen, 1997). In the light of the previous research and our current findings, we suggest that ToL^{DX} may be a useful tool in clinical settings in order to enhance diagnosis, treatment planning, and tracking client progress across time.

Second, as measured by continuous performance tests (CPTs), TOVA and IVA, all participants improved. Specifically, group data showed trends as well as significant improvement on the impulsivity scales on TOVA and IVA. After 40 NFB sessions, clients with AS were less likely to hit nontargets on these tests. Other variables, such as vigilance and response time, did not change to a significant degree. Because a previous study with a large sample size found significant improvement across all subtests on the TOVA and IVA measures (Reid, 2005), perhaps, a larger sample size is needed for a moderate effect size and significant results.

The third conclusion that can be drawn from our findings is that there do not appear to be significant age and IQ effects on the ToL^{DX} performance. Because standard scores were used, the age factor was already accounted for, so it was not surprising to find that ToL^{DX} performance in this study did not differ with age. This finding further supports the usefulness of this measure in a clinical setting. Nevertheless, previous research has indicated that as the frontal lobes mature, executive functioning develops (Welsh et al., 1991) and continues to unfold until adulthood is reached (Dennis, 1991). For example, children 7 to 9 years of age problem solve in a trial-and-error manner, make numerous mistakes, and rarely plan before initiating their moves on ToL^{DX}. Children 10 to 12 years of age show better control of these impulsive tendencies and are more likely to pause and plan before initiating the task and to keep the plan in mind (as indicated by lack of stoppage and hesitation). These higher level strategies become even more apparent in older populations with infrequent time and rule violations, increased speed, and more efficient planning (Culbertson & Zillmer, 2001). For that reason, age norms are used with raw scores transformed to standard scores ($M = 100$, $SD = 15$). Because ANOVA comparing lower and higher IQ groups and time (pre–post) with respect to ToL^{DX} scores did not show a significant interaction, it appears that clients with AS of all IQ levels improve equally well with respect to executive functions when NFB training is applied.

Fourth, this small pilot study offered the opportunity to compare the measures of impulsivity on three different tests. According to our findings, it appears that there is not a significant association between the improvement on the impulsivity measure on ToL^{DX} (total rule violations) and the impulsivity measures on TOVA and IVA. Previous research has not indicated high correlations between CPTs, such as TOVA and IVA, and clinically employed rating scales (Strauss et al., 2006), suggesting that these tools may measure somewhat different domains (Forbes, 1998). Nevertheless, for disorders such as ADHD there is a significant agreement between TOVA findings and *DSM–IV* criteria. In this study, despite already elevated initial scores, leaving little room for enhancement, there was improvement on each one of the measures of impulsivity. In addition, clients with AS are often anxious and like to obey rules. Consequently, they tend to score high on CPTs regardless of their difficulties. As a result, a larger sample size may be required to avoid Type II error when assessing a relationship between impulsivity measures on CPTs and ToL^{DX} (TRV). Overall, information on the correlation between diagnostic tests is lacking, and future research might address this understudied area in studies with a larger sample size.

Finally, we were able to conduct qualitative observations with two clients who were tested after 40 sessions of NFB and again after 60 sessions. In these two cases it was determined after 40 sessions that more training was needed. Figure 1 provides ToL^{DX} standard scores at three testing times for Client 1. It is interesting to note that this client had slightly lower scores after 40 NFB sessions, but his performance improved after

FIGURE 1. ToL^{DX} standard scores on six quantitative measures at three time points (pre-, post-40, and post-60 NFB sessions) for client 1.

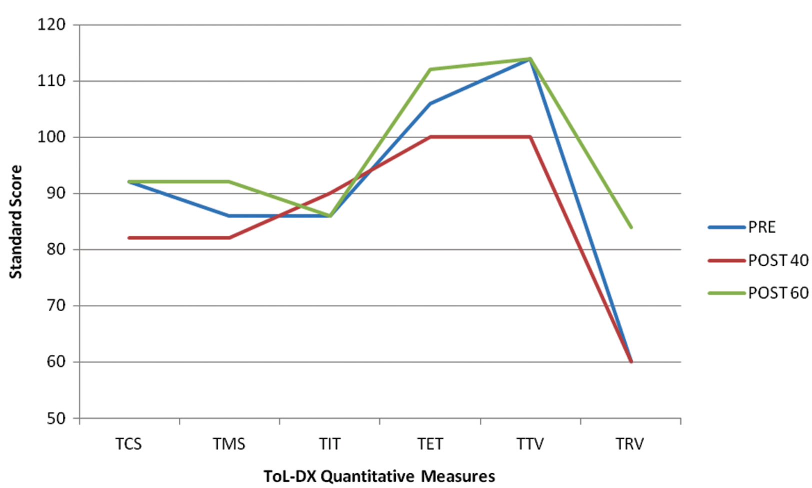
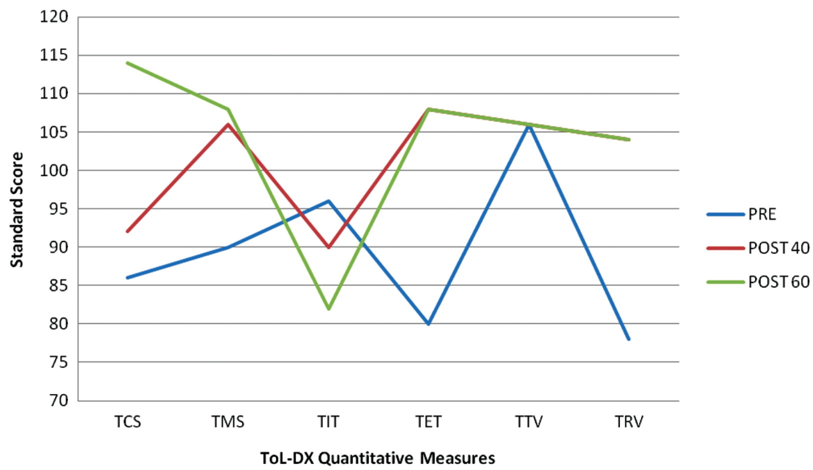
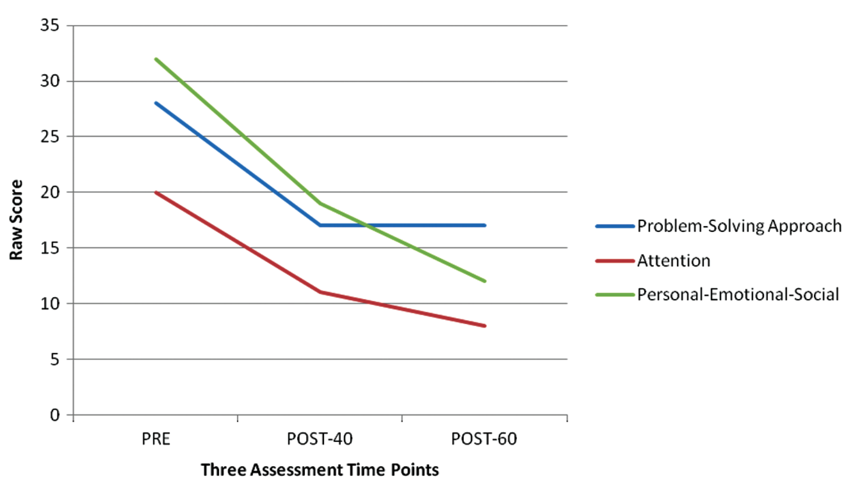


FIGURE 2. ToL^{DX} standard scores on six quantitative measures at three time points (pre-, post-40, and post-60 NFB sessions) for client 2.



60 sessions. At final testing he showed more efficient executive planning, violated fewer rules, and solved problems faster than at the initial assessment. Figure 2 presents ToL^{DX} standard scores at three testing times for the second client. In general, his performance seemed to improve steadily as he progressed through training. He became more efficient at problem solving and holding information online. Gains made with respect to speed of problem solving and impulsivity after 40 NFB sessions were maintained after 60 NFB sessions but did not show further improvement. Total initiation time showed a lower score each time, indicating he needed less time to think before making his first move. With respect to qualitative observations of their problem-solving approach, attention, and social interaction, both clients continued to improve over time (see Figure 3 and were rated as more systematic, task oriented, and cooperative during the testing. Although these findings are descriptive and not statistically grounded, an interesting

FIGURE 3. ToL^{DX} raw scores on three groups of qualitative measures at three time points (pre-, post-40, and post-60 NFB sessions) for clients 1 and 2.



pattern is seen. Although previous research has provided evidence for substantive gains in clients with ADHD subsequent to 40 NFB sessions (L. Thompson & Thompson, 1998) as well as clients with AS (Reid, 2005) on CPTs, intelligence and academic measures, and EEG ratios, it may be that some clients with AS may need more than 40 NFB sessions to make gains on tests of executive functions. Therefore, tracking their progress across time is essential, and future research with a larger sample size could further clarify their pattern of gains.

This study had a number of limitations. First, this pilot study had a small sample size that became further reduced on some measures when more stringent criteria were employed for analysis. Second, there was a subjective element when assessing clients' performance on ToL^{DX} qualitatively and no interrater reliability was established. Third, testing and retesting sessions were carried out at different times of the day. Initial testing was conducted in the morning, whereas retest was done in the afternoon. Time of day effects induce a dip in alertness level, reflected in the EEG as increased amount of slow-wave activity (Cacot, Tesolin, & Sebban, 1995).

Finally, these data must be viewed carefully, because the exact mechanisms of improvement are unknown. Specifically, the noted increase in confidence and possible decrease in impulsivity in clients with AS may have helped them become more reflective and better at test taking than before. Also, they may have developed a more positive attitude and an increased desire to please after 40 sessions of NFB training. Other possible factors contributing to positive outcomes may be familiarity with the tests, relationship with the examiner, increased parental support and encouragement, and nonspecific effects that arise from positive expectations. Practice effects would not be large since clients, on average, were retested approximately 5 months following the initial assessment. Nevertheless, future studies should include a control group in order to control for practice effects on ToL^{DX} performance as well as nonspecific (placebo) effects.

CONCLUSION

This pilot project demonstrated the utility of ToL^{DX} in a clinical setting for measuring executive functions pre and post 40 NFB sessions in clients presenting with AS. There were methodological short-comings, such as failure to have a control group. Our findings suggest that 40 NFB sessions coupled with training in metacognitive strategies have a positive effect on executive functioning in clients with AS including their planning efficiency, speed, and ability to switch sets and inhibit certain responses. It can be posited that learning how to maintain a focused and relaxed mental state through NFB, as well as increasing one's conscious awareness of thinking patterns, are useful when working on long-term change. In particular, clients with AS may realize that proper planning aids success. Furthermore, employing a measure of planning and organizing abilities, such as ToL^{DX}, in clinical settings seems to provide important information about clients' initial functioning and ongoing progress over the course of training. Such knowledge may be useful to clinicians when assessing and developing a treatment plan for clients with AS.

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