

## **Neurofeedback Combined with Training in Metacognitive Strategies: Effectiveness in Students with ADD<sup>1</sup>**

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*A review of records was carried out to examine the results obtained when people with Attention Deficit Disorder (ADD) received 40 sessions of training that combined neurofeedback with the teaching of metacognitive strategies. While not a controlled scientific study, the results, including pre- and post-measures, are consistent with previously published research concerning the use of neurofeedback with children. A significant addition is that a description of procedures is included. The 111 subjects, 98 children (age 5 to 17) and 13 adults (ages 18 to 63), attended forty 50-min sessions, usually twice a week. Feedback was contingent on decreasing slow wave activity (usually 4–7 Hz, occasionally 9–11 Hz) and increasing fast wave activity (15–18 Hz for most subjects but initially 13–15 Hz for subjects with impulsivity and hyperactivity). Metacognitive strategies related to academic tasks were taught when the feedback indicated the client was focused. Some clients also received temperature and/or EDR biofeedback during some sessions. Initially, 30 percent of the children were taking stimulant medications (Ritalin), whereas 6 percent were on stimulant medications after 40 sessions. All charts were included where pre- and post-testing results were available for one or more of the following: the Test of Variables of Attention (TOVA,  $n = 76$ ), Wechsler Intelligence Scales (WISC-R, WISC-III, or WAIS-R,  $n = 68$ ), Wide Range Achievement Test (WRAT 3,  $n = 99$ ), and the electroencephalogram assessment (QEEG) providing a ratio of theta (4–8 Hz) to beta (16–20 Hz) activity ( $n = 66$ ). Significant improvements ( $p < .001$ ) were found in ADD symptoms (inattention, impulsivity, and variability of response times on the TOVA), in both the ACID pattern and the full-scale scores of the Wechsler Intelligence Scales, and in academic performance on the WRAT 3. The average gain for the full scale IQ equivalent score was 12 points. A decrease in the EEG ratio of theta/beta was also observed. These data are important because they provide an extension of results from earlier studies (Lubar, Swartwood, Swartwood, & O'Donnell, 1995; Linden, Habib, & Radojevic, 1996). They also demonstrate that systematic data collection in a private educational setting produces helpful information that can be used to monitor students' progress and improve programs. Because this clinical work is not a controlled scientific study, the efficacious treatment components cannot be determined. Nevertheless,*

<sup>1</sup> ADD and the term attention deficit disorder are used in this paper to refer to students who meet diagnostic criteria for Attention-Deficit/Hyperactivity Disorder; Inattentive type, Hyperactive-Impulsive type, or Combined type (American Psychiatric Association, 1994). Thanks is expressed to Irene Rukavina, Ph.D. for her work on the data analysis for this article.

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*the positive outcomes of decreased ADD symptoms plus improved academic and intellectual functioning suggest that the use of neurofeedback plus training in metacognitive strategies is a useful combined intervention for students with ADD. Further controlled research is warranted.*

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**KEY WORDS:** ADD/ADHD; neurofeedback; intelligence; TOVA; metacognition.

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## BACKGROUND

The primary symptoms of Attention Deficit Disorder (ADD) include difficulties regulating attention, distractibility, and impulsivity. Hyperactivity is present in some of the children and is found to a lesser degree in adolescents and adults with this symptom picture. Estimates of prevalence range from 1 to 14% of school-age children (Szatmari, Offord, & Boyle, 1989). Prevalence is usually quoted as being 3 to 6% (American Medical Association, Council Report, 1998). It is diagnosed in a lower percentage of the adult population. These traits are associated with decreased arousal and decreased glucose metabolism in both frontal and certain subcortical regions (Zametkin *et al.*, 1990; Lou, Henrikson, Bruhn, Borner, & Nielsen, 1990). They are also associated with increased slow 4–8 Hz (theta) activity in frontal and central cortical regions (Mann, Lubar, Zimmerman, Miller, Muenchen, 1992; Janzen, Graap, Stephanson, Marshall, & Fitzsimmons, 1995).

The EEG differences between persons who have difficulty with attention span and impulsivity and those who do not have these traits provide the rationale for the use of neurofeedback. The goal of this form of biofeedback is to train the subject to maintain a calm, relaxed, alert, and focused mental state while carrying out cognitive tasks. These techniques have been developed over the last 20 years and have been described in previous publications (Lubar & Lubar, 1984; Lubar, 1991; Tansey, 1991).

The rationale for training in metacognitive strategies is that people with ADD typically demonstrate academic underachievement. Studies have demonstrated that good students use metacognitive strategies; that is, they are aware of and consciously monitor how they learn and remember things. Underachieving students do not demonstrate this capacity (Cheng, 1993).

Most writings on the topic of Attention Deficit Disorder (ADD) and Attention-Deficit/Hyperactivity Disorder (ADHD) have stressed negative symptoms and frustrations. There are, however, many positive aspects regularly seen in people who have these symptoms. The so-called inattention can be conceptualized as a dichotomy of focus in which the difficulty in paying attention to boring or slow-paced material contrasts with the strength of having hyperfocus during an activity of interest (Sears & Thompson, 1998). Creativity, energy, spontaneity, and ability to focus intensely all seem to be just as characteristic as the commonly cited negative symptoms (Hartmann, 1993; Sears & Thompson, 1998). The main objective of neurofeedback combined with training in metacognitive strategies is to reduce the negative traits of inattention, distractibility, and impulsivity, while at the same time emphasizing techniques for channeling the individual's positive qualities to work to their advantage. The treatment goal is to get to the point where the behavior is seen as spontaneous and not impulsive, energetic rather than hyperactive, with the person successfully able to juggle many tasks rather than seeming to flit from thing to thing. With improved self-regulation one can expect improved academic performance both because of improved attention and listening and because more time is spent on task.

Currently, stimulant medication is the most commonly used intervention for children who present with the symptoms of ADD (Barkley, 1990). Approximately 1.5 million children in the United States (about 3% of the school age population) were being prescribed methylphenidate (Ritalin) in 1995 (Safer, 1996). There was a five-fold increase in sales of Ritalin from 1990 to 1997, from approximately 2,000 Kg to nearly 10,000 Kg in the United States (Feussner, 1998). Research on the effect of stimulant medication shows that commonly used stimulant medications for ADD are effective for the short-term management of symptoms. Research does not support the outcome of long-term beneficial effects on learning, achievement, or social adjustment (Swanson *et al.*, 1993). Medications may be necessary and appropriately used for a limited time when symptoms are interfering to a serious degree with a child's functioning at home or school. An example would be a child who cannot stay in his seat for more than a few minutes or who is so impulsive that he frequently gets sent to the school disciplinary office for talking out in class. "Medications when necessary but not necessarily medications" is a conservative guideline (Sears & Thompson, 1998, p. 243). With no research on the effects of long-term use, with the prescription of stimulants having increased five-fold, and with the prospect of being on medication indefinitely, there is motivation to look for alternatives to drug treatment.

Recent work suggests that neurofeedback can be as effective as stimulant medication in reducing the symptoms of ADD (Rossiter & LaVaque, 1995). There is also evidence of significant improvements in measures of intelligence, academic performance, and behavior (Lubar, 1991; Lubar *et al.*, 1995; Linden *et al.*, 1996). Medications can also be combined with neurofeedback.

This paper reports the results of a chart review of clients seen consecutively at a learning center that specializes in using neurofeedback plus coaching in metacognitive strategies to improve concentration and attention. The purpose of the review was to examine the results obtained when this combined training is used with children and adults who exhibit the symptoms of ADD. The inclusion of adults along with children and adolescents is a novel feature of this series of cases. This work is a partial replication and an extension of similar work using neurofeedback with children with ADD (Lubar *et al.*, 1995; Linden *et al.*, 1996; Tansey, 1991).

## METHOD

### Participants

The participant pool consisted of 111 persons, 98 children between the ages of 5 and 16 years and 13 adults, 17 to 63 years. The age distribution was as follows: four children 5–6 years old, twenty-six 7–8 years old, thirty-six 9–11 years old, twenty-five 12–14 years old, seven 15–16 years old. Of the adult group there were seven 17–18 years old and the other six were over age 28. The participants were mixed in terms of racial backgrounds, countries of origin and socioeconomic status. The ratio of males to females was approximately 3 to 1. All subjects met the Diagnostic and Statistical Manual of Mental Disorders, 4th ed., criteria for Attention Deficit/Hyperactivity Disorder based on clinical interviews and questionnaires (SNAP version of the DSM-IV, Conners' Abbreviated Symptom Questionnaire for Parents, and Conners ASQ for Teachers; American Psychiatric Association, 1994). They also demonstrated an EEG power spectrum consistent with the diagnosis of

ADD, that is, increased 4–8 Hz theta at central cranial locations when compared with 16–20 Hz beta activity (Mann *et al.*, 1992). All participants who were taking stimulant medication (29 children at intake and 6 at posttest) were off their medication for at least 20 hrs prior to testing. Ritalin was the prescribed medication in all cases.

A number of factors in this learning setting resulted in only 55 clients (9 adults and 46 children) having pretest and posttest results on *all* of the measures. There were no drop-outs, but data was incomplete for many subjects. A number of factors contributed to incomplete test results: (a) Pretest scores from psychological testing done elsewhere (either privately or through the child's school board) were sometimes incomplete or had used different measures. Because IQ testing was not repeated at intake if testing had been done within the previous 24 months, this was the most frequent cause for missing data on the Wechsler tests. (b) Time constraints at posttest sometimes meant certain tests or subtests were dropped from the battery (with some clients, for example, only the ACID pattern subtests from the intelligence tests—Arithmetic, Coding, Information and Digit Span—were administered). (c) A few children moved and all of the posttest measures were not available. (c) Some children were untestable on some measures at pretest due to extreme restlessness, frustration, or young age. This was particularly true during the second half of the TOVA when the target stimuli are frequent and errors increase. (All clients were able to sit for the 22.5 min administration of the TOVA at posttest).

### Testing

Testing was done by the first author both at intake and after the completion of 40 fifty-min sessions, which combined neurofeedback with coaching in learning strategies. All charts were included where pretesting and posttesting results were available *for one or more* of the following: the Test of Variables of Attention (TOVA), Wechsler Intelligence Scales, Wide Range Achievement Test (WRAT 3), and the electroencephalogram (EEG) assessment protocol of the Autogen A620, which provides, among other measures, a ratio comparing theta (4–8 Hz) to beta (16–20 Hz) activity. Paired *t* tests of the difference between means for all subjects with available data were carried out and levels of significance computed.

### EEG Instruments and Trainers

The instruments used for training the students in this study were the F1000<sup>4</sup> and the Autogen A620<sup>5</sup>. The assessment program on the A620 instrument provided the EEG theta/beta ratios. The electrodermal response (EDR), a measure of skin conductance, and finger temperature feedback were done using the F1000, which has the capacity to simultaneously monitor and give feedback for EEG and/or EDR and/or temperature. Which instrument was used depended on client needs, client preference, and availability of instruments. All clients had experience with both instruments.

The eight trainers had bachelor's, master's or doctoral level degrees in health care, teaching, or psychological fields. They were chosen, however, not so much for their academic backgrounds as for their ability to relate to and coach students. At the center, students

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typically work with a number of different trainers over the course of their training. These are persons of different backgrounds, ages, and with quite different personalities. The training effects should be dependent on the neurofeedback and the strategies taught and not on the relationship with a particular trainer, although it is indisputably important to establish good rapport between a student and the trainer during each session.

### Neurofeedback

Neurofeedback is a form of biofeedback in which the subject trains to control attributes of brain wave activity. The students in this review were training to decrease the amplitude and variability of their dominant slow wave activity, which was usually activity in the 4–8 or 4–7 Hz bandwidth (theta). A number of the students, however, showed a pattern of excessive activity in the 9–11 Hz bandwidth (alpha). These individuals were trained to lower the amplitude of this slow alpha during cognitive tasks. As slow-wave activity was being decreased, the student was encouraged to increase fast-wave activity. Placement was typically referential to the left ear lobe. Occasionally a bipolar placement was used, FCz–CPz., as suggested by Lubar. This would be done mainly with hyperactive children so that common mode rejection would eliminate some of the movement and muscle artifact. For most students the electrode was placed at Cz. Left-side placement at C3 was sometimes used if functions that predominantly involve the left hemisphere, such as language, needed to be strengthened.

The fast-wave activity that was reinforced was usually between 15 and 18 Hz. Those students whose principle difficulties were impulsivity and hyperactivity were trained to increase the fast wave activity between 13 and 15 Hz (sensorimotor rhythm or SMR) with the electrode placed at Cz or C3. (More recently, SMR training has also been carried out locating the electrode at C4.) In a few children who displayed reading difficulties and who were also quite impulsive, sessions would include both reinforcement of beta activity in the 15–18 Hz range, for that part of the session while they practiced reading strategies, and SMR activity in the 13–15 Hz range for the remainder of the session.

### Reward System

Subjects' EEGs were sampled at a rate of 128 samples/second. EMG activity was defined as activity greater than 15 microvolts occurring above 50 Hz. The EMG inhibit is defined by the instrument being used. It assists the training to make sure that the feedback received by the student is due to increasing SMR or beta activity rather than increased muscle tension. Rewards are given by auditory and visual feedback from the computer, points accumulating on the monitor screen, and by a token reward system administered by the trainer.

Children earn tokens for effort and good performance, and the child has a bank account and can exchange tokens to purchase rewards from a "store" in the learning center. Prizes range from pens, bookmarks, and action figures to books, board games, and gift certificates for a local music shop. Points are given by the machine for each 0.5 s of activity (50 of 128 samplings on the A620) during which the slow-wave activity is maintained below threshold at the same time as fast-wave activity is maintained above threshold. The thresholds are

initially set by the center director (first author) who does all the intake assessments. They are based on the levels of slow-wave and fast-wave activity observed at that time. The slow-wave threshold is set 1 to 2 microvolts above the average activity level of the slow-wave band. The fast-wave threshold is set 0.2 to 0.6 microvolts below the average activity level. The threshold may be altered to emphasize either decreasing slow-wave or increasing fast-wave activity according to the needs of a particular student. Feedback was both auditory and visual on both of the EEG feedback instruments. The student would receive primarily auditory feedback when doing academic tasks. An example of feedback using the F1000 equipment is a screen with a large brightly colored oval on a black background with a thermometer (gauge) on each side. When the thermometer level on the left side (slow waves) revealed activity below the marked threshold and the thermometer level on the right side (fast waves) demonstrated activity above threshold then the central oval would light up and a pleasant tone was heard. Feedback displays on the A620 were more like games, such as moving a fish through a maze or assembling puzzles. Thresholds on the A620 were adjusted so that the student initially received approximately 15 to 20 points a minute. On the F1000, a faster rate, 30 to 40 points per minute, was used. Younger students usually require a higher point frequency.

The results of each few minutes (section) of training were reviewed with the student on a statistics screen after each section of training. Trainers were instructed to emphasize the neurofeedback, with the student watching the screen for two 3-to-6-min periods initially. The third section of training would last from 3 min for very young students to as much as 10 min for older students. During this section academic challenges and metacognitive strategies were introduced, appropriate to the needs of the student as determined by the director after initial academic and intellectual testing. During this section the feedback is auditory. This process of alternating pure feedback with feedback combined with cognitive activities was continued for the remainder of the session. The idea behind this approach is as follows: once the student is relaxed, alert and focused, one has a useful moment for discussing learning strategies. To practice maintaining a particular EEG pattern while engaged in academic tasks may also help in the transfer of skills from the training center to the classroom.

### **EDR and Temperature**

Alertness level drops precipitously in most students who have ADD when they are required to carry out cognitive tasks such as listening to the teacher in the classroom or reading and doing their homework. The F1000 equipment allows simultaneous auditory and visual feedback of brain waves, EDR, and peripheral temperature. In those students who demonstrated a low and flat (that is, quite unresponsive) electrodermal response, EDR feedback was given with the sensors on the left hand (index finger and ring finger) while they were also receiving neurofeedback. The goal was to make them aware of their alertness level and empower them to control it. These subjects were encouraged to use techniques such as sitting up straight to increase alertness while working on cognitive tasks.

A small number of students also demonstrated very low peripheral skin temperature. These students usually complained of anxiety, particularly when their academic or athletic abilities were being tested. They received temperature feedback and relaxation training (visualizing techniques and breathing techniques) while they were simultaneously receiving neurofeedback. For most students, only 5 to 15 sessions of combined feedback were needed

to alter their own and parent reports of anxiety responses in academic or competitive athletic situations. Data on EDR and temperature were not systematically collected and are not reported in this review. Learning to regulate these physiological measures seemed easier than learning self-regulation of brain wave activity because it took fewer sessions. This success encouraged students that they would also learn to regulate their brain waves.

### **Metacognitive Strategies**

Metacognition refers to thinking skills that go beyond basic perception, learning, and memory. It consists of the executive functions that consciously monitor our learning and planning. Metacognitive strategies increase awareness of thinking processes (Palincsar & Brown, 1987; Cheng, 1993; Gray, 1991). Strategies were taught during part of each session to all students while they were simultaneously receiving feedback.

Metacognitive strategies training consisted of coaching the students in thinking skills that let them monitor their learning. The strategies outlined above were taught for approximately one third of each session while the student was also receiving auditory feedback. These strategies help students think about thinking and reflect on what they know about knowing. The kinds of strategies taught included the following: word analysis skills for decoding; active reading strategies; listening skills; organizational skills for making a presentation, writing a paragraph or writing an essay; answering exam questions; tricks for times tables; solving word problems in math; organizing study time; creating mnemonic devices; and preparing study notes. Adult clients typically wanted to work on time management, efficient reading strategies, and in three cases, basic math skills for everyday life such as fractions, interest rates, budgeting. The techniques emphasized (a) remaining alert while listening or studying, and (b) organizing and synthesizing material to aid recall. In essence, students learned to be active learners. This is essential for those with ADD as they are not naturally reflective about the learning process and tend to get bored easily.

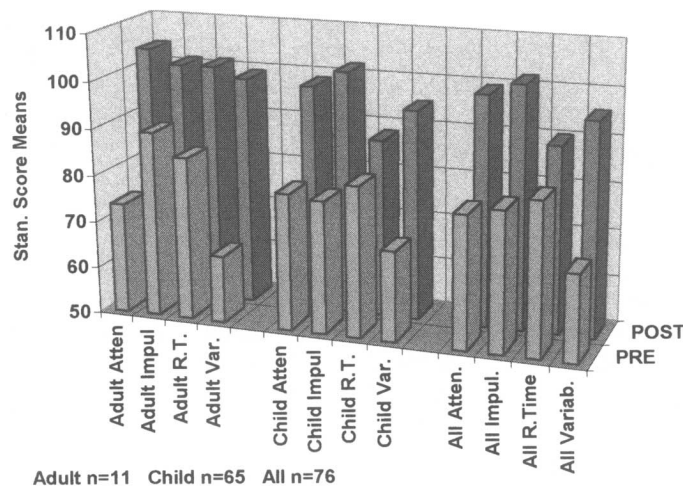
### **Note Re Medication Use**

Before entering the program, 29 of the 98 children (30%) were taking stimulant medication. The drug used was methylphenidate (Ritalin) in all cases. Of these students, 23 came off medication during the course of their training. Thus, 79% of those who were taking the stimulant drug when they started training stopped its use. In five students, the dose of medication was lowered as training proceeded. Just one student remained on Ritalin at the original dose level. Thus, six children (6% of the total group) were taking medication after training. No students began medication.

## **RESULTS**

### **Part I: Results on a Continuous Performance Task (TOVA)**

A continuous performance test, the Test of Variables of Attention (TOVA), was administered as part of the initial interview and again after 40 training sessions. The TOVA is



**Fig. 1.** Graphic representation of pre-post changes in mean standard scores on the TOVA. For the total group  $p < .01$  for changes on each of the four variables.

a visual continuous performance test in which the subject is instructed to press a button on a hand-held trigger as quickly as possible each time a simple visual stimulus is presented on the computer screen. The target is a rectangle with a black square in its top half. They are not to press the button when a different stimulus is presented (the same rectangle with a black square in its bottom half). The stimuli are presented for 100 ms every 2 sec during the 2½ min practice test and during the 20 min test. Four scores are recorded for (a) omission errors (inattention), (b) commission errors (impulsivity), (c) reaction time, and (d) variability of reaction time. Results are presented as standard scores and T-scores according to norms for age and sex. Greenburg (1987) reported that these variables are significantly different in ADD subjects on and off methylphenidate medication (Ritalin). He also demonstrated that there is no practice effect and that subjects generally do more poorly when retested, perhaps due to boredom. All the students were off medication when tested.

Results on the TOVA (see Figure 1) were available for 76 students (11 adults and 65 children). The TOVA changes for each of the four variables were assessed by the use of the  $t$  test for matched pairs. No participant was worse on posttesting. Results revealed consistent improvements, particularly in terms of less variability in reaction time. Significance levels were  $p < .001$  for variability, which is the most sensitive scale for indicating an ADD problem (Greenburg, 1987). For children, inattention and impulsivity also showed significant improvements ( $p < .0001$ ), whereas in the smaller adult group the mean for inattention improved significantly ( $p < .01$ ) but the change in impulsivity, though increasing from low average to mid average, did not reach significance.

Mean reaction time in children did not increase as much or as consistently as the other three variables because there was a subgroup of children who had slower reaction times on retest. The average increase was 6 standard score points from 82 to 88 ( $p < .02$ ) (Table I). There were 26 students who demonstrated a fast, impulsive style on intake whose reaction times became slower. Their impulsivity scores and variability scores, however, markedly improved. A nonparametric sign test (Fergusson, 1971) for two correlated samples showed that the relationship between slower reaction time and decreased impulsivity was significant



Table I. Mean TOVA Scores

	Pre	Post	<i>p</i> <
All ages attention span	78.3	99.1	.0001
All ages impulsivity	79.8	101.7	.0001
All ages reaction time	82.5	89.8	.003
All ages variability	68.5	95.4	.0001
Adult attention span	73.5	104	.01
Adult impulsivity	89.5	100.9	n.s.
Adult reaction time	84.7	101	.03
Adult variability	64.3	98.9	.0001
Child attention span	79.1	98.3	.0001
Child impulsivity	78.2	101.8	.0001
Child reaction time	82.1	87.9	.02
Child variability	69.2	94.8	.001

( $Z = 4.4$ ,  $p < .0001$ ). Although a slower reaction time is not the direction that is usually considered to be improvement on the TOVA, it represented an improvement clinically in this subset of 26, as these students were too fast initially (they were sacrificing accuracy for speed) and were responding more slowly and carefully after training. In the other 50 students, the initially slow reaction times got faster as accuracy scores improved.

### Discussion

Testing and retesting on the TOVA should ideally be carried out in the morning when the subject is most alert. Unfortunately, in a clinical setting, retesting times cannot be easily dictated to busy adults and parents. Although TOVA pretests were all done in the morning because the center schedule is to reserve mornings for new assessments, most of the retesting was done in the afternoon. There is a dip in alertness level in the afternoon for most people, which is reflected in the EEG. There is more slow-wave activity in adults in the afternoon (Cacot, Tesolin, Sebban, 1995) than at other times of the day. The gains in TOVA scores are the more impressive considering that good results would theoretically be harder to achieve in the afternoon. In contrast to stimulant medications that produce improvements on the TOVA only while the medication is at a therapeutic level in the blood stream (Brown, Bordon, Wyne, & Shieser, 1986), improvements in this study were found with posttesting done at various times during the day.

### Part II: Results on Academic Measures (WRAT-3)

A screening instrument for academic performance, the Wide Range Achievement Test (WRAT-3), was administered as part of the initial test battery and again after 40 training sessions. This instrument measures word recognition, spelling, and arithmetic calculations and provides standard scores, percentile ranks, and grade equivalents. Alternate forms (Blue or Tan) were used for the two testings to reduce any practice effect.

Results on the WRAT 3 (see Figure 2) were available for 99 students (11 adults and 88 children). The improvements were significant ( $p < .0001$ ) for the children. The small adult group showed significant gains only in their arithmetic scores (Table II). Of the 11 adults, the three youngest showed academic gains. In addition to improvements in

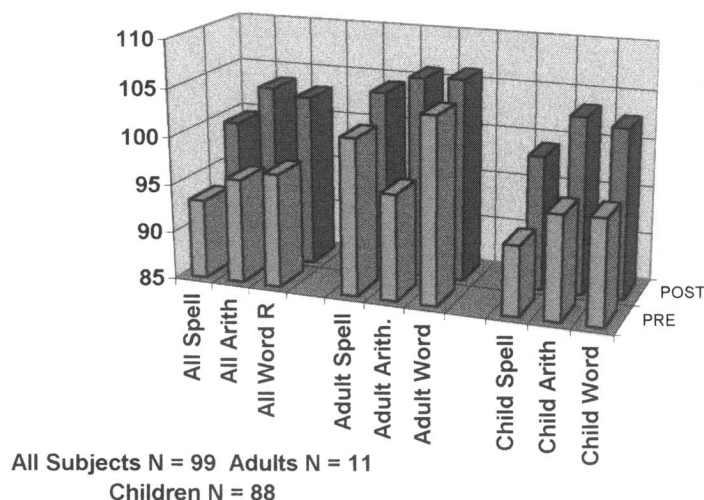


Fig. 2. Graphic display of changes in academic test scores: Spelling, Arithmetic, Word Recognition.

arithmetic and word recognition, their spelling scores rose by 10, 12, and 20 standard score points, respectively.

Of the 88 children, 20 children did not make gains in spelling, 18 did not make gains in word recognition, and 16 did not make gains in math. Among children who did not improve in all three areas, improvements were nonetheless made in areas that were most important to them. Some children, for example, had above average reading to begin with and needed to improve only in arithmetic. Others were nonreaders who mainly needed decoding strategies and received minimal coaching in math strategies.

There were four children who did not increase their WRAT 3 standard scores between pretesting and posttesting. These included twin girls who had been given intensive tutoring and had high pretest scores. Their initial scores represented over-achievement when compared with their low average intelligence levels. Both had been diagnosed with absence seizures just before entering training and had been placed on medications to control seizures. Their retesting was done on their eighth birthday so they were at a disadvantage with respect to age norms and possibly also excitement about their upcoming birthday party

Table II. Mean WRAT 3 Scores

	Pre	Post	<i>p</i> <
All ages, spelling	93.2	99.5	.0001
All ages, arithmetic	95.8	103.6	.0001
All ages, word recognition	96.8	102.9	.0001
Adult spelling	101.3	104.1	n.s.
Adult arithmetic	96	105.9	.0001
Adult word recognition	104.3	106.1	n.s.
Child spelling	92.2	98.9	.0001
Child arithmetic	95.8	103.3	.0001
Child word recognition	95.8	102.5	.0001

later that afternoon. Their parents felt that the results did not reflect the gains they had seen. One other child was tested a few days after his birthday and he too had lower standard scores due to the older comparison group. (This change in age could cut both ways with respect to age and it was not looked at statistically as a variable.) The fourth child, who had fetal alcohol syndrome, was having problems in the family at the time of retesting. Note that no subjects were eliminated from the study because of extenuating circumstances: if test scores were available, they were included.

### *Discussion*

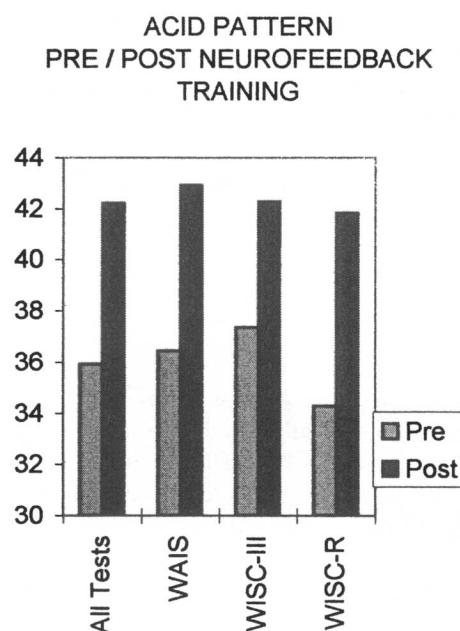
Of particular note were the gains made by children who were nonreaders or extremely poor readers on entry to the program. Among the most improved in reading were two learning disabled children. One eventually rose from early grade 2 levels to grade 6 levels in reading and arithmetic but he did not show large changes until between the 44th and 50th session. He required about 85 sessions to catch up to his grade 6 level. These cases serve to show that one should not stop after 40 sessions if some progress is being made; there is still work to be done. The second child rose by more than two grade levels after only 40 sessions and was able to leave his contained special education class. A number of children who did not show much gain after 40 sessions demonstrated good improvement on their testing after 60 sessions. This review examined test results after 40 sessions so these additional improvements are not reflected in the results reported here. Improved school performance was a common goal mentioned by parents at the beginning of training, and cognitive strategies to help with school learning were part of the program. These included strategies for word analysis, active reading, learning times tables, and thinking through word problems in an organized fashion. Details on these are found in Sears & Thompson (1998). Reviewing the reading gains prompted the addition of a test of reading comprehension to the test battery used at the center. The WRAT requires only the reading aloud of individual words. Though school and parent reports suggested that comprehension improved, only the word recognition aspect of reading is assessed using the WRAT 3.

In the adult group there was some instruction in math skills for three of the clients who initially were very weak in arithmetic skills and virtually math phobic. This contributed directly to the significant arithmetic gains for this group. For all ages decreased impulsivity could be posited as a factor in reducing careless errors on arithmetic calculations.

Gains were not expected in spelling or decoding skills for adults as they were not deficient to begin with and no coaching in strategies for these skills was provided. In the case of adults, active reading strategies were being coached. A measure of reading comprehension, rather than oral reading of words in isolation, would thus be a better way to measure gains.

### **Part III: ACID Pattern Results**

The ACID pattern is an acronym for four of the subtests on the Wechsler Intelligence Scales (WAIS (adults), WISC-III (children), WISC-R (children)), which are affected most by factors associated with attention. These scales are Arithmetic, Coding, Information, and Digit Span. Significant improvements (Figure 3) were observed in these ACID pattern scales



**Fig. 3.** Changes in the sum of scaled scores on four Wechsler subtests (ACID pattern).

( $n = 68$ , 13 adults and 55 children). When examining subtest scores, scaled scores with a mean of 10 are used. A score of 40 for the sum of the 4 subtests would thus be exactly mid-average.

### *Discussion*

The pre and post averages for the 68 subjects demonstrated an average gain from 35.9 to 42.2 scaled score points (Table III). This was significant at the  $p < .0001$  level. This level of significance held for each of the subgroups [Children tested on the WISC-R ( $n = 28$ ), children tested using the WISC III ( $n = 27$ ), and adults tested on the WAIS-R ( $n = 13$ )]. The WISC-R scores were from our earliest clients and from those where the school psychologist had used that version of the test. Whatever form was used at pretest was repeated at posttest.

**Table III.** Mean Scaled Scores of ACID subtests on the Wechsler Intelligence Scales

	Pre	Post	$p <$
ACID-all ages	35.9	42.2	.0001
WAIS	36.5	42.9	.0001
WISC-III	37.4	42.3	.0001
WISC-R	34.3	41.9	.0001

*Note.* All ages:  $n = 68$ , WAIS:  $n = 13$ , WISC III:  $n = 27$ , WISC-R:  $n = 28$ .

The findings paralleled the results of a smaller number of subjects for whom the full IQ tests were carried out. The ACID subtests were still the lowest at posttest for the group who had the full IQ testing done, indicating that there were improvements across the board and not just in these four areas.

Somewhat greater gains were observed in the WISC-R group compared to the WISC III group. Factors affecting the greater gains in the WISC-R group as compared to the WISC III changes might include those earlier clients having multiple problems, with 18 of the 28 clients tested using the WISC-R showing learning disabilities and social problems in addition to ADD. These clients started at a lower level and had a greater potential range for improvement and for regression toward the mean. Of these 18 clients with severe learning disabilities plus ADD, 12 had the full WISC-R carried out. Their WISC-R scores went from a mean Full Scale Score of 82 to 97, a slightly larger gain than for the whole group noted below.

#### Part IV: Results on Wechsler Intelligence Scales

All subtests of the Wechsler Intelligence Scales (WAIS, WISC III, WISC-R) were available for 55 students, 9 adults and 46 children. The pre-post test interval varied from 6 months to 2.5 years because IQ testing was not initially repeated if it had been done within two years of intake. If Wechsler scores were not available, testing was done prior to the student commencing training. The posttests were all done at the ADD Centre. There did not appear to be a difference in the results related to where testing was originally done but this variable was not statistically controlled.

The findings (Figure 4) demonstrated that all subjects made increases in their IQ scores and significant increases ( $p < .0001$ ) were achieved in the full-scale scores of the Wechsler Intelligence Scales with IQ equivalent standard scores averaging a 12-point gain. In a detailed look at the results it was found that in full-scale IQ, two-thirds (38/55) of the sample made more than a 10-point gain in IQ ( $4 \geq 20$  points,  $17 \geq 15$  points,  $17 \geq 10$  points). Six children made a  $<7$ -point gain. These six children all continued in the program after

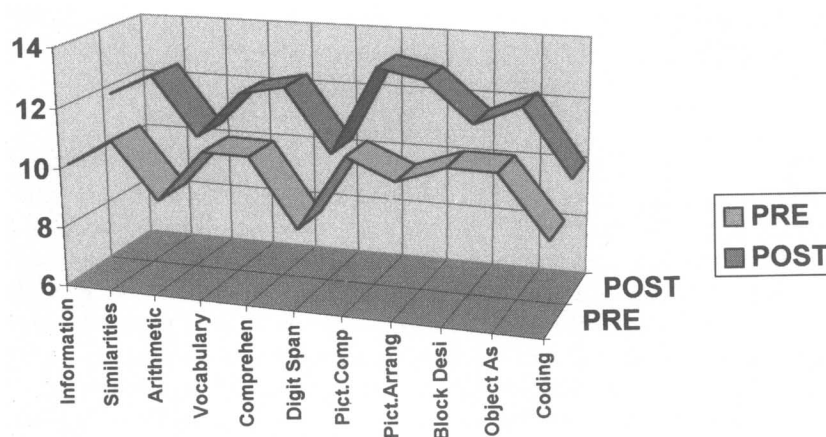


Fig. 4. Changes in subtest scores on intelligence measures.

Table IV. Mean Wechsler IQ Equivalent Scores

	Pre	Post	$p <$
WAIS Verbal	107.7	118.7	.0001
WAIS Performance	108.2	126.1	.0001
WAIS Full	108.6	124.2	.0001
WISC III Verbal	103.0	111.4	.0001
WISC III Performance	102.3	115.9	.0001
WISC III Full	103.0	114.7	.0001
WISC-R Verbal	100.2	109.6	.0001
WISC-R Performance	103.7	113.8	.0001
WISC-R Full	102.3	113.3	.0001
All Verbal	103.0	112.6	.0001
All Performance	103.6	117.0	.0001
All Full	103.7	115.9	.0001

*Note.* All ages:  $n = 55$ , Adults:  $n = 9$ , Children, WISC-R:  $n = 16$ , WISC III:  $n = 30$ .

the progress testing. They required more than 40 sessions of training to get optimal results. More than 90% of the students made a  $\geq 5$ -point gain in full scale IQ with 40 sessions of training.

The test-retest improvement due to a practice effect reported in the WISC-III manual is 7 points for the full scale score. The test-retest interval in the studies quoted in the manual averaged only 3 weeks, and one would expect less practice effect with longer time intervals. When working on Canadian norms for the WAIS III, one investigator found practice effects when comparing WAIS-R and WAIS III results with a 3-week test-retest interval but these were negligible with a 6-month interval (Saklofski, D. Department of Psychology, University of Saskatchewan, personal communication). Similarly, Linden *et al.* (1996) found a nonsignificant one-point increase in IQ for a waiting list control group who were retested on the Kaufman-Brief Intelligence Test after 6 months. (His experimental group who received neurofeedback had a mean gain of 9 points.) In the interests of greater rigor, further  $t$  tests were performed using scores corrected by 7 points for practice effects. The changes were still significant. The significance level with the correction factor changed to  $p < .02$  for the smaller WAIS-R group. Significance was maintained at  $p < .0001$  for the larger WISC-III group ( $n = 30$ ) and for the total group.

### Discussion

Part of the positive effect of training could have been due to a more positive attitude and increased desire to please in children who have been through the training program. It could be that they became less impulsive and more reflective, which lead to better test taking ability or that they developed more confidence in their own ability to succeed. It might be, given recent knowledge about the plasticity of the brain, that there were significant changes in blood flow, dendritic connections, neurotransmitters, and/or metabolism that could account for improvements in the subjects' ability to carry out cognitive tasks. It may be some combination of these and other factors. It is also possible that the precise underlying mechanisms for positive change may differ among individuals. Certainly the fidgety, active children were observed to be more settled on posttesting and stuck to tasks better. More

**Table V.** Changes in Mean Theta/Beta Microvolt Ratios

	<i>n</i> =	Pre	Post	<i>p</i> <
Adults	8	2.6	1.5	.08
Children	58	3.3	2.3	.0001
Adults + Children	66	3.2	2.2	.0001

complete verbal responses were also noted in many students. There was less of a tendency to give up on hard items so frustration tolerance seemed to have improved.

### EEG CHANGES

Lubar *et al.* (1995) referred to the work of Etevenon (1986) and of Fein *et al.* (1983) who reported that multichannel EEG brain mapping demonstrates stability in the EEG over time. Changes observed after training are therefore considered to be due to a training effect. Subjects in this review were tested before and after training using the EEG assessment program designed by J. F. Lubar for the Autogenics A620 instrument (see Table V). The students were trained on this instrument and also on the Focused Technology F1000. A portion of all the students' training addressed decreasing theta and increasing beta activity. After approximately 40 sessions they were retested and the microvolt ratio of theta (4–8 Hz)/beta (16–20 Hz) was calculated and compared with the same ratio at pretraining. Note that other investigators (Monastra, 1997) have used Lubar's database ratios of 4–8/13–21 and report power ratios in picowatts rather than ratios in microvolts. Readers used to these units may find that the numbers reported here seem low, but this is due in part to the mathematical relationship between the units being used: the power ratio is the square of the microvolt ratio. Both ratios are available using the standard A620 software.

### Discussion

These data must be viewed cautiously because many variables contribute to EEG activity. Activity in adults is known to vary depending on the time of day when it is measured, as noted above under TOVA results (Cacot *et al.*, 1995). In planning studies, one should ideally do assessments and re-assessments at the same time of day. In addition to diurnal variations, it can vary with fatigue and boredom. Relative amounts of slow and fast wave activity also vary with age, with higher slow wave activity found in younger children. Activity may also vary dramatically within a single session. Nevertheless, there was a remarkable consistency in the results obtained on the EEG measure with the subject doing the same tasks under the same conditions; namely, one minute sitting quietly and instructed to watch the screen and two minutes of silent reading of material suited to their reading level. Those subjects who were given a second EEG assessment at intake, which was artifact rejected by a second person, demonstrated consistency of theta to beta ratios between the two tests. This type of reliability test was not frequently done in our educational setting but was done whenever results seemed extreme and in need of verification. An excellent idea suggested to the first author by Ken Graap is to repeat the assessment protocol during the first training session for each client, so as to provide a reliability measure.

Lubar (1997) has reported from his work with hundreds of children that those who achieve significant EEG changes are the ones who also show positive behavioral/psychological effects of training, and these effects appear to last. In the current review there was one child whose ratio stayed the same and the other 65 clients for whom pre-post ratios were available all had some decrease in their theta/beta ratio, though the amount of change varied widely. We do not know what a significant decrease is. Some changes were small and in the younger children might be due to aging. Thatcher (1997) has suggested that EEG changes occur about every two years, so perhaps in some cases we may have been adding to changes that would have occurred just with the passage of time. Our subjective impression was that changes in school performance often began before we were able to see changes in the theta/beta ratio. The coaching in strategies might contribute to that early improvement.

A sensitive indicator of improvement seemed to be theta variability. This was routinely monitored as a means of rewarding the children for their EEG improvements when using the F1000 equipment. Children are encouraged to find a way of holding the theta thermometer gauge as low and steady as they can. They do this for 5-minute periods and then 20 overlapping 30-s screens are reviewed for the variability statistic (variability equals standard deviation/mean amplitude  $\times 100$ ). A variability score of less than 35 (at a smoothing factor of 5) is typically obtained when subjects seem highly focused on what they are doing. Initially, subjects with ADD were observed to meet this criterion on fewer than 3 of the 20 screens. Normal subjects, and persons with ADD after training, can hold their variability below 35 on 15 or more of the 20 screens. Data were not systematically collected on this but it is a direction for future research using the F1000 and other instruments that report the variability statistic.

## GENERAL DISCUSSION

This is a clinical outcome study based on a review of the records of consecutive clients trained in a private educational setting. It is helpful in two ways; first, it provides evidence that a training program which includes neurofeedback and instruction in metacognitive (learning) strategies produces positive clinical outcomes and, second, it demonstrates that a private educational center, which is not set up primarily for research, can nevertheless carry out systematic data collection. These data can be used both to monitor the progress of students in the program and to guide changes that will improve these programs. The results in this setting were found to be similar to previously published findings (Lubar, 1997; Linden *et al.*, 1996).

Although the results reported in this paper support neurofeedback (EEG biofeedback) combined with training in metacognitive strategies as an intervention for achieving self regulation of brain wave activity, decreasing symptoms associated with ADD, and making gains on measures of intelligence and academic performance, these data cannot be used to determine the precise mechanism(s) of the effect. It is the nature of clinical practice that a variety of interventions, which are judged to be of possible utility, are combined. In this study these multifactor interventions included neurofeedback and coaching in metacognitive strategies for all clients and skin conduction and temperature biofeedback for a subset of the group. Other possible factors contributing to positive outcomes include: familiarity with the tests, examiner, and test setting; medication (though only 6% continued taking



a stimulant drug and all testing was done off medication); increased parental support and attention; spending time twice a week with an enthusiastic adult who provided praise and encouragement; prior individual history; placebo effects associated with positive expectations, and other nonspecific effects. For a discussion of the power of nonspecific effects, see Roberts & Kewman (1993).

Our impression is that the positive outcomes using neurofeedback plus metacognitive strategies affect a wider area of functioning and generalize better than other interventions for ADD. This impression is based on experience with other interventions for over 25 years. These include approaches such as medications, behavior modification, supplemental education, training in metacognitive strategies, psychotherapy, family therapy, dietary changes, and combinations of the foregoing. However, this does not mean that neurofeedback should be used as a stand-alone intervention. A thorough intake evaluation will suggest which combination of interventions should be tried for each client. Our rationale for using neurofeedback combined with metacognitive strategies was based on observation that the students appeared to produce a performance state that included an ability to be flexible in terms of shifting their mental state as the task demanded. They could plan and monitor their performance using strategies. Improvements in the children's objective test scores were paralleled by subjective parent and teacher reports of their success. Parent interviews were conducted but questionnaires were not collected systematically at posttest so this is an impression rather than a reportable result. This provides another opportunity for future research and improved data collection.

There are children with learning disabilities who require more than 40 sessions. Their improvements may only emerge after 50 to 60 sessions. All of the learning disabled clients in the study had received very extensive extra help before entering this program. Therefore, introducing neurofeedback was comparable to doing a repeated baseline study. Though special education support stopped or slowed the falling behind of these LD students, catch up was only possible after neurofeedback was added. Common sense suggests that remedial instruction done when a child is paying attention would have a greater effect than those same attempts when the child's mind is wandering. Again, research using control groups would be necessary to determine whether neurofeedback was an active, efficacious, training component.

Learning disabled students with ADD usually take much longer to train (80 to 110 sessions). Their basic academic skills, in our experience, improve and in most cases are close to their appropriate grade level in reading and arithmetic by the end of training. Their written work, however, often remains weak. We do not know if these children will require further training in future years. Larger numbers of children and controlled studies would be helpful in order to define which types of learning difficulty can be best helped using neurofeedback.

Another subgroup that requires more training sessions is hyperactive children. They seem to take longer to settle down and generalization of the gains to the classroom also take longer. Attention seems to improve before physical restlessness. With stimulant medication one also sees different dose response curves for attention and hyperactivity: the dose that produces the greatest effect on attention and learning may be lower than the dose required to get the child to sit still (Sprague & Sleator, 1977).

The IQ tests demonstrated a general improvement on all subscales but the subscales included in the ACID pattern were still generally lower than the other scales at posttest. The first author observed during testing that the students appeared more reflective and

more verbally forthcoming after training. Feeling more comfortable with the examiner and familiar with the setting could contribute to these effects, but the changes were large for this alone to be the cause. The coaching in thinking skills would also contribute to gains but in the first author's experience as a school psychologist and as the director of learning centers, significant IQ gains are not expected with tutoring alone. Tutoring is effective in the specific subject area being targeted. The results found in this work with neurofeedback are associated with gains across many areas of intellectual and academic functioning. Neurofeedback appears to raise functioning in many domains, sports (Landers *et al.*, 1991) as well as academics and intelligence (Lubar, 1997; Linden *et al.*, 1996). It seems to raise the entire baseline. Performance after training may be more in line with potential that was always there but had not shown itself previously. Gains may be partially due to families choosing to make a financial investment in their children and the expectations and pressures that go with that investment. It may also be in part a result of combining neurofeedback training with teaching metacognitive strategies. It would be useful to carry out a controlled scientific study, perhaps in a school setting, where all training was without charge, to examine more closely the contribution of various factors, the characteristics of children who benefit most from this approach, and the areas of functioning that may reasonably be expected to demonstrate improvement.

Although the participants in this review uniformly had ADD symptoms, very few of them were described as having behavior problems, which would fit diagnostic categories such as Oppositional Defiant Disorder or Conduct Disorder. This stands in marked contrast to most research in the psychiatric literature. The population coming to a private educational center is perhaps skewed towards children with ADD who do not exhibit major behavior problems, just as the population in mental health clinics is skewed toward those who have extensive comorbidity. This does not mean that all the students in this study were easy cases. Many presented with complex problems, and neurofeedback was a last resort after medications, private schools, and counseling had all been tried with limited success.

A subgroup of children with severe social difficulties and learning disabilities was included in this study. Major social gains were observed in this subgroup of 18 children. Two of the children had been previously diagnosed as autistic and others demonstrated the symptom picture of Asperger's Syndrome. None of these children had been able to maintain age appropriate peer friendships. The training had been requested by their parents to improve their attention span, decrease impulsivity, and hopefully, to increase self esteem. We cautioned the parents not to expect much change in their social appropriateness or their ability to initiate and maintain friendships within their peer group. Yet by the end of training all of them were socializing, having friends call on them and even invite them to events such as birthday parties. This does not mean that they appeared entirely normal. They did not. It does mean, however, that they were now being accepted by their peer group. These findings have been reported elsewhere (Thompson & Thompson, 1995).

This review has stimulated a number of changes in the testing procedures at the Centre. The academic testing reported in this paper used the WRAT 3. We have now added the reading comprehension subtest of the CAT (Canadian Achievement Test). This CAT is parallel to the California Achievement Test used in the United States. This measure allows the tracking of a broader range of reading skills than just word recognition and decoding. A recent pilot study at the ADD Centre with 40 clients demonstrated a significant gain ( $p < .001$ ) on the normal curve equivalent score for the reading comprehension subtest of the CAT. A mean gain of 1.6 grade equivalent units was achieved (Paleologos, 1997).

Subjectively, adults noted improvements in their organizational and time management skills and in their memory. Adults are now being tested using the LET-II (Learning Efficiency Test), which taps memory skills. Questionnaires were used as part of the diagnostic work-up before the clients enter the program. Currently, these are collected at posttest as well. These are a subjective measure that may differ from one reporter to another (mother vs. father, parents vs. teacher). Because the most commonly used questionnaires include symptoms associated with behavior problems and these symptoms did not apply to the majority of the ADD Centre clients, the center has developed its own adult and child questionnaires and uses these in addition to standardized scales.

The TOVA seemed prone to false negatives and missed some clients who very obviously exhibited the symptoms of ADD. A second continuous performance test, the IVA (Intermediate Visual and Auditory Continuous Performance Test), which combines visual and auditory stimuli in the same test period, has therefore been added to the testing. This combination of tests will contribute to the initial diagnostic assessment and also provide a further measure for monitoring changes taking place during training. The tracking of test results has thus not only improved the test battery, but it has also allowed a better prediction of what may reasonably be expected from the use of neurofeedback combined with training in metacognitive strategies.

## CONCLUSION

This was not a controlled scientific study, therefore no conclusions can be drawn concerning the active or efficacious treatment components. In this series of cases, forty sessions of neurofeedback combined with training in metacognitive strategies was associated with a decrease in symptoms of ADD and an increase in intellectual and academic performance. Significant changes were measured on standardized tests but it cannot be determined what produced the changes because there were no control groups.

Nevertheless, the good outcomes suggest that the approach described is worth considering as part of a treatment plan for ADD. It may be particularly attractive when children do not respond to medications, when they have side effects on drugs, or when parents want to work on long-term change, which allows their child to control and regulate his/her own functioning. This learning technique involves monitoring a person's brain waves and giving them feedback about whether they are maintaining their focus or letting their mind wander. They learn how to maintain the state of being relaxed, alert, and concentrating. Coaching people in metacognitive strategies to increase their conscious awareness of their thinking and behavior while in this state is hypothesized to further contribute to efficient learning. The conclusions that can be drawn from these data are limited. Further controlled studies are warranted to investigate the question of which variable, or combination of variables, is the critical one in producing these positive results.

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