Reducing Hyperactivity with a Feedback Actigraph: Initial Findings

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ABSTRACT

Schulman and colleagues demonstrated that classroom activity level can be reduced in hyperactive boys using activity-level feedback and positive reinforcement. This article reports preliminary results using a device that combines modern beeper and actigraphy technology for the purpose of measuring, monitoring, and modifying motor excess in children with confirmed diagnoses of Attention Deficit Hyperactivity Disorder (ADHD). Nine boys ranging in age from 8 to 9 years with the ADHD Combined Type wore prototype BuzzBee® feedback actigraphs during school periods and were reinforced for activity-level reductions in the context of a simple pre/post research design. The findings indicated that 7 of the 9 boys reduced their activity level from 20 to 47% of baseline levels while the activity levels of the two remaining boys increased from 2 to 7% of baseline levels. These changes were statistically significant and constitute a large effect.

KEYWORDS

actigraphy, ADHD, biofeedback, positive reinforcement

THE NATIONAL INSTITUTES OF HEALTH (NIH) held a Consensus Conference regarding Attention Deficit/Hyperactivity Disorder (ADHD), and the Report (NIH, 2000) reviewed evidence that ADHD is the most commonly diagnosed behavior disorder of childhood affecting 3 to 5% of school-age children in the USA and accounts for 30 to 50% of all child referrals for mental health services. The absence of long-term outcome information about treatments for ADHD set the occasion for the Multimodal Treatment study of ADHD (MTA), a collaborative study that compared medication management, intensive behavioral treatment, a combination of both treatments, and a

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standard community care comparison group which largely entailed medication (MTA Co-operative Group, 1999). The main results of this study were that: (a) All four interventions produced statistically significant decreases in symptom ratings over the 14 month treatment phase; (b) the effects of medication alone were similar to those of medication plus behavioral treatment; and (c) medication alone was generally more effective than intensive behavioral treatment or the community standard, which in two-thirds of the cases were based on stimulant medication but at a lower dose and frequency of dosing than that specified by the MTA medication algorithm. These findings support the widespread practice of prescribing psychostimulant medication to treat ADHD as first-line treatment. Psychostimulant prescriptions have increased during the last decade (Safer, Zito, & Fine, 1996; Zito et al., 2000) despite the lack of long-term safety information (Jensen et al., 1999), negative side effects (Barkley, 1990, pp. 586–587, 634–635), and parental concerns about chronically medicating young children throughout their formative years.

The definition of ADHD in the *Diagnostic and Statistical Manual* (American Psychiatric Association [APA], 1994) specifies hyperactivity as a core component, along with impulsivity, as one of the two symptom domains of ADHD (Hyperactivity-Impulsivity), which complements the other domain of Inattention. The presence of both of these

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symptom domains in an assessment qualifies a child for a diagnosis of ADHD Combined Type. Clinic referrals for disruptive externalizing behaviors, such as hyperactivity–impulsivity, are higher than their prevalence because these behaviors disrupt the adults who make the referrals (Kamphaus & Frick, 1996, p. 342). Children with externalizing disorders disrupt the school as well as home environments, prompting referrals by teachers and principals as well as parents. The focus of this Report is on the development of a behavioral technology for reducing activity level in children with ADHD Combined Type.

The methodology of the present study is based on the work of Schulman, Stevens, and Kupst (1977) who developed a device they called a 'biomotometer' to provide a discriminative stimulus to set the occasion for positive reinforcement of activity-level reductions in children with ADHD. Schulman, Stevens, Suran, Kupst, and Naughton (1978) used this device to present a tone through earphones when activity level exceeded a preset threshold. Positive reinforcement contingent upon activity-level reductions was provided. This treatment package was evaluated using an A (baseline) – B (treatment) – A (return to baseline) design to reduce the activity levels of two emotionally disturbed boys. The first participant was an 11-year-old boy diagnosed as having an aggressive behavior disorder. His hyperactivity caused removal from state school and placement into a special day-hospital classroom where his disruptive behavior continued. He wore a biomotometer at his waist, which recorded his activity level for five baseline periods. In the conditioning phase, these investigators allowed him to choose a reward from a variety of toys, games, and candy if his activity level was 20% below mean baseline level. Earphones were connected to the biomotometer and each time his movements exceeded a specified number of activity counts during a preset time interval, he heard a 'beep' through the earphones. He was told that he had an opportunity to earn a reward and that his chance of doing so was greater if he kept the number of beeps heard to a minimum. Conditioning continued for ten 30-minute sessions during which time his activity level declined markedly below the 20% criterion needed for a reward on every trial. During the return to baseline condition, the child was rewarded noncontingently for just wearing the biomotometer. His activity level returned to preconditioning levels.

Schulman et al. (1978) used the same technique to increase the playroom activity level of a hospitalized 10-year-old boy who was diagnosed with borderline (psychotic) disorder. During his conditioning phase, he was told that his chance of receiving a reward was greater when he heard more beeps. He reached criterion for reward during six of ten daily 30-minute sessions. During return to baseline, his activity level dropped markedly, and he even slept during one session.

Schulman, Suran, Stevens, and Kupst (1979) employed the same treatment package with an ABA design to successfully decrease the classroom activity level of 11 emotionally disturbed hyperactive children (9 boys, 2 girls) to at least 20% below their mean baseline levels during all 5 treatment days. The decrease in biomotometer-measured activity level was corroborated by observational data, which showed a significant decrease in children's out-of-seat behavior during treatment trials as compared to baseline.

These studies combine activity-monitoring technology with operant conditioning techniques to modify activity level. A noteworthy feature of this approach is that the device used to treat hyperactivity also measures activity level, which means that continuous behavioral measurements can be obtained, without involving teachers or independent raters, before, during, and after treatment to evaluate treatment effects. Previously, actigraphy was used to measure, but not modify, activity level in children with ADHD (e.g., Porrino, Rapoport, Behar, Ismond, & Bunney, 1983; Porrino, Rapoport, Behar, Sceery, Ismond, & Bunney, 1983). This article reports on the initial clinical testing of a BuzzBee® feedback actigraph that measures activity level and provides vibratory and visual feedback to set the occasion for activity-level reduction.

Method

Participants

Nine boys participated in this study, ranging in age from 8 to 9 years (M = 8.6 years). All participants were students at the Child Development Center at the University of California, Irvine. The IQ of all children was within normal limits. The *Diagnostic Interview Schedule for Children* (DISC; Shaffer, Fisher, Lucas, Dulcan, & Schwab-Stone, 2000) confirmed the DSM-IV (APA, 1994) clinical diagnosis of combined ADHD for all children, and that also 5 met the criteria for comorbid Oppositional Defiant Disorder, 4 had a phobia, 3 had an Anxiety Disorder, and 1 had Enuresis. All boys had been on stimulant medication for several months but room for additional behavioral improvement was clearly evident.

Apparatus

Feedback actigraph A prototype of the BuzzBee® (Ambulatory Monitoring Inc., Ardsley, NY) feedback actigraph that measured 2.75 × 1.69 × 0.625 inches and weighed 2.5 ounces with its 1/2 AA lithium battery that powers the data collection and feedback was used. The actigraph technology used in the BuzzBee® was derived from AMI's Mini Motionlogger® BASIC model. A piezoelectric sensor generates a voltage that is directly proportional to the rate of change of movement; positive voltages are associated with acceleration, negative voltages with deceleration. This signal is pass-band filtered in the 2–3 Hz range with a sensitivity of .02 g at mid-band to remove artifact. Movement frequencies higher than 3 Hz and lower than 2 Hz probably derive from sources other than the participant's behavior such as holding on to a vibrating object. The resulting voltages are rectified (the absolute value taken) and integrated (summed) over 0.1-second intervals resulting in measurement units of volt-seconds.[1] It is important to note that resulting Activity Units are directly proportional to movement intensity and form a ratio scale with absolute zero and equal unit of measurement up to the saturation point of the device.

Vibratory feedback regarding current behavior was provided by the same type of motor used in vibrating pagers. One of five evenly spaced durations of vibratory feedback, ranging from 0.5 to 5.0 seconds, was provided each time average activity level during the prior 5-second epoch exceeded a lower threshold equal to the mean activity during baseline. Duration of vibratory feedback was directly proportional to the degree to which measured activity level exceeded the lower threshold. The maximum feedback signal of 5.0 seconds duration was provided for activity levels equal to or exceeding the baseline mean plus two baseline standard deviations. Activity-level recording was designed to be suspended during this 10-second period to avoid recording vibratory feedback as activity. It was discovered prior to starting the study that the BuzzBee® recorded zero activity during the 10-second feedback intervals. Therefore a standard actigraph with the same data acquisition properties was attached to the participants' waist on the opposite side of their body. All activity data reported here were from that second actigraph. Placement on the opposite hip minimized any vibration artifact that was not removed by the 3 Hz high-pass filter.

Visual feedback regarding cumulative activity was provided by illuminating one of three light-emitting diodes (LEDs) that were clearly visible when looking down at the waist-worn actigraph. They were used to signal the level of reward that a child could earn at the end of an activity level feedback session. The *Green* LED was illuminated as long as the cumulative feedback average was 20% or more below the baseline mean as that was the criterion used by Schulman and his colleagues cited earlier. It signaled receipt of a full reward if it was on at the end of the feedback session. The *Red* LED was illuminated as long as the cumulative feedback average exceeded the baseline mean plus one baseline standard deviation. It signaled the absence of reward if it was on at the end of the feedback session. The *Yellow* LED was illuminated at all other times and signaled receipt of a lesser reward if it was on at the end of the feedback session.

A simple folded aluminum belt clip was integrated into the back cover of the feedback actigraph to allow easy, but secure, attachment and removal from the child's belt or waistband. Removal of four screws from the back allowed access to the battery. An O-ring seal on the back plate provided a degree of water-tightness. The BuzzBee® feedback actigraph was configured with an interface to a computer to allow for initialization and data transfer.

Standard actigraph Pilot studies determined that this prototype BuzzBee® device recorded zeros while providing vibratory feedback. Therefore, a standard AMI Mini Motionlogger® BASIC actigraph was attached to the waist on the opposite side to record the data reported here. It was slightly smaller and lighter than the BuzzBee® (1.75 × 1.30 × .038 inches and weighed approximately 1.7 ounces), but had the same measurement characteristics as both instruments use the same measurement technology. Placement on the opposite hip minimized any vibration artifact that was not removed by the 3 Hz high-pass filter. Its computer clock was synchronized with the computer clock of the BuzzBee® feedback actigraph.

Procedures

Teachers at the University of California at Irvine (UCI) Child Development Center School were trained to initialize the actigraphs using Ambulatory Monitoring Inc. software, to attach the actigraphs to the waist of each child at the beginning of science class, which required students to remain seated and work continuously at their desks for a 30-minute time period, to remove the actigraphs and download them at the end of each period. All classrooms contained from 12 to 18 students; all with ADHD or related disorders. Sometimes science class occurred before recess and sometimes afterwards and was not controlled for. All classes occurred between 8:30 am and 2:30 pm. Between two and four baseline sessions were used and between two and eight feedback sessions as per Table 1. Rewards, typically edibles, were provided at the end of each reward period.

Table 1. Number of baseline and feedback sessions per participant

Participant	*Number of baseline sessions*	*Number of feedback sessions*
1	3	4
2	3	4
3	3	4
4	2	2
5	3	3
6	3	8
7	3	6
8	3	6
9	4	6

Illumination of the green LED set the occasion for a larger reward. Illumination of the yellow LED set the occasion for a small reward. Illumination of the red LED signaled no reward. A simple pre/post design was used for this initial feasibility study, with baseline observations without feedback preceding a series of sessions with BuzzBee® feedback and contingent reinforcement.

Results

The activity level data were averaged separately for baseline and intervention days. Table 2 presents the descriptive statistics for the 9 participants during baseline and intervention conditions. Change during intervention was expressed as a percentage of baseline value, with a positive difference reflecting reduced activity level. As shown in Table 2, reduced activity level was observed for 7 of the 9 participants. These 7 positive responders reduced their activity level from 20 to 47% of baseline levels. The 2 negative responders increased their activity level from 2 to 7% of baseline levels. A *t*-test on the nine pre/post differences was statistically significant ($t(8) = 4.082, p < .004$), and the effect size was large ($d = 41.02/25.32 = 1.62$). The box plot of these data in Figure 1 clearly shows that the entire activity level distribution shifted downward during the intervention phase compared to the baseline phase of the study.

Discussion

The data presented earlier suggest that most children diagnosed with ADHD Combined Type and being treated with stimulant medication can exert substantial self-control over their activity level when given contingent feedback and positive reinforcement for activity-level reductions. The observed effect size ($d = 1.62$) was large, with the mean after intervention at the 5th percentile of the baseline distribution. These data are consistent with previously published reports by Schulman et al. (1978, 1979) and expand the extensive literature showing that discriminative stimuli and contingent positive reinforcement can modify a wide variety of behaviors, including activity level.

The activity-level reductions reported here are over and above those already achieved by medication and were targeted for academic periods when the effects of medication may not adequately reduce the activity level of these children. Hence, our baseline condition may be considered a medication-alone condition and the intervention

Table 2. Average activity for baseline and intervention for 9 participants plus descriptive statistics arranged in descending effect size order

Participant	*Baseline*	*Intervention*	*Difference*	*Percent difference*
9	166.66	87.78	78.88	.47
6	147.60	85.13	62.47	.42
8	148.87	88.10	60.77	.41
5	209.35	151.84	57.51	.27
4	200.01	148.15	51.86	.26
7	146.66	110.36	36.31	.25
2	175.98	141.53	34.46	.20
1	170.75	174.34	–3.59	–.02
3	134.90	144.33	–9.43	–.07
M	166.75	125.73	41.02	
SD	25.32	33.32	30.15	

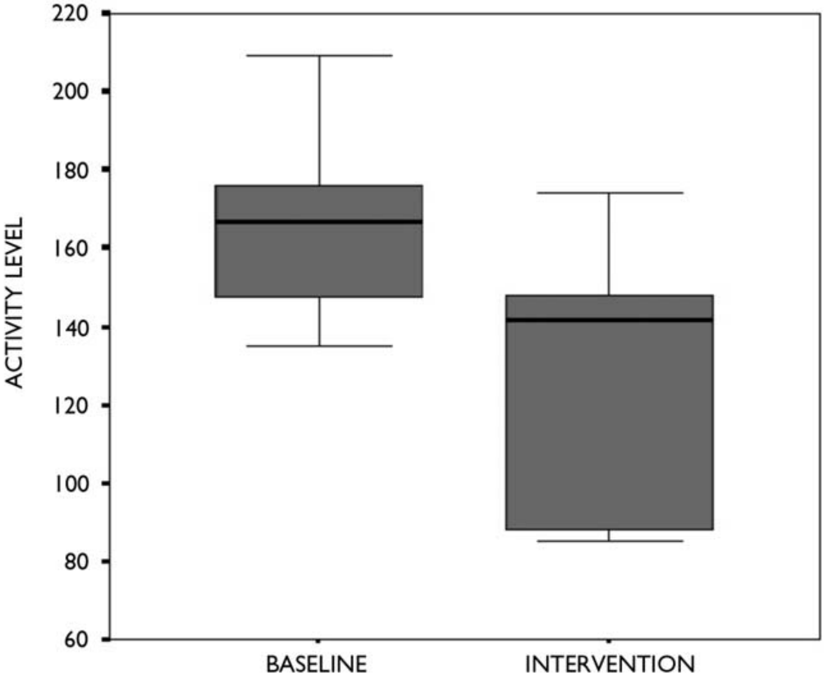

Figure 1. Activity level distribution of 9 boys aged 8 to 9 years at baseline and intervention.

condition a combined condition of medication plus behavior modification using the BuzzBee® to both provide a discriminative stimulus for being less active and to record activity levels.

It is possible that medication provided children with the attentional and cognitive resources needed to comply with the actigraphy feedback procedures, suggesting that contingent activity-level feedback and reinforcement may only work in the presence of medication. However, the literature on behavior modification clearly indicates that its effects are not restricted to medicated participants (see Pelham et al., 2006). Also, using similar procedures as in the present study, Schulman et al. (1978, 1979) observed similar effects in a study of 'hyperactive' children who were not taking stimulant medication. Future research is needed on a medication-free sample of children who meet the current diagnostic criteria for ADHD to adequately examine this hypothesis, using designs of convenience (drug withdrawal or medication holidays) or controlled randomized trials to compare effects of the BuzzBee® in drug and placebo conditions.

In this study we focused on motor excess aspects of the hyperactivity/impulsivity symptom domain rather than attention deficits associated with the inattention domain for historical, clinical (practical), and theoretical reasons. Early definitions of the disorder emphasized the motor component of ADHD, and symptoms of hyperactivity have remained a core component of the disorder. Some early studies of the effectiveness of stimulant medications focused on their ability to reduced motor activity (Rapaport et al., 1978), and over the years this has remained a focus of some evaluations of the effects of medication (Swanson et al., 2002). Clinically, the diagnosis of ADHD Combined Type requires the presence of motor excess, and the central clinical importance of motor excess as a core characteristic was emphasized by the NIH consensus study (NIH, 2000). Motor excess has been clearly linked to externalizing disorders, which are often comorbid with ADHD (Achenbach & Edelbrock, 1978; Hinshaw, 1987). Practically, motor excess may disrupt the learning environment for all children in a class and this, as well as impairment of the ADHD child, may contribute to decisions by teachers to refer children for assessment and treatment of ADHD. Theoretically, the behavioral inhibition deficit hypothesis (Barkley, 1997) suggests that the cognitive, academic, and social problems manifested by children with ADHD stem from inadequate development of executive control over thought and action. Motor excess is an objective marker of the resulting cortical release (cf. Milich, Hartung, Martin, & Haigler, 1994; Pennington & Ozonoff, 1996; Schachar, Tannock, Marriott, & Logan, 1995; Tannock & Schachar, 1996).

Hinshaw (1994) and Taylor (1994) provide empirical evidence that childhood hyperactivity is a risk factor for psychosocial maladjustment in adolescence. Studies that have followed ADHD children for 4 to 14 years have reported a major risk for subsequent aggressive, antisocial, and delinquent behaviors (August, Stewart, & Holmes, 1983; Barkley, Fischer, Edelbrock, & Smallish, 1990; Gittelman, Mannuzza, Shenker, & Bonagura, 1985; Hinshaw, 1992; Loney, Whaley-Klahn, Kosier, & Conboy, 1983; Mannuzza, Klein, & Addalli, 1991). Methodological problems associated with these studies (Thorley, 1984) questioned whether hyperactivity itself constitutes a developmental risk and if hyperactivity is specific to these adverse outcomes. Taylor, Chadwick, Heptinstall, and Danckaerts (1996) conducted an epidemiological study of 2462 6- and 7-year-old boys and reported empirical evidence that pervasive hyperactivity during the primary school years is a specific risk factor for: (a) violence, (b) disruptive behaviors, (c) poor relationships with peers, (d) lack of involvement in school activities, (e) lack of engagement in constructive activities generally, and (f) poor academic achievement. The authors cautioned against dismissing pervasive hyperactivity as immaturity for it was still present at school-leaving age. The authors concluded that 'conduct disorder is a complication of hyperactivity' (p. 1225). The Inhibitory Deficit Hypothesis noted earlier regarding inadequate development of executive control over thought and action helps explain why hyperactive children are at risk for developing conduct disorder. The methodology of the present study – activity level feedback plus reinforcement – addresses this core problem because it is designed to teach self-control and improve behavioral inhibition.

The most significant limitation of this study was the lack of control for temporal processes. The decrease in activity level from the baseline to the intervention phase may be due to a general trend of decreasing activity level with repeated observations over time. This limitation could be overcome by using either single-subject methods, such as the A-B-A-B reversal design, or by group methods, such as a randomized assignment to placebo and drug conditions counterbalancing the order of the drug–placebo crossover. The preliminary nature of this study justifies this first step, but additional studies are essential to document this effect under controlled circumstances.

The present study extends the literature, which shows that activity level can be objectively measured with high reliability and validity by actigraphs (Tryon, 1991, 2005; Tryon & Williams, 1996) and can be changed by direct feedback of activity level plus reinforcement for reductions in activity level. The preliminary findings presented here suggest that feedback provided by the BuzzBee® actigraph may be an effective method for reducing a core component – hyperactivity – of ADHD in children.

Note

1. This process is illustrated at http://www.ambulatory-monitoring.com/modes.html

References

Achenbach, T.M., & Edelbrock, C.S. (1978). The classification of child psychopathology: A review and analysis of empirical efforts. *Psychological Bulletin*, *85*, 1275–1301.

American Psychiatric Association [APA]. (1994). *Diagnostic and statistical manual of mental disorders* (4th ed.). Washington, DC: Author.

August, G.J., Stewart, M.A., & Holmes, C.S. (1983). A four-year follow-up of hyperactive boys with and without conduct disorder. *British Journal of Psychiatry*, *143*, 192–198.

Barkley, R.A. (1990). *Attention deficit hyperactivity disorder: A handbook for diagnosis and treatment.* New York: Guilford Press.

Barkley, R.A. (1997). Behavioral inhibition, sustained attention and executive functions: Constructing a unifying theory of ADHD. *Psychological Bulletin*, *121*, 65–94.

Barkley, R.A., Fischer, M., Edelbrock, C.S., & Smallish, L. (1990). The adolescent outcome of hyperactive children diagnosed by research criteria: I. An 8-year prospective follow-up study. *Journal of the American Academy of Child and Adolescent Psychiatry*, *29*, 546–557.

Gittelman, R., Mannuzza, S., Shenker, R., & Bonagura, N. (1985). Hyperactive boys almost grown up: 1. Psychiatric status. *Archives of General Psychiatry*, *42*, 937–947.

Hinshaw, S.P. (1987). On the distinction between attention deficit/hyperactivity and conduct problems/aggression in child psychopathology. *Psychological Bulletin*, *101*, 443–463.

Hinshaw, S.P. (1992). Externalizing behavior problems and academic underachievement in childhood and adolescence: Causal relationships and underlying mechanisms. *Psychological Bulletin*, *111*, 127–155.

Hinshaw, S.P. (1994). *Attention deficits and hyperactivity in children*. London: SAGE Publications.

Jensen, P.S., Bhatara, V.S., Vitello, B., Hoagwood, K., Fell, M., & Burke, L.B. (1999). Psychoactive medication prescribing practices for US children: Gaps between research and clinical practice. *Journal of the American Academy of Child and Adolescent Psychiatry*, *38*, 557–565.

Kamphaus, R.W., & Frick, P.J. (1996). *Clinical assessment of child and adolescent personality and behavior.* Boston: Allyn and Bacon.

Loney, J., Whaley-Klahn, M.A., Kosier, T., & Conboy, J. (1983). Hyperactive boys and their brothers at 21: Predictors of aggressive and antisocial outcomes. In K.T. van Dusen, & S.A. Mednick (Eds.), *Prospective studies of crime and delinquency* (pp 181–206). Boston: Kluwer-Nijhoff.

Mannuzza, S., Klein, R.G., & Addalli, K.A. (1991). Young adult mental status of hyperactive boys and their brothers: A prospective follow-up study. *Journal of the American Academy of Child and Adolescent Psychiatry*, *30*, 743–751.

Milich, R., Hartung, C.M., Martin, C.A., & Haigler, E.D. (1994). Behavioral disinhibition and underlying processes in adolescents with disruptive behavior disorders. In D.K. Routh (Ed.), *Disruptive behavior disorders in childhood* (pp. 109–139). New York: Plenum.

MTA Co-operative Group. (1999). A 14-month randomized clinical trial of treatment strategies for Attention Deficit/Hyperactivity Disorder. *Archives of General Psychiatry*, *56*, 1073–1086.

National Institutes of Health [NIH]. (2000). National Institutes of Health consensus development conference statement: Diagnosis and treatment of Attention Deficit/Hyperactivity Disorder (ADHD). *Journal of the American Academy of Child and Adolescent Psychiatry*, *39*, 182–193.

Pelham, W.E., Burrows-MacLean, L., Gnagy, E.M., Fabiano, G.A., Coles, E.K., Tresco, K.E., et al. (2005). Transdermal methylphenidale, behavioral, and combined treatment for children with ADHD. *Experimental and Clinical Psychopharmacology*, *13*, 111–126.

Pennington, B.F., & Ozonoff, S. (1996). Executive functions and developmental psychopathology. *Journal of Child Psychology and Psychiatry*, *37*, 51–87.

Porrino, L.J., Rapoport, J.L., Behar, D., Ismond, D.R., & Bunney, W.E., Jr. (1983). A naturalistic assessment of the motor activity of hyperactive boys II: Stimulant drug effects. *Archives of General Psychiatry*, *40*, 688–693.

Porrino, L.J., Rapoport, J.L., Behar, D., Sceery, W., Ismond, D.R., & Bunney, W.E., Jr. (1983). A naturalistic assessment of the motor activity of hyperactive boys I: Comparison with normal controls. *Archives of General Psychiatry*, *40*, 681–687.

Rapaport, J.L., Buchsbaum, M.S., Zahn, T.P., Weingartner, H., Ludlow, C., & Mikkesen, E.J. (1978). Dextroamphetamine: Cognitive and behavioral effects in normal prepubertal boys. *Science*, *199*, 560–563.

Safer, D.J., Zito, J.M., & Fine, E.M. (1996). Increased methylphenidate usage for attention deficit disorder in the 1990s. *Pediatrics*, *98*, 1084–1088

Schachar, R.J., Tannock, R., Marriott, M., & Logan, G. (1995). Deficient inhibitory control in attention deficit hyperactivity disorder. *Journal of Abnormal Child Psychology*, *23*, 411–437.

Schulman, J.L., Stevens, T.M., & Kupst, M.J. (1977). The Biomotometer: A new device for the measurement and remediation of hyperactivity. *Child Development*, *48*, 1152–1154.

Schulman, J.L., Stevens, T.M., Suran, B.G., Kupst, M.J., & Naughton, M.J. (1978). Modification of activity level through biofeedback and operant conditioning. *Journal of Applied Behavior Analysis*, *11*, 145–152.

Schulman, J.L., Suran, B.G., Stevens, T.M., & Kupst, M.J. (1979). Instructions, feedback, and reinforcement in reducing activity levels in the classroom. *Journal of Applied Behavior Analysis*, *12*, 441–447.

Shaffer, D., Fisher, P., Lucas, C.P., Dulcan, M.K., & Schwab-Stone, M.E. (2000). NIMH Diagnostic Interview Schedule for Children Version IV (NIMH DISC-IV): Description, differences from previous versions, and reliability of some common diagnoses. *Journal of the American Academy of Child and Adolescent Psychiatry*, *39*, 28–38.

Swanson, J.M., Gupta, S., Williams, L., Agler, D., Lerner, M., & Wigla, S. (2002). Efficacy of a new pattern of delivery of methylphenidate for the treatment of ADHD: Effects on activity level in the classroom and on the playground. *Journal of the American Academy of Child and Adolescent Psychiatry*, *41*, 1306–1314.

Tannock, R., & Schachar, R. (1996). Executive dysfunction as an underlying mechanism of behavior and language problems in attention deficit hyperactivity disorder. In J.H. Beitchman, N.J. Cohen, M.M. Konstantareas, & R. Tannock (Eds.), *Language, learning and behavior disorders: Developmental, biological, and clinical perspectives* (pp. 128–155). New York: Cambridge University Press.

Taylor, E. (1994). Syndromes of attention deficit and overactivity. In R.M. Taylor & E. Hersov (Eds.), *Child and adolescent psychiatry: Modern approaches* (pp. 285–307). Oxford: Blackwell.

Taylor, E., Chadwick, O., Heptinstall, E., & Danckaerts, M. (1996). Hyperactivity and conduct problems as risk factors for adolescent development. *Journal of the American Academy of Child and Adolescent Psychiatry*, *35*, 1213–1226.

Thorley, G. (1984). *Clinical characteristics and outcome of hyperactive children*. Unpublished PhD thesis, University of London, UK.

Tryon, W.W. (1991). *Activity measurement in psychology and medicine.* New York: Plenum Press.

Tryon, W.W. (2005). The reliability and validity of two ambulatory monitoring actigraphs. *Behavior Research Methods Instruments & Computers*, *37*, 492–497.

Tryon, W.W., & Williams, R. (1996). Fully proportional actigraphy: A new instrument. *Behavior Research Methods Instruments & Computers*, *28*, 392–403.

Zito, J.M., Safer, D.J., dosReis, S., Gardner, J.F., Boles, M., & Lynch, F. (2000). Trends in the prescribing of psychostimulant medications to preschoolers. *Journal of the American Medical Association*, *283*, 1025–1033.