Sensory modulation dysfunction in children with attention-deficit–hyperactivity disorder

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This study investigates the presence of sensory modulation dysfunction (SMD) among children with attention-deficit-hyperactivity disorder (ADHD). Twenty-six children with ADHD (mean age 8.3 years, 18 males, 8 females), and 30 typically developing children (mean age 8.2 years, 21 males, 9 females) were tested using a laboratory procedure that gauges responses to repeated sensory stimulation by measuring electrodermal reactivity (EDR). Parental report measures of limitations in sensory, emotional, and attentional dimensions were administered using the Short Sensory Profile, the Leiter International Performance Scale–Revised, Parent Rating subscales, and the Child Behavior Checklist (CBCL). Compared to the typical sample, the children with ADHD displayed greater abnormalities in sensory modulation on both physiological and parent-report measures. The children with ADHD also displayed more variability in responses. Within the group with ADHD, levels of SMD were highly correlated with measures of psychopathology on the CBCL. Implications of findings relate to the importance of considering sensory processing abilities in a subgroup of children with ADHD.

Attention-deficit–hyperactivity disorder (ADHD) is characterized by developmentally inappropriate impulsivity, inattention, and hyperactivity, which can create varying degrees of difficulty in daily functioning (Kaplan et al. 1994, Barkley 1998, Fisher 1998). ADHD is a costly and prevalent childhood disorder affecting 3 to 5% of school-aged children (Schachar 2000) and accounting for approximately half of all pediatric referrals to mental health services in the US (Glicken 1997, Goldman et al. 1998). ADHD is a significant risk factor for academic performance, psychosocial adjustment, and future psychopathology (Mannuzza et al. 1998). Despite the prevalence and serious sequelae of ADHD, the etiologies and comorbidities of ADHD are poorly understood.

Some experts do not consider ADHD to be a distinct syndrome (Pennington 1991). Over half of children diagnosed with ADHD also satisfy diagnostic criteria for other psychological/behavioral disorders (Tannock 1998). Among children with ADHD, significant variability in the presence of other symptoms occurs. Understanding these symptoms will help us better understand the spectrum of problems included within the broad label 'ADHD'. A wide variety of factors in ADHD have recently been examined such as attention, impulsivity, and hyperactivity, oppositional and aggressive behaviors, social skills, anxiety and depression symptoms, parent–child relations, academic achievement, parent and teacher ratings, self-ratings (MTA Cooperative Group 1999a, b; Anastopoulos 2000). However, sensory processing functions are typically not studied in research describing the ADHD phenotype.

Sensory modulation is the capacity to regulate and organize the degree, intensity, and nature of responses to sensory input in a graded and adaptive manner, so that an optimal range of performance and adaptation to challenges can be maintained (McIntosh et al. 1999a, Lane et al. 2000). Sensory modulation dysfunction (SMD) presents with two diverse behavioral patterns: sensation seeking, where a child seeks out high intensity or increased duration of sensory stimulation; and sensation avoiding, in which a child exhibits 'fight or flight' sympathetic nervous system responses to harmless or non-noxious sensory input (Parham and Mailloux 1996, Hanft et al. 2000). Examples of behaviors observed in the SMD phenotype are identified in Table I.

In addition to the dysfunctional sensory behaviors in SMD, emotional and attentional behaviors have been associated with the phenotype (Miller et al. 2001). Emotional responses associated with sensory avoiding are typically explosive, aggressive, and hostile behaviors or, when over-stimulated, anxious, clingy, or withdrawn behaviors. Emotional behaviors associated with sensation seeking include disregard for others, inability to regulate intensity and duration of interactions with others, and mania.

Abnormal attentional symptoms are described in the SMD phenotype (Mulligan 1996). In sensory avoiders, attention is described as hyperfocused and in sensory seekers, attention is characterized by inattention, poor impulse control, and hyperactivity. Clearly some of these behaviors overlap with behaviors described in the ADHD phenotype.

Both conceptual and empirical evidence highlight the importance of examining symptoms of sensory dysfunction among children with ADHD. First, descriptions of ADHD and SMD include an inability to modulate systematically physiological, sensory, and affective responses that can have an effect on emotion regulation (Greenspan and Wieder 1993). Both

ADHD and SMD include hyperactivity and impulsive behaviors. Second, a high percentage of children with attention disorders also have sensory processing disorders (Cermak 1991, Parush, et al. 1997, Miller et al. 2001). Children diagnosed with ADHD are reported to have been overly sensitive to sensory stimuli, and easily upset by environmental changes in infancy (Kaplan et al. 1994). Moreover, children with ADHD show behavioral evidence of difficulty modulating sensory responses and demonstrate over responsivity significantly more frequently than typically developing children (Dunn 1999). To study the potential dysfunction of sensory processing in ADHD we examined physiological reactions to sensory stimulation in children with ADHD.

Previous work has examined electrodermal reactivity among individuals with SMD and ADHD. Electrodermal responses (EDR) are changes in the electrical conductance of the skin associated with eccrine sweat-gland activity. EDR occurs in the presence of startling or threatening stimuli, aggressive or defensive feelings (Fowles 1986), and during positive and negative emotional events (Andreassi 1989). Larger and more frequent EDRs to stimuli suggest stronger responses. Consistent with this pattern, children with SMD show greater frequency and magnitude of EDRs compared to typically developing children (McIntosh et al. 1999b).

However, studies have been inconsistent in demonstrating differences in physiological reactions between children with ADHD and typically developing control individuals (Iaboni et al. 1997, Barkley 1998). Rosenthal and Allen (1978) concluded that children with ADHD do not differ from typically developing children on tonic electrodermal measures. However, they found that children with ADHD show smaller phasic orienting responses to loud tones, and faster-than-normal habituation to repeated auditory sensation.

Failure to replicate consistently these findings differentiating children with and without ADHD makes interpretation difficult. One explanation for the inconsistent results may be that children with ADHD are not a homogenous group; thus, their patterns of autonomic nervous system arousal or responses to sensory stimuli differ according to subgroups within ADHD. Some children with ADHD may be under aroused, while others are over-aroused (Hastings and Barkley 1978). Further research is needed to clarify possible patterns of physiological activity among children with ADHD and to determine whether an association exists between response to sensation and physiological variability.

The theoretical and empirical links between ADHD and SMD led us to investigate the presence of symptoms of SMD in children with ADHD. A clinical sample of 26 children diagnosed with ADHD was evaluated for the presence of SMD characteristics, using both physiological and parent-report measures.

We had three hypotheses. First, we predicted that children with ADHD would differ from typically developing control children on physiological reactivity and on parent-report measures of sensory responsivity. Second, we predicted significantly more variability in sensory reactivity among children with ADHD compared to the control group, with some children with ADHD displaying normal sensory processing and others displaying abnormal processing. Finally, we hypothesized that within the group with ADHD, the degree of SMD would predict the degree of psychological symptoms (i.e. withdrawal, somatic complaints, anxiety/depression, social problems, thought problems, attention problems, and aggressive and/or delinquent behavior).

Method

PARTICIPANTS

Twenty-six children (18 males, eight females) clinically diagnosed with an attention-deficit–hyperactivity disorder (ADHD) and 30 typically developing control children (21 males, nine females) of similar ages, participated in this study. Ages ranged from 5 to 13 years (ADHD group mean age 8.3 years, SD 2.4; control group mean age 8.2 years, SD 2.0; Table II).

The control sample was recruited using flyers posted at the Children's Hospital in Denver, Colorado, USA and by word-of-mouth. Children with ADHD were referred by local clinics specializing in the diagnosis and treatment of ADHD, including the Child Development Unit at the Children's Hospital of Denver, the Child Study and Developmental Neuropsychology Clinics at the University of Denver, and the Attention and Behavior Center in Denver. All children in the group with ADHD had a primary diagnosis of ADHD, identified strictly by DSM-IV criteria (American Psychiatric Association 1994), although the possibility of comorbid diagnoses was not evaluated systematically. The presence of ADHD-related functional behavior problems was confirmed using the ACTeRS (Ullmann et al. 1997) and the Attention, Activity Level, and Impulsivity subscales of the Leiter International Performance Scale–Revised, parent rating subscales (Leiter-P; Roid and Miller 1997).

At the time of testing, eight of the children with ADHD were taking methylphenidate, two were taking clonidine,

Table I: Examples of under responsive and overresponsive observable behaviors in SMD

Sensory domain	*Examples of seeking sensation behaviors*	*Examples of avoiding sensation behaviors*
Dysfunction in modulation of tactile stimuli	Touches others too often or too hard; touches/mouths hair, or objects constantly	Aggressive response to touch; withdraws from unexpected touch or avoids activities where unexpected touch might occur, such as sand or water play
Dysfunction in modulation of vestibular stimuli	Over active, continually seeks movement by jumping and running; engages in risky behaviors e.g. climbs high or moves too quickly for safety	Fears or becomes sick with movement or when feet leave the ground e.g. dislikes playground or car rides
Dysfunction in modulation of proprioceptive stimuli	Craves jumping, bump-and-crash activities; bangs or taps head, arms, and legs; constantly squeezes and bangs objects and/or sucks on hands	Over responds to deep pressure touch such as hugs, or holding hands, uncomfortable in jumping, running, or gymnastic activities and many sports

and one child each was taking sertraline, dextroamphetamine, methylphenidate with clonidine, methylphenidate with phenobarbitol, and carbamazepine with clonidine. Medications were discontinued for 24 to 48 hours before the physiological testing.

Children from the comparison group were selected from a pool of typically developing children, including children of staff and volunteers of the Children's Hospital of Denver and other interested parents from the Denver area. There were no significant differences in age or sex between the group with ADHD and comparison group. To be eligible, the comparison group completed a 'Typical Screening' and were negative for evaluation or treatment for or any other developmental or behavioral condition. In addition, they demonstrated a normal birth history, no abnormal medical or surgical conditions, typical educational development, and no reported traumatic life events. Their parents reported age-appropriate behavior and learning abilities.

PROCEDURE

Children participated in the Sensory Challenge Protocol (see McIntosh et al. 1999b), which has been used successfully with children who have SMD (McIntosh et al. 1999b) and Fragile X syndrome (Miller et al. 1999). The protocol gauges an individual's physiological reactivity to repeated sensory stimulation by measuring EDRs.

The protocol is carried out in our psychophysiology laboratory designed to look like a pretend space ship. Children are told that during their 'space trip' they will smell, hear, see, and feel some 'funny' things. Experimenters, blind to participants' group, administer each stimuli (one type for each sensory domain) 10 times for 3 seconds in a standard schedule 15 or 19 seconds apart. The five sensory stimuli are: olfactory – vial of wintergreen extract on cotton ball 4:1 dilution with water; auditory – a siren at 90 decibels; visual – a 20-watt strobe light at 10 Hz; tactile – feather lightly moved from right ear to chin to left; vestibular – chair tipped backward slowly 30 degrees.

In addition, one parent of each child completed several parent information measures including the Child Behavior Checklist (CBCL; Achenbach 1991), Leiter-P (Roid and Miller 1997), and the Short Sensory Profile (SSP; McIntosh et al. 1999a).

INSTRUMENTATION

Electrodermal responses

EDRs were assessed using changes in skin conductance associated with the presentation of stimuli. The general method followed the procedures recommended by Fowles and colleagues (1981), and used previously (McIntosh et al. 1999a, Miller et al. 1999). Two 5-mm electrodes were applied to either the palmar surfaces of the distal phalanges of the second and third fingers of the left hand (n=47) (Scerbo et al. 1992), or the thenar and hyopthenar surface of the left hand (n=9). (The palmar location was used due to the relative difficulty of applying the electrodes to small fingers.) Electrodes were applied to each finger using a 5 cm×1.5 cm velcro band; double-stick electrode pads were used to secure the electrodes to the hand. The electrodes were attached to a Coulbourn Isolated Skin Conductance Coupler (S71-23, Allentown PA, USA, Coulbourn Instruments). The coupler applied a constant 0.5 volt potential across each electrode pair and conditioned the skin conductance signal. Because we were interested in reactions to each stimulus, we used alternating current (AC) coupling which corrects for drifts in baseline conductance level over the extended time of stimuli presentation (Boucsein 1992). The signals were sampled at 50 Hz, then digitized and stored on a microcomputer.

Next, a data analyst blind to group membership checked the electrodermal record for movement artifact, and eliminated questionable responses using a custom written computer program (McIntosh et al. 1999b, Miller et al. 1999). The amplitude of the peaks was measured from the point at which the skin conductance increases sharply (i.e. baseline) to the point at which the conductance begins to fall (i.e. peak). Only peaks greater than 0.05 micromhos (Dawson et al. 1990), and beginning between 0.8 and 5 seconds post-stimulus were considered valid.

The magnitude of the main (largest) peak in response to each stimulus was the dependent measure of physiological response. We were interested in both overall differences in size of magnitude and in their decrement over trials (i.e. habituation of the responses). As is typical for studies evaluating magnitude of skin conductance responses, our magnitude data required logarithmic transformation before analysis (Kirk 1982, Dawson et al. 1990, Boucsein 1992).

Short Sensory Profile

One parent of each participant completed the SSP (McIntosh et al. 1999a), a reliable and valid parent-report measure of functional behaviors associated with abnormal responses to sensory stimuli. The seven SSP subtests are: (1) Tactile Sensitivity, (2) Movement Sensitivity, (3) Visual/Auditory Sensitivity, (4) Taste/Smell Sensitivity, (5) Auditory Filtering, (6) Low Energy/Weak, and (7) Under-responsive/Seeks Sensation. The possible range of raw scores on the total scale is 38 to 190, with higher scores reflecting more normal performance. We defined SMD

Table II: Demographics of samples[a]

	Total Sample		*CBCL*		*Leiter-P*	
	Typical	*ADHD*	*Typical*	*ADHD*	*Typical*	*ADHD*
n	30	26	25	20	11	18
Males	21	18	18	11	6	11
Females	9	8	7	9	5	7
Mean age (y:m)	8:2	8:3	7:9	8:4	7:3	8:6

[a] Sample sizes on each measure varied slightly due to missing data on some parent-report measures.
CBCL, Child Behavior Checklist; Leiter-P, Leiter International Performance Scale–Revised, parent rating subtest.

as a score on the SSP of more than 1 standard deviation below the mean of the sample of typically developing children in the national standardization sample, i.e. a raw score below 152 (Dunn 1999).

Leiter International Performance Scale
One parent of each participant completed the Leiter-P (Roid and Miller 1997). Items on the rating scales were derived from literature on child psychopathology, temperament, and personality theories that were mapped directly onto DSM-IV criteria (Stinnett 2001). Subscales measure parents' perception of their children's cognitive, social, emotional, and sensory functioning. The Leiter-P was developed specifically to assist in identifying both ADHD and SMD behaviors. The items for the Attention, Activity Level, and Impulsivity subscales were mapped on DSM-IV (American Psychiatric Association 1994) criteria for attention-deficit disorders with and without hyperactivity.

Child Behavior Checklist (CBCL)
The CBCL (Achenbach 1991) is a parent-report scale that assesses a variety of behaviors related to psychosocial functioning. It provides information about a child's activities, social interactions, and basic psychological behaviors. It is widely used and its construct, content, and criterion validity are well established (Mooney 1984, Elliott and Busse 1992, Macmann et al. 1992, Chen et al. 1994, Jensen et al. 1996). The CBCL subtests include: Withdrawn, Somatic Complaints, Anxious/Depressed, Social Problems, Thought Problems, Attention Problems, and Aggressive and/or Delinquent Behavior.

Results

GROUP DIFFERENCES IN SENSORY FUNCTIONING

Our first hypothesis was that compared to typically developing peers, children with ADHD would show more SMD, measured by both parent-reported responses on rating scales (SSP and Leiter-P) and by physiological reactions to stimuli (EDR). Table III presents scores from the SSP and Leiter-P parent rating scales of behavioral responses. To decrease inflation of type I error due to the number of *t*-tests, we report only differences significant at $p<0.001$. As predicted, the group with ADHD showed significantly lower scores on six of seven subscales of the SSP (lower scores indicate abnormality). Also, as predicted, children with ADHD had scores that were significantly lower on measures of emotion and attention than those of typically developing children on all Leiter-P subscales, except Energy and Feelings: a measure of depression.

For the analyses of physiological reactions, we analyzed the magnitude of EDR using a 2 (Group) by 8 (Trials, within-participants repeated-measure) analysis of variance (ANOVA), collapsed across all five sensory domains (Fig. 1). We collapsed across sensory domains (e.g. trial 1 olfactory + trial 1 auditory + trial 1 visual + trail 1 tactile + trial 1 vestibular is indicated by 1 on the x-axis in Fig. 1) because our previous findings suggest that reactivity is consistent across sensory domains (McIntosh et al. 1999b). In both groups, earlier reactions were larger, and later reactions demonstrated decrements (see Fig. 1).

The effect of Group was marginally significant ($p=0.056$; Table IV), suggesting that the group with ADHD showed greater reactivity to sensory stimuli than did the comparison group. There was also a main effect for Trial (see Table IV). Main effects were modified by a significant Group by Trial interaction ($p=0.030$); this appears to be a result of a larger initial reaction in the group with ADHD, with subsequent habituation to levels statistically similar to those of the typically developing children.

Table III: Children with ADHD versus control participants on parent-report measures of sensory modulation dysfunction

Measure (n)	*Mean scores (SD)*		*df*[a]	*t-test*
	Typical	*ADHD*		
SSP (*n*)	30	26		
Seeks Movement Sensation	4.52 (0.41)	2.98 (0.97)	32.67	7.60[c]
Tactile Sensitivity	4.17 (0.39)	3.53 (0.95)	32.23	5.96[c]
Taste/Smell Sensitivity	4.64 (0.49)	3.49 (1.23)	31.93	4.47[c]
Auditory Filtering	4.44 (0.46)	2.55 (0.88)	54	10.20[c]
Visual/Auditory Sensitivity	4.56 (0.39)	3.12 (1.06)	31.01	6.58[c]
Low Energy/Weak	4.81 (0.35)	3.89 (0.84)	32.51	5.23[c]
Movement Sensitivity	4.54 (0.58)	3.76 (1.16)	35.51	3.12[b]
Leiter–P (*n*)	11	18		
Adaptation	9.18 (1.94)	4.33 (2.40)	27	5.65[c]
Moods/Confidence	9.36 (1.12)	6.33 (2.33)	25.99	4.71[c]
Energy/Feelings	8.91 (1.38)	7.50 (2.82)	27	1.85
Social Abilities	9.27 (1.27)	6.22 (2.10)	27	4.34[c]
Sensitivity/Regulation	9.64 (.67)	6.22 (2.02)	22.51	6.61[c]
Cognitive Composite	108.91 (10.68)	72.06 (9.69)	27	9.56[c]
Emotional Composite	103.00 (11.18)	80.00 (7.51)	27	6.64[c]

[a] For all *t*-tests, the Levene test for homogeneity of variance was used. If homogeneity of variance could not be assumed separate variance estimates were used, resulting in decimals in degrees of freedom.
[b] $p<0.05$; [c] $p<0.001$; all two-tailed.

VARIABILITY WITHIN ADHD GROUP IN RESPONSE TO SENSORY STIMULATION

Variability of SSP scores

The second hypothesis is that children with ADHD would show more within group variability in sensory responses compared to typically developing children would occur. We used Levene's test for equality of variances on the SSP. Levene's test essentially computes the absolute value of the difference of each child's score from their group mean score. It then performs an ANOVA on these deviations (Glaser 1981). We found greater variability among the group with ADHD compared to the control group ($p<0.001$), on all subscales of the SSP except Auditory Filtering (Table V).

Within the typically developing group, every child except one scored within normal limits on the SSP (i.e. total score >152). The group with ADHD demonstrated much greater variability, with scores ranging from 77 to 170. Twenty-four percent of children with ADHD scored within normal limits on the SSP. Twenty out of 26 of the children with ADHD had scores at least 1 standard deviation below the mean on the SSP. Some children with ADHD displayed normal sensory responses, whereas a larger proportion had at least some degree of difficulty.

Variability of Leiter-P scores

Levene's test for equality of variance revealed greater variability in the group with ADHD on three of eight Leiter-P parent-rating subscales ($p<0.001$; see Table V). Like the SSP findings, some children with ADHD had considerably lower scores than typically developing children on the Leiter-P subscales, while other children with ADHD scored the same as typically developing children.

SSP and CBCL correlations

Our third hypothesis was that differences in sensory processing scores would predict the degree of psychological symptoms among those with ADHD by examining correlations between SSP and CBCL subtest scores. To protect against inflation of type 1 error from multiple correlations, we used $p<0.001$ as our critical value (Table VI). Within the group with ADHD, the CBCL Aggressive Behavior subtest was highly correlated with the SSP Seeks Sensation and Tactile Sensitivity subtests; the CBCL Delinquent Behavior subtest was correlated with the SSP Seeks Sensation subtest; and CBCL Somatic Complaints subtest was correlated with the SSP Movement Sensitivity subtest.

Discussion

As there are numerous behavioral similarities between symptoms of ADHD and SMD, we hypothesized that a subgroup of children with ADHD has a disabling sensitivity to sensory stimuli, not previously discussed in the literature. This finding could have implications for treatment of such a subgroup of children with ADHD.

In this study, we established that children with ADHD

Table IV: Group and Trial effects on EDR, collapsed across sensory domain (*n*=31 controls; *n*=30 ADHD)

Factor	*F*	*df*[a]	*p*
Group (ADHD vs typical)	3.81	1, 59	0.056
Trial	16.51	3.17, 187.27	<0.001
Group by Trial	2.98	3.17, 187.27	0.030

[a]Mauchly W was computed to determine whether sphericity could be assumed for the Trial repeated measure. As it could not, we corrected the degrees of freedom using Greenhouse-Geisser epsilon. If sphericity were assumed and degrees of freedom are not corrected, Trial remains significant at $p<0.001$, and the p value for the Condition by Trial interaction becomes 0.005.

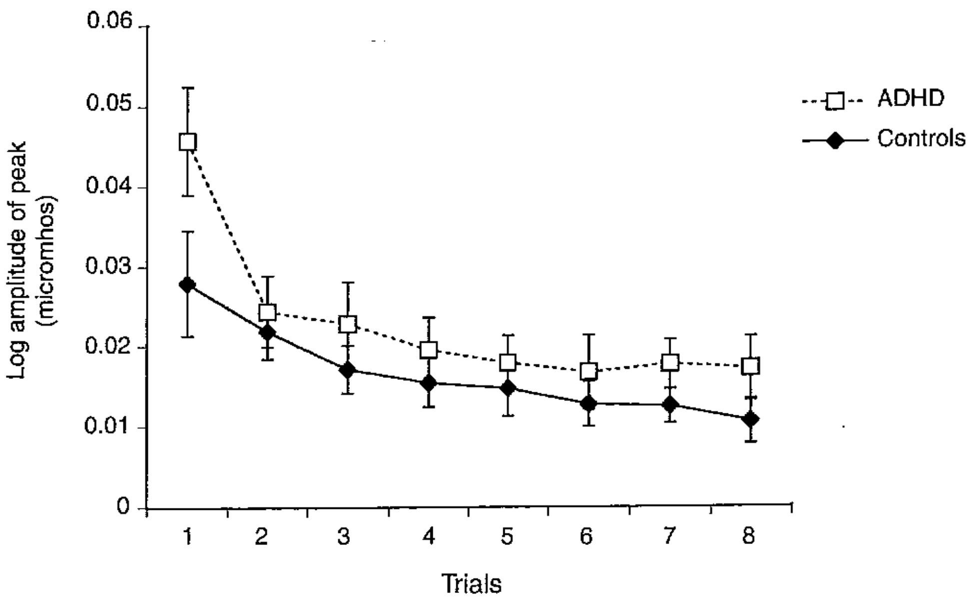

Figure 1: *Magnitude (log) of primary EDR responses across trials, displayed for ADHD and typically developing comparison groups. Lines represent standard errors.*

displayed significantly greater difficulties with sensory processing than a sample of typically developing children. Second, we showed that considerable variability in sensory processing occurs among children with ADHD. Third, we document that specific sensory symptoms predict particular behavioral problems such as aggression, delinquent behavior, and somatic complaints in children with ADHD. Implications for each of these findings are discussed below.

GROUP DIFFERENCES IN RESPONSE TO SENSORY STIMULATION

Compared to typically developing controls, children with ADHD displayed greater magnitudes of EDR after sensory stimulation. The difference in EDRs appears driven by an atypically large reaction to the initial presentation of the stimulus (see Miller and Summers [2001] for discussion of varying patterns of EDR among clinical groups).

Table V: Levene's test for equality of variances between samples on parent-report SSP and Leiter-P scales

Measure	*Typical*	*ADHD*	*F*
SSP (30 typical, 26 ADHD)[a]			
Seeks Movement Sensation	0.17	0.93	16.25[e]
Tactile Sensitivity	0.15	0.90	14.28[e]
Taste/Smell	0.24	1.52	37.19[e]
Auditory Filtering	0.22	0.78	5.03[c]
Visual/Auditory	0.16	1.12	45.07[e]
Low Energy	0.12	0.70	26.66[e]
Movement Sensitivity	0.33	1.34	11.50[e]
Leiter-P[b]	11	18	
Attention	0.16	4.64	14.27[e]
Activity Level	0.00	4.59	12.95[e]
Impulsivity	1.25	7.32	10.59[d]
Adaptation	3.76	5.76	2.18
Moods/Confidence	1.25	5.41	7.70[d]
Energy/Feelings	1.89	5.21	4.41[c]
Social Abilities	1.62	4.42	6.06[c]
Sensitivity/Regulation	0.45	4.07	21.00[e]

[a]$df=1, 54$; [b]$df=1, 27$.
[c]$p<0.05$; [d]$p<0.01$; [e]$p<0.001$.

Children with ADHD also showed functional manifestations of sensory problems as measured by parental report on the SSP and Leiter-P, particularly in sensory seeking, auditory filtering, and in sensitivity to tactile, auditory, visual, taste, and olfactory stimuli. This is the first study to demonstrate empirically the relation between ADHD and SMD across a number of sensory domains. These data suggest that SMD may be an important, yet often unrecognized, component of behaviors observed in a subgroup of children with ADHD.

Whereas previous studies have evaluated EDR only in response to auditory stimulation in ADHD (Hastings et al. 1978, Rosenthal et al. 1978), this is the first study to document EDR reactions to a number of different sensory stimuli. Although the literature suggests that children with ADHD have smaller phasic orienting responses (Hastings et al. 1978), the current study does not support this finding. Why would the current EDR results differ from prior studies? We believe it may be because previous research was conducted primarily in the 1970s, using the construct known then as hyperkinesis, or minimal brain dysfunction. Because the ADHD diagnosis has evolved considerably since that time, the current ADHD sample may differ in important ways from previously used hyperkinetic samples.

VARIABILITY WITHIN THE ADHD GROUP IN RESPONSE TO SENSORY STIMULATION

We found a large degree of variability in sensory processing across the sample with ADHD. This suggests that a group of children with ADHD may have normal physiological reactions and behavioral responses to sensory stimuli, whereas another group may be hyperreactive and overresponsive. That the group with ADHD had such large variability with respect to sensory processing has important implications for further understanding the role of sensory functions within ADHD. Although our sample size was too small to divide the group with ADHD into those with normal sensory processing and those with SMD, a larger sample size may confirm that two distinct subgroups exist within the population with ADHD. Determining whether some children with ADHD have SMD has implications for recommending rehabilitation treatment approaches.

Further, the suggestion that SMD may predict other behavioral problems or psychopathology in ADHD should

Table VI: Correlations between CBCL and SSP among children with ADHD (n=19)

CBCL subscales	*SSP subscales*						
	Seeks Movement Sensation	*Tactile Sensitivity*	*Taste/Smell*	*Auditory Filtering*	*Visual/ Auditory*	*Low Energy*	*Movement Sensitivity*
Withdrawn	0.18	–0.19	–0.11	–0.20	0.12	–0.16	–0.42[a]
Somatic Complaints	–0.07	–0.62[b]	–0.51[a]	–0.23	–0.25	–0.29	–0.72[c]
Anxious/Depressed	–0.25	–0.39[a]	–0.25	–0.49[a]	–0.20	0.00	–0.58[b]
Social Problems	–0.27	–0.37	–0.05	–0.19	–0.30	–0.29	–0.40[a]
Thought Problems	–0.10	–0.15	–0.46[a]	–0.15	0.04	–0.22	–0.28
Attention Problems	–0.23	–0.30	0.01	–0.01	–0.41[a]	–0.51[a]	–0.26
Delinquent Behavior	–0.71[c]	–0.42[a]	–0.15	–0.54[b]	–0.31	–0.20	–0.15
Aggressive Behavior	–0.73[c]	–0.66[c]	–0.18	–0.55[b]	–0.50[a]	–0.20	–0.29
Sex Problems	–0.29	–0.23	–0.03	–0.020	–0.07	–0.48[a]	–0.33

[a]$p<0.05$; [b]$p<0.01$; [c]$p<0.001$; all two-tailed.

be explored further. Correlations among CBCL and SSP scales demonstrated that higher levels of SMD among children with ADHD were related to greater levels of aggressive or delinquent behavior, and concerns about their body and health. Large correlations between the Tactile Sensitivity subtest of the SSP, and two CBCL subscales (Aggressive Behaviors and Somatic Complaints; $p<0.001$) particularly noteworthy. Problems with sensitivity to touch may lead to psychopathology or emotional and behavior problems (see Ayres 1964, 1972, 1989; Kinnealey 1989). If a child reacts negatively to other people touching them or invading their personal space, the child may engage in aggressive behaviors as protection.

LIMITATIONS, CONCLUSIONS, AND FUTURE DIRECTIONS

Our data provide preliminary indications of the role of SMD in ADHD. However, a limitation of this study is that we did not assess intelligence (IQ) in both groups. There did not appear to be wide variation in IQ across samples, and mechanisms by which IQ could influence the physiological responses are unclear. Nonetheless, future work should determine whether this is a confounding factor. Another limitation is the high degree of comorbidity occurring in children with ADHD. A larger sample should be tested to further investigate the important variability observed in this sample, as well as the influence of comorbid disorders on sensory processing disorders in ADHD. We expect that further study will reveal two distinct sensory subgroups within ADHD, one group with normal sensory processing functions and one with SMD. Identifying a subgroup within ADHD who have sensory dysfunction may inform more effective treatment options.

Our findings suggest that sensory problems may be underdiagnosed in children with ADHD. Unless recognized, these problems cannot be treated. We hope future studies will evaluate the effectiveness of treatments aimed at remediating SMD in children with ADHD.

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References

Achenbach TM. (1991) *Manual for the Child Behavior Checklist/4-18 and 1991 Profile.* Burlington, VT: University of Vermont Department of Psychiatry.

American Psychiatric Association. (1994) *Diagnostic and Statistical Manual of Mental Disorders,* 4th edn. Washington, DC: American Psychiatric Association.

Anastopoulos AD. (2000) The MTA study and parent training in managing ADHD. *ADHD Report* **8:** 7–9.

Andreassi JL. (1989) *Psychophysiology: human behavior and physiological response.* Hillsdale, NJ: Lawrence Erlbaum.

Ayres AJ. (1964) Tactile functions: their relation to hyperactive and perceptual motor behavior. *American Journal of Occupational Therapy* **18:** 6–11.

Ayres AJ. (1972) *Sensory Integration and Learning Disorders.* Los Angeles: Western Psychological Services.

— (1989) *Sensory Integration and Praxis Tests.* Los Angeles: Western Psychological Services.

Barkley RA. (1998) *Attention Deficit Hyperactivity Disorder: a handbook for diagnosis and treatment,* 2nd edn. New York: Guilford Press.

Boucsein W. (1992) *Electrodermal Activity.* New York: Plenum Press.

Cermak SA. (1991) Somatodyspraxia. In: Fisher AG, Murray EA, Bundy AC, editors. *Sensory Integration: theory and practice.* Philadelphia, PA: FA Davis. p 137–70.

Chen WJ, Faraone SV, Biederman J, Tsuang MT. (1994) Diagnostic accuracy of the Child Behavior Checklist scales for attention-deficit hyperactivity disorder: a receiver-operating characteristic analysis. *Journal of Counseling and Clinical Psychology* **62:** 1017–25.

Dawson ME, Schell AM, Filion DL. (1990) The electrodermal system. In: Cacioppo JT, Tassinary LG, editors. *Principles of Psychophysiology: physical, social, and inferential elements.* New York: Cambridge University Press.

Dunn W. (1999) *The Sensory Profile: examiner's manual.* San Antonio, TX: Psychological Corporation.

Elliott SN, Busse RT. (1992) Review of the Child Behavior Checklist. In: Kramer J, Conoley JC, editors. *Mental Measurements Yearbook,* Vol 11. Lincoln, NE: Buros Institute of Mental Measurement. p 166–9.

Fisher BC. (1998) *Attention Deficit Disorder Misdiagnosis: approaching ADD from a brain-behavior and neuropsychological perspective for assessment and treatment.* Boca Raton, FL: CRC Press.

Fowles DC. (1986) The eccrine system and electrodermal activity. In: Coles MGH, Donchin E, Porges SW, editors. *Psychophysiology: systems, processes, and applications.* New York: Guilford Press. p 51–96.

— Christie MJ, Edelberg R, Grings WW, Lykken DT, Venables PH. (1981) Publication recommendations for electrodermal measurements. *Psychophysiology Research* **18:** 232–9.

Glaser RE. (1981) Levene's robust test of homogeneity of variances. In: Kotz S, Johnson NL, editors. *Encyclopedia of Statistical Sciences,* Vol 4. NY: Wiley. p 608–10.

Glicken AD. (1997) Attention deficit disorder and the pediatric patient: a review. *Physician Assistant* **21:** 101–23.

Goldman LS, Genel M, Bezman RJ, Slanetz PJ. (1998) Diagnosis and treatment of attention-deficit/hyperactivity disorder in children and adolescents. *Journal of the American Medical Association* **279:** 1100–7.

Greenspan SI, Wieder S. (1993) Regulatory disorders. In: Zeanah CH, editor. *Handbook of Infant Mental Health.* New York: Guilford Press. p 280–90.

Hanft BE, Miller LJ, Lane SJ. (2000) Toward a consensus in terminology in sensory integration theory & practice. III: Observable behaviors: sensory integration dysfunction. *Sensory Integration Special Section Quarterly* **23:** 1–4.

Hastings JE, Barkley RA. (1978) A review of psychophysiological research with hyperkinetic children. *Journal of Abnormal Child Psychology* **6:** 413–47.

Iaboni F, Douglas VI, Ditto B. (1997) Psychophysiological response of ADHD children to reward and extinction. *Psychophysiology* **34:** 116–23.

Jensen PS, Wantanabe HK, Richters JE, Roper M. (1996) Scales, diagnosis, and child psychopathology: comparing the CBCL and the DISC against external validators. *Journal of Abnormal Child Psychology* **24:** 151–68.

Kaplan HI, Sadock BJ, Grebb JA. (1994) *Kaplan and Sadock's Synopsis of Psychiatry,* 7th edn. Baltimore, MD: Williams & Wilkins.

Kinnealey M. (1989) Tactile functions in learning-disabled and normal children: reliability and validity considerations. *Occupational Therapy Journal of Research* **9:** 3–15.

Kirk RE. (1982) *Experimental Design: procedures for the behavioral sciences,* 2nd edn. Pacific Grove, CA: Brooks/Cole.

Lane SJ, Miller LJ, Hanft BE. (2000) Toward a consensus in terminology in sensory integration theory and practice. II: Sensory integration patterns of function and dysfunction. *Sensory Integration Special Interest Section Quarterly* **23:** 1–3.

Macmann GM, Barnett DW, Burd SA, Jones T. (1992) Construct validity of the Child Behavior Checklist: effects of item overlap on second-order factor structure. *Psychological Assessment* **4:** 113–6.

Mannuzza S, Klein RG, Bessler A, Malloy P, LaPadula M. (1998) Adult psychiatric status of hyperactive boys grown up. *American Journal of Psychiatry* **155**: 493–8.
McIntosh DN, Miller LJ, Shyu V, Dunn W. (1999a) Overview of the Short Sensory Profile (SSP). In: Dunn W, editor. *The Sensory Profile: examiner's manual*. San Antonio, TX: Psychological Corporation. p 59–73.
— — — Hagerman R. (1999b) Sensory-modulation disruption, electrodermal responses, and functional behaviors. *Developmental Medicine & Child Neurology* **41**: 608–15.
Miller LJ, McIntosh DN, McGrath J, Shyu V, Lampe M, Taylor AK, Tassone F, Neitzel K, Stackhouse T, Hagerman R. (1999) Electrodermal responses to sensory stimuli in individuals with fragile X syndrome: a preliminary report. *American Journal of Medical Genetics* **83**: 268–79.
— Reisman J, McIntosh DN, Simon J. (2001) An ecological model of sensory modulation: performance of children with fragile X syndrome, autism, attention-deficit/hyperactivity disorder and sensory modulation dysfunction. In: Roley S, Schaaf R, Blanche E, editors. *The Nature of Sensory Integration with Diverse Populations*. San Antonio, TX: Therapy Skill Builders. p 57–87.
— Summers C. (2001) Clinical applications in sensory modulation dysfunction: assessment and treatment considerations. In: Roley S, Schaaf R, Blanche E, editors. *The Nature of Sensory Integration with Diverse Populations*. San Antonio, TX: Therapy Skill Builders. p 249–76.
Mooney KC. (1984) Review of the Child Behavior Checklist. In: Keyser D, Sweetland R, editors. *Test Critiques*, Vol 1. Kansas City, MO: Westport Publications. p 168–84.
MTA Cooperative Group. (1999a) A 14-month randomized clinical trial of treatment strategies for attention-deficit/hyperactivity disorder. *Archives of General Psychiatry* **56**: 1073–86.
— (1999b) Moderators and mediators of treatment response for children with attention-deficit/hyperactivity disorder. *Archives of General Psychiatry* **56**: 1088–96.
Mulligan S. (1996) An analysis of score patterns of children with attention disorders on the Sensory Integration and Praxis Tests. *American Journal of Occupational Therapy* **50**: 647–54.
Parham LD, Mailloux Z. (1996) Sensory integration. In: Case-Smith J, Allen AS, Pratt PN, editors. *Occupational Therapy for Children*. St. Louis, MO: Mosby-Year Book. p 307–55.
Parush S, Sohmer H, Steinberg A, Kaitz M. (1997) Somatosensory functioning in children with attention deficit hyperactivity disorder. *Developmental Medicine & Child Neurology* **39**: 464–8.
Pennington BF. (1991) *Diagnosing Learning Disorders: a neuropsychological framework*. London: Guilford Press.
Roid GH, Miller LJ. (1997) *Leiter International Performance Scale-Revised*. Wood Dale, IL: Stoelting Company.
Rosenthal RH, Allen TW. (1978) An examination of attention, arousal, and learning dysfunctions of hyperkinetic children. *Psychological Bulletin* **75**: 689–715.
Scerbo AS, Freedman LW, Raine A, Dawson ME, Venables PH. (1992) A major effect of recording site on measurement of electrodermal activity. *Psychophysiology* **29**: 241–6.
Schachar R. (2000) The MTA Study: implications for medication management. *ADHD Report* **8**: 2–6.
Stinnett TA. (2001) Review of the Leiter International Performance Scale–Revised. In: Plake BS and Impara JC, editors. *The Fourteenth Mental Measurements Yearbook*. Lincoln, NE: Buros Institute of Mental Measurement. p 683.
Tannock R. (1998) Attention deficit hyperactivity disorder: advances in cognitive, neurobiological, and genetic research. *Journal of Child Psychology and Psychiatry* **39**: 65–99.
Ullmann RK, Sleator EK, Sprague RL. (1997) *ACTeRS Teacher and Parent Forms Manual*, 2nd edn. Champaign, IL: MetriTech.