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Sensory profiles in adults with and without ADHD

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ABSTRACT

Background: Our previous work demonstrates that adults with ADHD produce more force at the fingertips compared to adults without ADHD. One possibility is that somatosensation is impaired in ADHD. However, ADHD is often comorbid with anxiety, and anxiety influences sensory responsivity.
Aims: The goal of the current work was to evaluate differences in the self-report of sensory experiences in adults with and without ADHD, while controlling for internalizing behaviors.
Methods and Procedures: Forty-five adults (23 with ADHD) completed a semi-structured interview for the diagnosis of ADHD, the Adolescent/Adult Sensory Profile (AASP), and the Achenbach Adult Self Report (ASR).
Outcomes and Results: Adults with ADHD reported more hyper- and hypo- sensitivity compared to adults without ADHD, even when controlling for internalizing behaviors. Specifically, between group differences were found for low registration, sensation seeking, and sensory sensitivity scores, but not for sensation avoiding, and for movement, visual, touch, activity, audition, or taste/smell.
Conclusions and Implications: These findings demonstrate that sensory hyper- and hypo- sensitivity may be features of ADHD in adults. Further, they demonstrate that internalizing behaviors influence the perception of sensory experiences and thus should be accounted for in studies of sensory processing, integration, and modulation in adults with ADHD.

1. Introduction

Sensory processing is the way in which the nervous system receives, modulates, integrates, organizes, and responds to external and internal stimuli (Miller & Lane, 2000; Miller, Anzalone, Lane, Cermak, & Osten, 2007). An area of growing interest is the study of clinical populations whose sensory processing may differ from the general population (Miller & Lane, 2000; Miller et al., 2007). Attention-deficit/hyperactivity disorder (ADHD) is a neurodevelopmental disorder that persists into adulthood in up to 65% of cases (Faraone, Biederman, & Mick, 2006; Simon, Czobor, Balint, Meszaros, & Bitter, 2009; Turgay et al., 2012) and results in functional impairments in multiple life domains. A handful of studies suggest that a subset of children (2011, Ghanizadeh, 2008; Lane & Reynolds, 2019; Mangeot et al., 2001) and adults (Bijlenga, Tjon-Ka-Jie, Schuijers, & Kooij, 2017; Clince, Connolly, & Nolan, 2016)

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with ADHD have atypical sensory processing. This is important because Clince and colleagues (Clince et al., 2016) demonstrated that sensory preferences influence daily functioning and participation in academic environments, as well as leisure activities and social interaction.

A common method to assess sensory problems is the Sensory Profile, which uses parent- and/or self- reports about sensory experiences (Brown, Tollefson, Dunn, Cromwell, & Filion, 2001; Dunn, 1999). The Sensory Profile was derived from Dunn's model of sensory processing, which provides a framework for understanding the nervous system's thresholds for stimulus detection and the propensity to respond to those stimuli (Dunn, 1997). Thresholds and responsivity exist on a continuum, and as such, are anchored by the four outermost points on each scale, giving rise to four quadrants (for greater detail see (Dunn, 1999)). The four quadrants result from the interaction of the neurological threshold and behavioral response continuum stimuli (Dunn, 1997). Specifically, "low registration" is the anchor for high thresholds with passive responding, whereas "sensation seeking" is the anchor for high thresholds and active responding. "Sensory sensitivity" is the anchor for low thresholds with passive responding, and "sensation avoiding" is the anchor for low thresholds for active responding. Each individual experiences these thresholds to various degrees, giving rise to an individual score in each quadrant. Six sensory modalities are represented on the Sensory Profile: taste/smell, movement, vision, touch, activity level, and auditory processing. Therefore, in addition to the four overall quadrant scores, quadrant scores for each sensory modality can be obtained.

Previous work using the sensory profile reports that adults with ADHD are different than the normative data reported in the Adolescent/Adult Sensory Profile (AASP) manual for all four quadrant scores (Bijlenga et al., 2017; Clince et al., 2016). For example, Bijlenga and colleagues studied 116 adults with a confirmed diagnosis of ADHD. Notably, this study did not employ a control group of non-ADHD adults and thus comparisons were conducted using the normative data provided in the AASP manual. Bijlenga et al. (2017) report that individuals with ADHD have abnormal hyper- and hypo- sensitivity. In addition, self-reported ADHD symptoms were associated with the quadrant scores for low registration, sensation seeking, and sensory sensitivity, but not sensation avoiding. The authors report quadrant scores for each modality (2017); however, normative data are not available for modality scores, which limits the interpretation of these data. Clince and colleagues (Clince et al., 2016) report differences in the AASP for adults with a confirmed diagnosis of ADHD or autism spectrum disorder (ASD). Similarly, comparisons made using normative data in the AASP manual demonstrated that the ADHD group was different across all quadrants. Clince and colleagues (Clince et al., 2016) did not report sensory modality data.

Since internalizing disorders are often co-morbid with ADHD (Biederman et al., 2006; Spencer, Biederman, & Mick, 2007), the goal of the current work was to evaluate differences in the self-report of sensory experiences in adults with and without ADHD, while controlling for internalizing behaviors. Indeed, Ayres' work (1972) reported hypersensitivity to tactile stimuli was associated with patterns of anxiety in children. More recent work from Engel-Yeger & Dunn (2011) demonstrates a relationship between anxiety and sensory reactivity in healthy adults. Specifically, individuals with elevated anxiety demonstrated sensory hypersensitivity, as well as low registration of sensory input (Engel-Yeger & Dunn, 2011). Here, we extend these findings to a sample of young adults with a confirmed diagnosis of ADHD, and age- and sex- matched non-ADHD controls.

2. Methods

2.1. Participants

Participants were recruited from an existing database of research participants from the Brain and Behavior Lab (PI: Neely). Individuals in this database had previously participated in a laboratory session in which they had completed the Conners' Adult ADHD Diagnostic Interview (CAADID; Multi-Health Systems Inc.). In addition, during that visit, portions of the Wechsler Adult Intelligence Scale-Fourth Edition (WAIS-IV) (Wechsler, 2008) were conducted to estimate intelligence quotient (IQ). Participants completed a self-report of ADHD-related symptoms using the Connors Adult ADHD Rating Scales (Conners, Erhardt, & Sparrow, 1999) and a self-report of adaptive functioning using the Achenbach Adult Self-Report (ASR) (Achenbach & Rescorla, 2003). Participants recruited for this study had to be right-hand dominant as measured by the Edinburgh Handedness Survey, and had to meet the criteria for ADHD, or non-ADHD control.

Adults with ADHD met DSM-V criteria including cross-situational severity and impairment as determined by the CAADID. Adults had $\geq$ 5 symptoms of inattention or hyperactivity, that were impairing in at least two settings (e.g., family and work). In total, 23 young adults (14 females) met the criteria for ADHD. Non-ADHD controls reported < 3 total symptoms and $\leq$ 2 symptoms per ADHD dimension. Self-report of anxiety and/or depression was not exclusionary. In total, 22 young adults (12 female) met the criteria for non-ADHD control.

The tasks reported here were collected and analyzed specifically for the current study, but were also part of a larger battery of experimental and standardized measures being collected for other planned studies. All procedures were approved by the Institutional Review Board at The Pennsylvania State University and were consistent with the Declaration of Helsinki. All participants received monetary compensation for their participation. After a complete description of the study, written informed consent was obtained from all participants.

2.2. Procedures

All participants completed the Adult/Adolescent Sensory Profile (AASP™) (Dunn, 1999) during the laboratory session. The AASP is a 60-item questionnaire consisting of statements such as "I leave or move to another section when I smell a strong odor in a store

Table 1
Participant characteristics.

Variables	Group		Group Differences
	Control	ADHD	
Sample size (females)	22 (12)	23 (14)	
Age, yrs	21.14 (2.25)	21.87 (1.98)	ADHD = CTRL, F(1,43) = 0.26, p = .612, *ns*
FSIQ	111.18 (10.14)	109.13 (8.75)	ADHD = CTRL, F(1,43) = 0.10, p = .757, *ns*
CAADID			
Inattention symptoms in adulthood	0.09 (0.43)	6.57 (1.90)	ADHD > CTRL, F(1, 43) = 242.81, p < .001
Hyperactive symptoms in adulthood	0.05 (0.21)	5.26 (2.24)	ADHD > CTRL, F(1, 43) = 118.07, p < .001
Total symptoms in adulthood	0.14 (0.47)	11.83 (3.13)	ADHD > CTRL, F(1, 43) = 300.47, p < .001
CAARS-S:L			
Inattention/Memory Problems T-score	38.32 (5.69)	63.83 (12.74)	ADHD > CTRL, F(1, 43) = 74.02, p < .001
Hyperactivity/Restlessness T-score	40.23 (6.26)	56.65 (10.36)	ADHD > CTRL, F(1, 43) = 40.93, p < .001
ADHD Index T-score	38.82 (6.28)	60.91 (8.70)	ADHD > CTRL, F(1, 43) = 94.68, p < .001
ASR			
Aggressive Behavior T-score	51.14 (2.95)	57.78 (8.54)	ADHD > CTRL, F(1, 43) = 11.96, p = .001
Rule-breaking Behavior T-score	52.45 (6.52)	58.35 (8.74)	ADHD > CTRL, F(1, 43) = 6.53, p = .014
Internalizing Composite T-score	42.59 (8.26)	57.39 (14.15)	ADHD > CTRL, F(1, 43) = 18.15, p < .001

Notes: Means and standard deviations (in parentheses) reported for each measure, with the exception of sample size. Abbreviations: FSIQ: full-scale intelligence quotient. CAADID: Conners' Adult ADHD Diagnostic Interview. CAARS-S:L: Conners' Adult ADHD Rating Scales-Self: Long version, ASR: Achenbach Self Report.

(for example, bath products, candles, perfumes)" and "I choose to shop in smaller stores because I'm overwhelmed in large stores". Participants rated each statement using a five-point scale with one being "Almost Never" and five being "Almost Always". Each of the four quadrants are associated with 15 statements, and the sum of the participant's ratings of those statements was calculated in order to achieve the "Quadrant Raw Score Total", hereafter referred to as quadrant total. The 60 items on the AASP encompass experiences related to the sensory processing categories of taste/smell, movement, vision, touch, activity level, and audition. Individual scores for each of these sensory processing categories was obtained by averaging the raw scores for that particular processing category (Dunn, 1999).

Prior to the laboratory session, all participants had completed the ASR. The ASR is a 126-item self-report of adaptive functioning, problems, and substance use. The scoring system includes normative scales for adaptive functioning, substance use, internalizing, externalizing, and total problems. The ASR-internalizing score is obtained by summing the syndrome scales for "anxious/depressed", "somatic complaints", and "withdrawn." This score was used as a covariate in a multivariate analysis of covariance (MANCOVA) to evaluate whether the self-report of sensory experiences differs for adults with ADHD compared to non-ADHD controls, while controlling for internalizing.

3. Results

Test statistics, means, and standard deviations for variables characterizing the sample appear in Table 1. Independent samples t-tests demonstrated no differences between the ADHD and non-ADHD groups for age and estimated IQ. A multivariate analysis of variance (MANOVA) was conducted to tests for differences in multiple continuous variables characterizing the sample. The results demonstrated that the ADHD group reported more ADHD-related symptoms in adulthood as measured by the CAARS. As expected (Anastopoulos et al., 2018; Hinshaw et al., 2012), adults with ADHD self-reported more internalizing (e.g., anxiety or depression) and externalizing (e.g., aggression, rule-breaking behavior) difficulties on the ASR ($ps \leq .001$).

To compare quadrant scores between groups while controlling for internalizing, we conducted a MANCOVA in which the ASR-internalizing score was used as a covariate. The multivariate test for revealed effects of the covariate, ASR-internalizing, $F(4, 39) = 6.47$, $p < .001$, and diagnosis, $F(4, 39) = 4.39$, $p = .005$. As shown in Fig. 1 and reported in Table 2, there was a main effect of diagnosis for low registration, sensation seeking, and sensory sensitivity scores, $Fs\ (1,42) = 14.64$, 5.62, and 10.91, respectively, $ps < .022$, but not for sensation avoiding, $F(1,42) = 0.41$, $p = .525$, after controlling for ASR internalizing scores. Table 3 reports the distribution of data for each quadrant score. There was a main effect of the covariate, ASR-internalizing, for low registration, sensory sensitivity, and sensation avoiding, $Fs(1,42) = 19.74$, 8.51, 4.71, respectively, $ps < .036$, but not sensation seeking, $F(1, 42) = 0.11$, $p = .744$.

To compare modality scores between groups while controlling for internalizing, we conducted a MANCOVA in which the ASR-internalizing score was used as a covariate. The multivariate test for modality scores revealed effects of the covariate, ASR internalizing, $F(6, 37) = 3.33$, $p = .010$, and diagnosis, $F(6, 37) = 4.14$, $p = .003$. As shown in Fig. 2 and reported in Table 2, there was a main effect of diagnosis for movement, visual, touch, activity, and auditory, $Fs\ (1,42) = 10.32$, 5.17, 5.35, 20.71, 7.81, respectively, $ps < .028$, but not for taste/smell, $F(1,42) = 0.05$, $p = .817$, after controlling for ASR internalizing scores. There was a main effect of the covariate, ASR-internalizing, for movement, visual, touch, and activity, $Fs\ (1,42) = 6.80$, 6.60, 7.00, 14.89, respectively, $ps < .014$; but not for taste/smell or auditory, $Fs\ (1,42) = 3.10$ and 1.83, respectively, $ps < .184$.

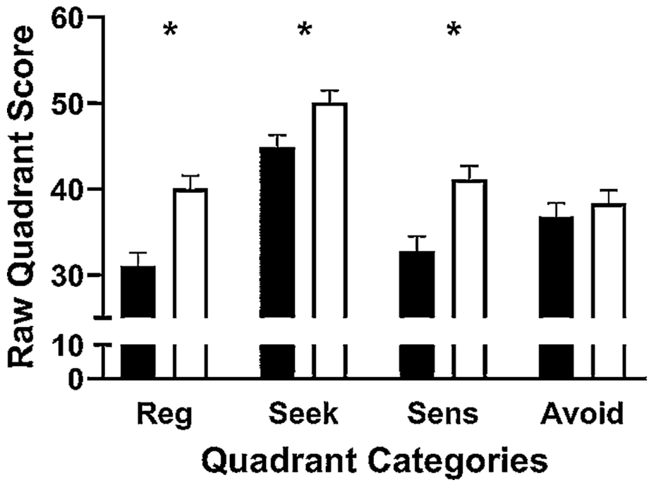

Fig. 1. Raw quadrant scores, adjusted for the covariate, are reported for low registration (Reg), sensation seeking (Seek), sensory sensitivity (Sens), and sensation avoiding (Avoid). Filled bars represent non-ADHD controls. Error bars represent the standard error of the mean.

Table 2
AASP Scores.

Variables	Group		Group Differences
	Control	ADHD	
Quadrant Total Raw Score			
Low Registration	28.14 (4.48)	42.83 (10.18)	ADHD > CTRL, $F(1, 42) = 14.64$, $p < .001$
Sensation Seeking	45.05 (6.88)	49.87 (5.30)	ADHD > CTRL, $F(1, 42) = 5.62$, $p = .022$
Sensory Sensitivity	30.77 (6.29)	43.04 (8.74)	ADHD > CTRL, $F(1, 42) = 10.91$, $p = .002$
Sensation Avoiding	35.36 (6.89)	39.70 (7.04)	ADHD > CTRL, $F(1, 42) = 0.41$, $p = .525$
Sensory Modality Score			
Taste/Smell	2.47 (0.40)	2.66 (0.52)	ADHD > CTRL, $F(1, 42) = 0.05$, $p = .817$, *ns*
Movement	2.17 (0.42)	3.01 (0.63)	ADHD > CTRL, $F(1, 42) = 10.32$, $p = .003$
Visual	2.32 (0.41)	2.87 (0.49)	ADHD > CTRL, $F(1, 42) = 5.17$, $p = .028$
Touch	2.19 (0.32)	2.69 (0.47)	ADHD > CTRL, $F(1, 42) = 5.35$, $p = .026$
Activity	2.35 (0.40)	3.17 (0.40)	ADHD > CTRL, $F(1, 42) = 20.71$, $p < .001$
Auditory	2.46 (0.49)	3.15 (0.61)	ADHD > CTRL, $F(1, 42) = 7.81$, $p = .008$, *ns*

Notes: Means and standard deviations (in parentheses) reported for each measure. Abbreviations: AASP: Adult/Adolescent Sensory Profile.

Table 3
Score distribution of adults with (N = 23) and without (N = 22) ADHD in each quadrant of the AASP.

Endorsement	Much Less Than Most People		Less Than Most People		Similar To Most People		More Than Most People		Much More Than Most People	
Quadrant	Control	ADHD	Control	ADHD	Control	ADHD	Control	ADHD	Control	ADHD
Low Registration	11 (50)	6 (26.1)	10 (45.5)	3 (13.0)	1 (4.5)	5 (21.7)	0 (0)	7 (30.4)	0 (0)	2 (8.7)
Sensation Seeking	2 (9.1)	1 (4.4)	5 (22.7)	0 (0)	11 (50)	6 (26.1)	2 (9.1)	11 (47.8)	2 (9.1)	5 (21.7)
Sensory Sensitivity	14 (63.6)	7 (30.4)	5 (22.7)	2 (8.7)	1 (4.5)	3 (13.0)	2 (9.1)	4 (17.4)	0 (0)	7 (30.4)
Sensation Avoiding	7 (31.8)	7 (30.4)	8 (36.4)	5 (21.7)	4 (18.2)	7 (30.4)	3 (13.6)	1 (4.4)	0 (0)	3 (13.0)

NOTE: Number of subjects and percentage of the sample (in parentheses) reported for each quadrant.

4. Discussion

The goal of the current study was to evaluate differences in the self-report of sensory experiences, while controlling for internalizing behaviors in a sample of young adults with a confirmed diagnosis of ADHD and an age- and IQ- matched sample of adults without ADHD. We report three novel findings. First, a diagnosis of ADHD was related to the self-report of sensory experiences, even when controlling for internalizing. Second, we demonstrated differences in the sensory modality scores for adults with ADHD compared to adults without ADHD. Third, internalizing behaviors, as measured by the ASR-Internalizing composite score, were related to the self-report of sensory experiences.

Adults with ADHD scored differently on three of the four quadrants of the AASP. These findings are interpreted with the guidance

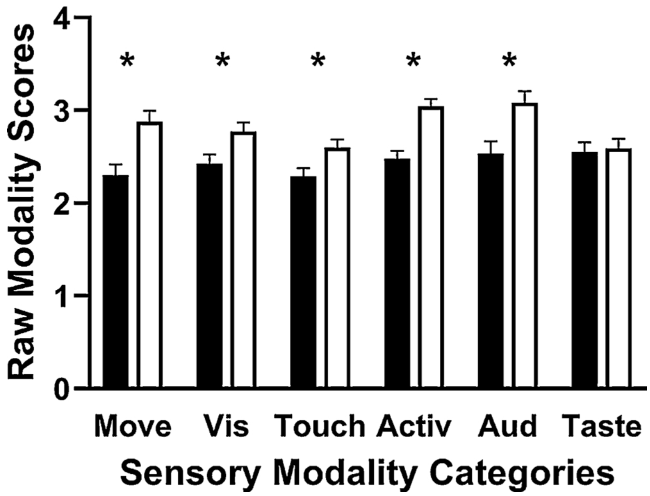

Fig. 2. Raw modality scores, adjusted for the covariate, are reported for each modality, movement (Move), visual (Vis), touch (Touch), activity (Activ), and auditory scores (Aud), and taste/smell (Taste). Filled bars represent non-ADHD controls. Error bars represent the standard error of the mean.

of the AASP Manual (Dunn, 1999); however, it is important to note that the interpretation is based on group data. The ideal use of the AASP is to interpret scores on an individual basis and in concert with a clinical history. Adults with ADHD scored higher for both low registration and sensory sensitivity, consistent with findings from Bijlenga et al. (2017) and Clince et al. (2016). Individuals who score high on low registration have difficulty reacting quickly to stimuli, especially less salient or weak stimuli. Although advantageous in the context of being able to focus without distraction, important stimuli may be missed. Adults with ADHD also scored higher on sensory sensitivity. Individuals with high sensory sensitivity respond quickly to low threshold stimuli. The advantage is an awareness to detail in the environment; however, this also presents the potential for constant distraction. The combination of high scores for low registration and sensory sensitivity suggests that adults with ADHD may simultaneously notice and miss stimuli, resulting in behavioral responses that may seem erratic or unpredictable. Further, individuals with this combination of traits may not be able modulate their environment. Adults with ADHD also scored higher on sensation seeking, a finding in contrast to Bijlenga et al. (2017) and Clince et al. (2016) who report lower scores for adults with ADHD. Individuals with high scores in sensation seeking tend to look for opportunities to increase sensory experiences and, generally, find these experiences pleasurable. However, these individuals have a tendency to become easily bored in low-stimulus environments and/or create or seek stimuli that may be distracting for others. Last, adults with ADHD did not score differently in the sensation avoiding quadrant, indicating that they did not report being overwhelmed or bothered by stimuli any more or less than their non-ADHD counterparts. This finding suggests that adults with ADHD might be less aware of how sensory information affects their daily life. Notably, however, although the difference between groups was not statistically different, the score for the ADHD group was higher than that of the non-ADHD controls, which is consistent with work from Bijlenga et al. (2017) and Clince et al. (2016).

In addition to the four quadrant scores, the current work found differences between adults with and without ADHD on all modality indices, with the exception of taste and smell. To our knowledge, only one previous study has examined the modality indices, but without a non-ADHD control group for comparison (Bijlenga et al., 2017). The literature examining specific sensory modalities in children and adults with ADHD is equivocal and difficult to summarize because the methods, samples, and outcome measures vary widely. The current results suggest that adults with ADHD may process stimuli differently than adults without ADHD across modalities. Importantly, however, hyper- or hypo- sensitivities are unlikely to be consistent across all modalities, even in non-ADHD controls. Therefore, future work should consider reporting the properties of stimuli used in experiments to allow for replication. Further, varying the properties of stimuli within an experiment would allow for the precise evaluation of behavioral responses, as function of internalizing behaviors and in response to different stimuli.

Finally, the current work demonstrates a relationship between self-reported internalizing behaviors and perceived sensory experiences. Specifically, internalizing behaviors were related to the quadrant scores for low registration, sensory sensitivity, and sensation avoiding, but not sensation seeking. In addition, internalizing was related to the modality scores for movement, visual, touch, and activity, but not for taste/smell or audition. These findings are consistent with work from Neal and colleagues reporting that higher levels of anxiety are associated with increased sensitivity to environmental stimuli in adults ages 17–75 (Neal, Edelmann, & Glachan, 2002). Indeed, the notion that anxiety is associated with sensory perception is not a new concept, and was introduced by Ayres who suggested that anxiety is related to deficits in sensory and information processing (Ayres, 1972). The current work is notable because ADHD is frequently co-morbid with anxiety and other internalizing disorders (Biederman et al., 2006, 2012). Therefore, it may be prudent to account for comorbid disorders in future studies of sensory sensitivity. More important, since anxiety and depression affect approximately 10–11 % in adolescents and young adults (Mojtabai, Olfson, & Han, 2016), behavioral studies might consider including tools to measure internalizing behaviors in their otherwise “healthy” participants.

A limitation of the current work is that the sample size prevented evaluation of sex differences. Engel-Yeger & Dunn (2011) report that men with lower registration (on the AASP) report higher trait anxiety than women. Such a finding suggests the relationship between sensory processing and internalizing behaviors may be different for men and women. A second limitation of the current work is that we did not conduct in-house diagnostic interviews for anxiety and depression. Interviews provide an opportunity to better characterize internalizing behaviors and to determine if symptom ratings are useful predictors of sensory hyper-/hypo- sensitivity. The trade-off, however, is that in-house diagnostic interviews are lengthy and must be supervised by licensed clinicians.

The finding that adults with ADHD differ from adults without ADHD on nearly all components of the AASP is consistent with previous work reporting that children (Mangeot et al., 2001; Miller, Nielsen, & Schoen, 2012) and adults (Bijlenga et al., 2017; Clince et al., 2016) with ADHD report abnormal sensory experiences. The current work extends the current literature by demonstrating that group differences in sensory experiences persist when controlling for internalizing. In addition, internalizing behaviors affect the perception of sensory experiences in adults. This is important because sensory processing influences motor output. Recent work from our group reports that adults with ADHD produce more force at the fingertips, in both visually (Neely et al., 2017) and memory-guided force control (Neely et al., 2016), compared to adults without ADHD. Performance of such motor tasks requires the integration of tactile feedback from the fingertips and upper extremity, as well as the integration of real-time visual feedback about force output. Thus, we theorized that atypical sensory processing might be influencing the control of goal-directed movement. In light of the current findings, we suggest that psychophysical experiments should consider the type and intensity of sensory stimuli used in behavioral paradigms. Quantitative measurements of behavioral responses and/or motor output to various stimulus intensities could inform the design of behavioral paradigms that use sensory stimuli as a cornerstone for measuring cognitive and motor control.

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CRediT authorship contribution statement

M.S. Kamath: Writing - original draft, Writing - review & editing, Data curation. **C.R. Dahm:** Conceptualization, Investigation, Data curation. **J.R. Tucker:** Investigation, Data curation. **C.L. Huang-Pollock:** Writing - review & editing. **N.M. Etter:** Conceptualization, Writing - review & editing, Project administration, Funding acquisition. **K.A. Neely:** Conceptualization, Formal analysis, Resources, Writing - original draft, Writing - review & editing, Supervision, Project administration, Funding acquisition.

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