Article:

Panagiotidi, M., Overton, P. orcid.org/0000-0003-4334-261X and Stafford, T. (2020) The relationship between sensory processing sensitivity and Attention Deficit Hyperactivity Disorder traits: a spectrum approach. Psychiatry Research, 293. 113477. ISSN 0165-1781

https://doi.org/10.1016/j.psychres.2020.113477

The relationship between sensory processing sensitivity and Attention Deficit Hyperactivity Disorder traits: a spectrum approach

Abstract

The aim of the present study was to examine the relationship between sensory processing sensitivity (SPS) and symptoms of Attention Deficit Hyperactivity Disorder (ADHD) in adults. The Highly Sensitive Person Scale (HSPS) scale and the Adult ADHD Self-Report Scale (ASRS) were administered to a non-clinical group of 274 participants recruited from a university volunteers list. We found a highly significant positive correlation between number of self-reported ADHD traits and sensory sensitivity. Furthermore, ADHD traits and age were predictors of SPS and exploratory factor analysis revealed a factor that combined ADHD traits and items from the HSPS. The psychometric properties of the HSPS were also examined supporting the unidimensional nature of the concept. To our knowledge, this is the first study to identify a positive relationship between HSPS and ADHD traits in the general population. Our results further support recent findings suggesting abnormal sensory processing in ADHD.

1. Introduction

Sensory processing sensitivity (SPS) is a personality trait characterized by sensitivity to internal and external stimuli and the tendency to process stimuli and information more strongly and deeply than others (Aron & Aron, 1997; Aron, Aron, & Jagiellowicz, 2012). In particular, the temperamental trait of SPS is associated with increased sensitivity to sensory processing of emotions, pain, environmental stimuli, and aesthetic experiences (Aron & Aron, 1997). Approximately 20% of the population is hypothesized to be highly sensitive to various types of information and stimuli (Jagiellowicz et al., 2006). Individuals reporting higher levels of SPS appear to have a lower threshold for stimuli and be more aroused by subtle stimuli in their environment (Aron et al., 2012). Previous research suggests that these individual differences have a genetic component (Aron et al., 2012). Evidence from neuroimaging and physiological studies have further supported the biological basis of SPS (Acevedo et al, 2014; Musser et al., 2011; Jagiellowicz et al., 2010).

The concept of SPS is measured by the Highly Sensitive Person Scale (HSPS), which developed and validated by Aron and Aron (1997). The scale consists of 27 items measuring various aspects of SPS. Findings regarding the dimensionality of HSPS have been inconsistent. Even though it was originally designed to measure a one-dimensional SPS construct (Aron & Aron, 1997), more recent studies have identified several factors. More specifically, a study by Smolewska, McCabe, and Woody (2006) identified three separate factors; aesthetic sensitivity, low sensory threshold, and ease of excitation. A two-factor structure was reported in another study by Evans and Rothbart (2008), who identified a negative emotionality factor (consisting of negative affect resulting from sensory stimulation) and an orienting sensitivity/openness factor (consisting of items measuring automatic attentional processing of sensory events).

Processing sensory events plays an important role in everyday life and abnormalities can have a negative impact on human wellbeing and behaviour. High levels of SPS in adults have been associated with higher levels of physical and mental health problems (Benham, 2006; Liss, Mailloux, & Erchull, 2008). More specifically, higher SPS is related to higher levels of anxiety and depression (Benham, 2006). In addition to this, a number of studies have shown that high scores on HSPS are associated with sleeping and behavioural problems (Reynolds, Lane, & Thacker, 2012; Shochat, Tzischinsky, & Engel-Yeger, 2009).

Many developmental disorders such as autism, dyslexia and ADHD are characterized by abnormal sensory processing (Engel-Yeger & Ziv-On, 2011;Robertson & Simmons, 2013; Kern et al., 2007; Rosen, 2003;). DSM-5 defines ADHD as a behavioural disorder presenting with symptoms of attentional dysfunction, hyperactive/impulsive behavior, or both (DSM-5; American Psychiatric Association, 2013). Understanding ADHD is important since it is the most common neurodevelopmental disorder in childhood (Faraone et al., 2003; Barkley, 1997) with symptoms often persisting into adulthood (Faraone & Biederman, 2005). The most common treatment for ADHD is medication; a recent review by Cortese et al. (2018) found that methylphenidate is the preferred first-choice pharmacotherapy in children and adolescents, and amphetamines in adults. ADHD symptomatology can be seen dimensionally. More specifically, impulsive and inattentive symptoms are thought to be distributed continuously in the general population (Hudziak et al., 2007). The dimensionality of ADHD symptomatology has been supported at the molecular genetic level with evidence showing that risk alleles found in diagnosed ADHD also influence the distribution of inattention and hyperactivity/impulsivity traits in a general population (Martin et al., 2014; Reuter et al., 2006). Further support for the dimensional nature of ADHD has been provided by a number of recent studies, which identified significant differences between neurotypical individuals with high and low levels of ADHD traits in a variety of behavioural measures and self-reports (Crosbie et al., 2013; Polner et al., 2015; Panagiotidi et al., 2016; Panagiotidi et al., 2017; Panagiotidi et al., 2018). In particular, individuals reporting high levels of ADHD from a non-clinical population have poorer performance in cognitive tasks measuring response inhibition in a similar manner to that observed in clinical populations (Crosbie et al., 2013; Polner et al., 2015). Previous research examining the lower extremity of the distribution of ADHD traits showed that children and adolescents with lower ADHD traits have better cognitive performance and positive behaviours compared to those at the higher extreme (Greven et al., 2016; Greven at al., 2018) further supporting the continuum approach in ADHD research. ADHD traits in a non-clinical population have also been linked to problematic behaviors such as gambling, excessive internet use, and impulsivity (Chamberlain et a., 2017). In addition to this, abnormalities resembling those found in clinical studies have been found in undiagnosed individuals with high ADHD traits (eye movements, Panagiotidi et al., 2017; neural activity, Kitching et al., 2017).

The pathophysiology of ADHD is not completely understood but previous research has provided evidence of abnormalities in specific neurotransmitters, particularly the dopaminergic system (Tripp & Wickens, 2009; Swanson et al., 2007). In addition to their widely discussed roles in reinforcement learning, dopaminergic neurons are also involved in perception and response to sensory stimuli (Overton et al., 2014; Servan-Schreiber & Cohen, 1990; Cohen et al., 2002; Schultz, 2007). As a result, abnormalities in perceptual functions in ADHD could be expected. Findings regarding sensory processing abnormalities are consistent with a recent theory suggesting that a deficit in sensory gating capacity could explain some of the core deficits found in ADHD (Sable et al., 2012; Micoulaud-Franchi, et al., 2015; Micoulaud-Franchi et al., 2016). Sensory gating refers to a normal physiological process, which allows individuals to filter or gate irrelevant cognitive and sensory processes. Abnormalities in sensory gating is also consistent with other theories of ADHD, which propose that areas involved in sensory processing, such as the superior colliculus (SC), are implicated in ADHD (Overton, 2008; Panagiotidi, Overton, & Stafford, 2016; 2017; Castellanos & Proal, 2012). Preliminary evidence seems to support this assumption and suggests that there is a link between sensory processing abnormalities and ADHD symptomatology (Cermak 1988; Panagiotidi, Overton, & Stafford, 2018; Engel-Yeger & Ziv-

On, 2011). More specifically, differences between ADHD and control groups have been reported in multiple modalities such as vision (Gonen-Yaacovi et al., 2016; Panagiotidi et al., 2017; Martin et al., 2008; Stevens et al., 2012; Mihali et a., 2018; McAvinue et al., 2012), touch (Hern & Hynd, 1992), smell (Romanos et al., 2008), and hearing (Ghanizadeh, 2010; Gonen-Yaacovi et al., 2016).

Perceptual abnormalities have also been linked to ADHD and could explain some of the higher cognitive function deficits found in the disorder (Micoulaud-Franchi et al., 2016; Sable et al., 2012; Gonen-Yaacovi et al., 2016). Studies have found that adults with ADHD, as well as neurotypical individuals with high levels of ADHD symptoms, report more atypical sensory processing symptoms (Panagiotidi et al., 2018; Bijlenga et al., 2017). More evidence supporting this comes from studies looking at differences in ADHD presentations and sensory abnormalities, which show that sensory issues are found across all presentations of the condition (Engel-Yeger & Ziv-On, 2011).

Previous research has linked SPS to increased emotional responsivity (Avecedo et al., 2014; Aron et al., 2012; Jagiellowicz et al., 2016). Individuals with higher scores on the HSPS tend to show pay more attention to subtle stimuli, and are more reactive to emotional stimuli (Aron et al., 2012; Jagiellowicz et al., 2016). ADHD is seen as a disorder affecting an individual's ability to regulate their behavior. Emotion regulation abnormalities have been observed in children with ADHD (Barkley, 1997). In particular, a study by Musser at al. (2011) found that when exposed to stimuli of negative and positive valence, children with ADHD displayed a stable pattern of elevated parasympathetic activity compared to controls. ADHD has also been linked to emotional reactivity and with a reduced ability to inhibit and recognise emotions (Jensen & Rosen, 2004). Consequently, emotional reactivity could potentially lead to the core symptoms of impulsivity, inattention, and hyperactivity associated with the disorder.

It is worth noting that the majority of published papers on this topic have used self-reports or parent/guardian ratings (Engel-Yeger & Ziv-On, 2011; Panagiotididi et al., 2018; Bijlenga et al., 2017; Hern & Hynd, 1992; Ghanizadeh, 2010) to measure the sensory sensitivity and evidence from empirical studies is scarce (Martin et al., 2008; Panagiotidi et al., 2017: Romanos et al., 2008). In addition to this, as pointed out by a recent review of perceptual abnormalities in ADHD (Fuermaier et al., 2018), there is great inconsistency among published studies. Several factors, such as methodology, stimulant medication use, and symptoms of attention, might have contributed to those differences. In particular, the most commonly used medication for ADHD, methylphenidate (Cortese et al., 2018), has been shown to affect sensory processing (Navarra et al., 2017). Using the spectrum approach in ADHD studies could potentially allow us to control for the effect of medication.

Even though sensory sensitivity abnormalities are often reported in individuals with ADHD and they have been found to affect one's levels of life satisfaction and overall mental health (Booth, Standage, & Fox, 2015), the link between sensory sensitivity and ADHD traits has been largely ignored by previous research. The main aim of this study was to investigate the relationship between sensory sensitivity and ADHD traits in the general population. A non-clinical population was chosen as a way to control for potential effects of ADHD medication. First, we examined the factor structure of the HSPS to determine whether a three, a two, or a one factor solution provided the best fit to the data. Second, we examined the relationship between level of ADHD traits and self-reported sensitivity to sensory stimuli. We hypothesized that there would be a positive correlation between level of ADHD traits and scores on HSPS.

2. Methods

2.1 Participants

274 participants (203 female,) were recruited from the volunteers' list of the University of

Sheffield. This list included a number of current students, university employees, and alumni. The age of the participants varied from 18 to 69 (*M*=33.16, *SD*= 13.5). Only native or excellent English speakers were eligible for the study. Due to the nature of the study only individuals with normal or corrected-to-normal vision and hearing were recruited. This was established by stating that only participants with normal vision and hearing were eligible to take part in the study and including a number of relevant screening questions at the start of the survey. Due to the nature of the study (i.e. online), we could not test hearing and visual acuity of the participants.

2.2 Materials

ADHD-like traits were measured with the Adult ADHD Self-Report Scale (ASRS; Kessler et al. 2005). The ASRS is a widely used instrument consisting of the 18 DSM-IV-TR (American Psychiatric Association, 2000) criteria for ADHD measuring inattention (e.g. "How often do you have trouble wrapping up the final details of a project, once the challenging parts have been done?") and hyperactivity/impulsivity ("How often do you have difficulty waiting your turn in situations when turn taking is required?"). Scores obtained in the ASRS are highly predictive of ADHD symptoms (Adler et al., 2006). Higher ASRS scores reflect a higher level of ADHD traits. The two ASRS subscales had satisfactory internal consistency (Cronbach's alpha); inattention subscale (.77), impulsivity subscale (.76), total ASRS (.93). These values were similar to values reported in earlier studies using the ASRS in a general population (Reuter et al., 2006; Panagiotidi et al., 2018; Bijlenga et al., 2017).

The Highly Sensitive Person Scale (HSPS; Aron & Aron, 1997) was used to measure the sensory sensitivity. The scale consists 27 items, which measure various aspects of SPS (e.g., "I am easily overwhelmed by strong sensory input", "I am made uncomfortable by loud noises"). Each item is rated from 0 to 7 ('0' = 'strongly disagree';'7' = 'strongly agree'). Higher SPS scores indicate higher levels of sensory sensitivity. SPS was considered as continuous variable in our study as recommended in previous research (Benham, 2006; Boterberg & Warreyn, 2016). In our study total HSPS scores had an internal consistency of .92.

Demographics for each participant were also recorded. Additionally, a number of questions assessing the presence of pre-existing mental health conditions (ADHD, autism, other) were included.

2.3 Procedure

An online study was conducted; invitation by email were sent to the participants providing them with a link to a Qualtrics survey, an online data collection platform.

2.4 Statistical Analysis

Data were analysed using SPSS 25 software. Gender differences between ASRS scores, Inattention and Hyperactivity ASRS subscales and HSPS scores were analysed with independent samples T-test. Correlations amongst ASRS, HSPS scores, and age were examined by Pearson correlation analysis. Finally, we conducted an exploratory factor analysis (EFA) to identify the factors underlying participants' responses in the ASRS and the HSPS scales.

3. Results

3.1 Demographics

The mean age of the participants was 33.65 (SD = 13.97, Min = 18, Max = 69). Most participants taking part in the study identified as female (74%) and 1.3% identified as non-binary/other. The majority of the participants who completed the study were British (74.3%). The level of education of the participants was also recorded with 31 % stating that they had or were studying towards a Bachelor's Degree, 28% a Master's Degree, 10% a Doctorate Degree, and the rest reported not having a degree.

3.2 Factor exploration of the HSPS

We applied a principal components analysis with oblimin oblique rotation to the set of 27 items. The Scree test indicated that a one component solution was optimal (eigenvalue: 9.21) and accounted for 34.13 of the variance. Our own exploratory factor analysis supported Aron & Aron's (1997) initial conception of SPS as a unidimensional measure. Consequently, we analysed the results using HSPS total scores and not subscales.

3.3 Primary Results

ASRS scores were between 4 and 55 and the mean score was 30.7 (*SD* = 8.83, *Min*= 4, *Max*= 55). The distribution of the scores is presented on Figure 1. The mean score on the inattention subscale was 17.1 (*SD* = 5.1, *Min*= 1 , *Max*= 33) and the hyperactivity subscale 13.64 (SD = 5.4, *Min*=2 , *Max*=29). Inattention and hyperactivity subscales were positively correlated with each other, $r(274) = .41$ ($p<.01$). The mean score on the HSPS was 112.9 (*SD* = 26.7, *Min* = 34, *Max* = 177). The Kolmogorov-Smirnov test statistic ($p>.05$) suggested that both questionnaires were normally distributed. Gender differences were examined but t-tests showed no significant differences in the ASRS scores between males (*M* = 29.43, *SD* = 6.8, *Min*=7 , *Max*=45) and females (*M* = 31.1, *SD* = 9.2, *Min*=8 , *Max*=55), t(272) =-1.3 ($p>.21$). Females (*M* = 116, *SD* = 2.6, *Min*=38 , *Max*=177) had significantly higher scores on the HSPS than males (*M* = 104.9, *SD* = 2, *Min*=70, *Max*=160), $t(272) = -2.97$, $p< .001$. A negative relationship was found between age and HSPS scores, $r(274) = -.2$ ($p<.01$).

3.4 Sensory sensitivity and ADHD traits

Self-reported HSP symptoms were positively associated with ADHD traits. In particular, we found a positive correlation between overall ASRS scores and HSPS scores (*r* (274) =.42, *p*<.001, Figure 2). The relationship between the two ASRS subscales and HSPS was also examined. A positive association was found between HSPS and both Inattention (*r* (274) =.404, *p*<.001) and Hyperactivity (*r* (274) =.304, *p*<.001), suggesting that individuals with higher ASRS scores reported higher levels of sensitivity to internal and external stimuli. Since gender differences between HSPS scores and gender were found, we split participants by gender and investigated the relationship between HSPS and ASRS scores. A positive correlation between HSPS and total ASRS scores was found for both female (*r* (202) =.48, *p*<.001) and male participants (*r* (67) =.548, *p*<.001).

A multiple linear regression was calculated to predict HSPS scores based on ASRS scores and age. A significant regression equation was found F(2,273) = 32.3, $p < .001$, indicating that both ASRS scores and age are good predictors of HSPS scores. The model accounted for 20% of the variability, as indexed by the R^2 statistic. Overall ASRS scores had the strongest relationship to sensory sensitivity, as indexed by a β value of .4 (p<.001). The β value for age was -.13 (p<.05).

EFA was used to investigate potential factors underlying participants' responses in the ASRS and the HSPS. The Kaiser-Meyer-Olkin measure of sampling adequacy was 0.842, which is above the recommended value of 0.6, and Bartlett's test of sphericity was also significant ($\chi2$ (990) = 5834.3, $p < 0.01$). These results suggested that factor analysis could be conducted in the existing dataset. The analysis revealed two factors that explained 31.45% of the variance. Factor 1 consisted of items from both scales and was labeled ADHD + Sensory Sensitivity. Factor 2 consisted only items from the ASRS scale and was labeled ADHD. There was a positive correlation between the two factors ($r = 0.3$, $p < 0.01$). The factor loading matrix is presented in Table 1.

4. Discussion

This study examined the relationship between ADHD traits and sensory sensitivity, measured using the HSPS. Our findings indicate that self-reported ADHD traits are associated with sensory sensitivity. Overall ASRS scores and age predicted 20% of the variance of sensory sensitivity symptoms; younger individuals with higher level of ADHD traits were more likely to report increased sensitivity to sensory stimuli. Furthermore, both subscales of the ASRS were associated with increased levels of SPS.

A few possible explanations are being proposed for our findings. Increased emotional responsivity is a characteristic of SPS (Avecedo et al., 2014; Aron et al., 2012). A positive relationship has been previously found between emotional sensitivity and impulsivity (Kim et al., 2016). Impulsivity is one of the main and most disruptive symptoms in individuals with ADHD, as is distractibility. Previous research on individuals with higher scores on the HSPS has showed that they pay more attention to subtle stimuli and are more reactive to emotional stimuli (Aron et al., 2012; Jagiellowicz et al., 2016). Being more reactive to external stimuli could lead to inattention, one of the main symptoms of ADHD (Fassbender et al., 2009). Previous research has shown that abnormalities in sensory modulation are associated with impairments in attention and impulsivity (Ayres, 1972). To further understand the role of sensory sensitivity in ADHD, future studies should examine the relationship between SPS and ADHD symptom severity in a clinical population.

The relationship between sensory sensitivity and ADHD traits offer further support for a more central role of sensory processing in ADHD symptomatology. This evidence is in line with sensory gating theories of ADHD (Sable et al., 2012; Micoulaud-Franchi, et al., 2015; Micoulaud-Franchi et al., 2016) and theories proposing that ADHD symptomatology is related to abnormalities in brain areas, which play a role in sensory processing such as the superior colliculus (Overton, 2008; Panagiotidi et al., 2016; 2017; Dommett, Overton, & Greenfield, 2009). This is consistent with neuroimaging studies that have identified higher resting-state activity in lower – level sensory areas in individuals with ADHD compared to controls (Tian et al., 2008), and a positive relationship between levels of inattention traits and activity in the SC during a visual attention task in a non-clinical population (Kitching et al., 2017). Evidence for sensory sensitivity in ADHD could also be related to the default-mode interference hypothesis in ADHD (Sonuga-Barke et al., 2007), which supports that disturbances in the default mode network functioning in the condition result in attentional deficits. It is worth noting that the combined ASRS and HSPS factor we found in our study included items from both ADHD subscales. The above findings suggest that atypical sensory processing could be part of the ADHD phenotype and should have a more central role in future ADHD studies.

Our findings have implications not only in ADHD diagnosis and assessment but also in treatment interventions. This is of particular importance considering that the long-term effects of ADHD medication prescribed to the majority of ADHD patients are still unknown. If sensory sensitivity leads to inattention and impulsivity, it would be possible to reduce or treat some of the symptoms of ADHD by focusing on sensory processing. Sensory processing interventions are common in individuals with autism and have a positive effect on reducing symptoms (Schaaf et al., 2014). Future research could examine whether a sensory based intervention could reduce ADHD symptoms.

Age was negatively associated with sensory sensitivity in our study. This is consistent with previous research that has showed that age needs to be taken into account when evaluating sensory processing (Cheung & Siu, 2009; Dunn & Westman, 1997). In particular, Kern and colleagues (2007) found that sensory sensitivities decrease with age. Future longitudinal studies should attempt to examine the relationship between ADHD and SPS.

Previous literature is inconsistent about the psychometric properties of the HSPS. More specifically, the inventory was originally designed to reflect the SPS construct as one dimension. A number of studies, however, have identified multiple factor solutions (Smolewska et al., 2006; Evans & Rothbart, 2008), suggesting that SPS reflects different constructs. Our analysis showed that a one factor solution provided the best fit to the data. This supported Aron & Aron's (1997) original research suggesting that SPS is a unidimensional construct.

A number of limitations can be identified in our study. First, our findings are based on self-reports, which are prone to biases. Future studies should attempt to empirically test sensory processing in ADHD by employing physiological measures of autonomic nervous system function or neuroimaging techniques. Furthermore, our study did not control for a number of variables that could be associated with HSPS (e.g. autistic symptoms). This should be examined in future research in order to clearly identify the relationship between ADHD traits and sensory sensitivity.

Another limitation of our study was the overrepresentation of females in our sample. ADHD in often considered a male dominant disorder. However, most studies measuring ADHD traits in adults report no significant difference between male and female scores (e.g., de Zwaan et al., 2012; Das et al., 2012). Additionally, research on adult populations have found a significantly increased female-to-male ratio in adults with ADHD (Huang et al., 2016). The difference could be due to presentation differences between males and females. In particular, ADHD in females is often associated with internalizing symptoms, which are less likely to lead to a diagnosis in childhood (Quinn & Madhoo, 2014; Berry at al., 1985).

The main focus of our study was ADHD traits and the relationship between attention and hyperactivity related symptomatology and sensory sensitivity. A non-clinical population was recruited in this study so our results should be interpreted with caution. It is worth noting that the scale employed to measure ADHD traits is a well-studied screening instrument for use in the general population with good structural and external validity (Reuter et al., 2006). Future research should attempt to replicate these findings in a clinical sample. Furthermore, sensory sensitivity appears to be commonly reported in a number of disorders, such as schizophrenia, depression, and anxiety (Liss et al., 2009). These constructs were beyond the scope of this work. Future studies should attempt to investigate potential differences in sensory sensitivity profiles in ADHD and other disorders, such as autism.

5. Conclusion

The present study examined the relationship between SPS and ADHD traits in a non-clinical population. ADHD symptomatology was positively associated with self-reported levels of sensory sensitivity. Our findings provide further evidence for abnormal sensory processing in ADHD and the provide insight into the underlying mechanisms of this condition. Our study is the first one to report correlation between sensory sensitivity and ADHD traits in a general population. The current findings build on the growing literature suggesting that abnormal sensory processing could be a core feature of ADHD (Bijlenga et al., 2017; Panagiotidi et a., 2018).

References

Adler, L. A., Spencer, T., Faraone, S. V., Kessler, R. C., Howes, M. J., Biederman, J., & Secnik, K. (2006). Validity of pilot Adult ADHD Self-Report Scale (ASRS) to rate adult ADHD symptoms. *Annals of Clinical Psychiatry*, *18*(3), 145-148.

American Psychiatric Association. (2013). *Diagnostic and statistical manual of mental disorders: DSM-5*. Washington, D.C: American Psychiatric Association.

Aron, E. N., & Aron, A. (1997). Sensory-processing sensitivity and its relation to introversion and emotionality. *Journal of personality and social psychology*, *73*(2), 345

Aron, E. N., Aron, A., & Jagiellowicz, J. (2012). Sensory processing sensitivity: A review in the light of the evolution of biological responsivity. *Personality and Social Psychology Review*, *16*(3), 262-282.

Acevedo, B. P., Aron, E. N., Aron, A., Sangster, M. D., Collins, N., & Brown, L. L. (2014). The highly sensitive brain: an fMRI study of sensory processing sensitivity and response to others' emotions. *Brain and behavior*, *4*(4), 580-594.

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

Barkley, R. A. (1997). Behavioral inhibition, sustained attention, and executive functions: constructing a unifying theory of ADHD. *Psychological bulletin*, 121(1), 65.

Benham, G. (2006). The highly sensitive person: Stress and physical symptom reports. *Personality and individual differences*, *40*(7), 1433-1440.

Berry, C. A., Shaywitz, S. E., & Shaywitz, B. A. (1985). Girls with attention deficit disorder: A silent minority? A report on behavioral and cognitive characteristics. *Pediatrics*, *76*(5), 801-809.

Booth, C., Standage, H., & Fox, E. (2015). Sensory-processing sensitivity moderates the association between childhood experiences and adult life satisfaction. *Personality and Individual Differences*, *87*, 24–29. https://doi.org/10.1016/j.paid.2015.07.020.

Boterberg, S., & Warreyn, P. (2016). Making sense of it all: The impact of sensory processing sensitivity on daily functioning of children. *Personality and Individual Differences*, *92*, 80-86.

Castellanos, F. X., & Proal, E. (2012). Large-scale brain systems in ADHD: beyond the prefrontal–striatal model. *Trends in cognitive sciences*, *16*(1), 17-26.

Cermak, S. (1988). The relationship between attention deficit and sensory integration disorders–Part I. *Sensory Integration Special Interest Section Newsletter*, 11(2), 1-4.

Chamberlain, S. R., Ioannidis, K., Leppink, E. W., Niaz, F., Redden, S. A., & Grant, J. E. (2017). ADHD symptoms in non-treatment seeking young adults: relationship with other forms of impulsivity. *CNS spectrums*, *22*(1), 22-30.

Cheung, P. P. P., & Siu, A. M. H. (2009). A comparison of patterns of sensory processing in children with and without developmental disabilities. *Research in Developmental Disabilities*, 30(6), 1468–1480. doi:10.1016/j.ridd.2009.07.009.

Cohen, J. D., Braver, T. S., & Brown, J. W. (2002). Computational perspectives on dopamine function in prefrontal cortex. *Current opinion in neurobiology*, *12*(2), 223-229.

Crosbie, J., Arnold, P., Paterson, A., Swanson, J., Dupuis, A., Li, X., ... & Schachar, R. J. (2013). Response inhibition and ADHD traits: correlates and heritability in a community sample. *Journal of Abnormal Child Psychology*, *41*(3), 497-507.

Das, D., Cherbuin, N., Butterworth, P., Anstey, K. J., & Easteal, S. (2012). A population-based study of attention deficit/hyperactivity disorder symptoms and associated impairment in middle-aged adults. *PloS one*, *7*(2).

de Zwaan, M., Gruß, B., Müller, A., Graap, H., Martin, A., Glaesmer, H., ... & Philipsen, A. (2012). The estimated prevalence and correlates of adult ADHD in a German community sample. *European archives of psychiatry and clinical neuroscience*, *262*(1), 79-86.

Dommett, E. J., Overton, P. G., & Greenfield, S. A. (2009). Drug therapies for attentional disorders alter the signal-to-noise ratio in the superior colliculus. *Neuroscience*, *164*(3), 1369-1376.

Dunn, W. (1999). The Sensory Profile. San Antonio, TX: PsychCorp.

Dunn, W, & Westman, K. (1997). The sensory profile: the performance of a national sample of children without disabilities. *The American Journal of Occupational Therapy*, 51(1), 25–34.

Engel-Yeger, B., & Ziv-On, D. (2011). The relationship between sensory processing difficulties and leisure activity preference of children with different types of ADHD. *Research in developmental disabilities*, *32*(3), 1154-1162.

Engel-Yeger, B., & Dunn, W. (2011). The relationship between sensory processing difficulties and anxiety level of healthy adults. *The British Journal of Occupational Therapy*, 74(5), 210–216. doi:10.4276/030802211X13046730116407.

Evans, D. E., & Rothbart, M. K. (2008). Temperamental sensitivity: Two constructs or one?. Personality and Individual Differences, 44(1), 108-118.

Faraone, S. V., Sergeant, J., Gillberg, C., & Biederman, J. (2003). The worldwide prevalence of ADHD: is it an American condition. *World psychiatry*, 2(2), 104-113.

Faraone, S. V., & Biederman, J. (2005). What is the prevalence of adult ADHD? Results of a population screen of 966 adults. *Journal of attention disorders*, 9(2), 384-391.

Fassbender, C., Zhang, H., Buzy, W. M., Cortes, C. R., Mizuiri, D., Beckett, L., & Schweitzer, J. B. (2009). A lack of default network suppression is linked to increased distractibility in ADHD. *Brain research*, *1273*, 114-128.

Fuermaier, A. B., Hüpen, P., De Vries, S. M., Müller, M., Kok, F. M., Koerts, J., ... & Tucha, O. (2018). Perception in attention deficit hyperactivity disorder. *ADHD Attention Deficit and Hyperactivity Disorders*, *10*(1), 21-47.

Ghanizadeh, A. (2009). Screening signs of auditory processing problem: does it distinguish attention deficit hyperactivity disorder subtypes in a clinical sample of children?. *International journal of pediatric otorhinolaryngology*, *73*(1), 81-87.

Ghanizadeh, A. (2010). Visual fields in children with attention-deficit/hyperactivity disorder before and after treatment with stimulants. *Acta Ophthalmologica*, 88(2), e56. doi:10.1111/j.1755-3768.2009.01520.x

Gonen-Yaacovi, G., Arazi, A., Shahar, N., Karmon, A., Haar, S., Meiran, N., & Dinstein, I. (2016). Increased ongoing neural variability in ADHD. *Cortex*, *81*, 50-63.

Greven, C. U., van der Meer, J. M., Hartman, C. A., Lappenschaar, M. G., Buitelaar, J. K., & Rommelse, N. N. (2018). Do high and low extremes of ADHD and ASD trait continua represent maladaptive behavioral and cognitive outcomes? A population-based study. *Journal of attention disorders*, *22*(10), 924-932.

Greven, C. U., Merwood, A., van der Meer, J. M., Haworth, C. M., Rommelse, N., & Buitelaar, J. K. (2016). The opposite end of the attention deficit hyperactivity disorder continuum: genetic and environmental aetiologies of extremely low ADHD traits. *Journal of Child Psychology and Psychiatry*, *57*(4), 523-531.

Hern, K. L., & Hynd, G. W. (1992). Clinical differentiation of the attention deficit disorder subtypes: do sensorimotor deficits characterize children with ADD/WO? *Archives of Clinical Neuropsychology*, 7(1), 77–83.

Hetrick, W. P., Erickson, M. A., & Smith, D. A. (2010). Phenomenological dimensions of sensory gating. *Schizophrenia bulletin, 38*(1), 178-191.

Hudziak, J. J., Achenbach, T. M., Althoff, R. R., & Pine, D. S. (2007). A dimensional approach to developmental psychopathology. *International journal of methods in psychiatric research*, 16(S1).

Jagiellowicz, J., Aron, A., & Aron, E. N. (2016). Relationship between the temperament trait of sensory processing sensitivity and emotional reactivity. *Social Behavior and Personality: an international journal*, *44*(2), 185-199.

Jagiellowicz, J., Xu, X., Aron, A., Aron, E., Cao, G., Feng, T., & Weng, X. (2010). The trait of sensory processing sensitivity and neural responses to changes in visual scenes. *Social cognitive and affective neuroscience*, *6*(1), 38-47.

Jensen, S. A., & Rosen, L. A. (2004). Emotional reactivity in children with attention-deficit/hyperactivity disorder. *Journal of Attention Disorders*, *8*(2), 53-61.

Kern, J. K., Trivedi, M. H., Grannemann, B. D., Garver, C. R., Johnson, D. G., Andrews, A. A., ... & Schroeder, J. L. (2007). Sensory correlations in autism. *Autism*, 11(2), 123-134.

Kessler RC, Adler L, Ames M, Demler O, Faraone S, Hiripi E, . . . Walters EE (2005). The World Health Organization adult ADHD self-report scale (ASRS): a short screening scale for use in the general population. *Psychological Medicine*, 245–256.

Kim, J. S., Kim, S., Jung, W., Im, C. H., & Lee, S. H. (2016). Auditory evoked potential could reflect emotional sensitivity and impulsivity. *Scientific reports*, *6*, 37683.

Kitching, Rebecca Elizabeth, Overton, Paul, Panagiotidi, Maria, Billington, Jac, Morland, Antony and Stafford, Tom (2017) *Evidence for hyperactivity in the superior* *colliculus in Attention-Deficit/Hyperactivity Disorder.* In: 6th World Congress on ADHD, 20-23/04/17, Vancouver, Canada.

Liss, M., Mailloux, J., & Erchull, M. J. (2008). The relationships between sensory processing sensitivity, alexithymia, autism, depression, and anxiety. *Personality and individual differences*, *45*(3), 255-259.

Martin, L., Aring, E., Landgren, M., Hellstrom, A, & Andersson Gronlund, M. (2008). Visual fields in children with attention-deficit / hyperactivity disorder before and after treatment with stimulants. *Acta Ophthalmologica*, 86(3), 259–264.

Martin, J., Hamshere, M. L., Stergiakouli, E., O'Donovan, M. C., & Thapar, A. (2014). Genetic risk for attention-deficit/hyperactivity disorder contributes to neurodevelopmental traits in the general population. *Biological psychiatry*, *76*(8), 664-671.

McAvinue, L. P., Vangkilde, S., Johnson, K. A., Habekost, T., Kyllingsbæk, S., Bundesen, C., & Robertson, I. H. (2015). A componential analysis of visual attention in children with ADHD. *Journal of attention disorders*, *19*(10), 882-894.

Micoulaud-Franchi, J. A., Lopez, R., Cermolacce, M., Vaillant, F., Péri, P., Boyer, L., ... & Vion-Dury, J. (2016). Sensory gating capacity and attentional function in adults with

ADHD: a preliminary neurophysiological and neuropsychological study. *Journal of attention disorders*, 1087054716629716.

Micoulaud-Franchi, J. A., Lopez, R., Vaillant, F., Richieri, R., El-Kaim, A., Bioulac, S., ... & Lancon, C. (2015). Perceptual abnormalities related to sensory gating deficit are core symptoms in adults with ADHD. *Psychiatry research*, *230*(2), 357-363.

Mihali, A., Young, A. G., Adler, L. A., Halassa, M. M., & Ma, W. J. (2018). A Low-Level Perceptual Correlate of Behavioral and Clinical Deficits in ADHD. *Computational psychiatry (Cambridge, Mass.)*, *2*, 141–163.

Musser, E. D., Backs, R. W., Schmitt, C. F., Ablow, J. C., Measelle, J. R., & Nigg, J. T. (2011). Emotion regulation via the autonomic nervous system in children with ADHD. *Journal of abnormal child psychology*, *39*(6), 841-852.

Navarra, R. L., Clark, B. D., Gargiulo, A. T., & Waterhouse, B. D. (2017). Methylphenidate enhances early-stage sensory processing and rodent performance of a visual signal detection task. *Neuropsychopharmacology*, *42*(6), 1326-1337.

Overton, P. G. (2008). Collicular dysfunction in attention deficit hyperactivity disorder. *Medical hypotheses*, *70*(6), 1121-1127.

Overton, P. G., Vautrelle, N., & Redgrave, P. (2014). Sensory regulation of dopaminergic cell activity: phenomenology, circuitry and function. *Neuroscience*, *282*, 1-12.

Panagiotidi, M., Overton, P. G., & Stafford, T. (2018). The relationship between ADHD traits and sensory sensitivity in the general population. *Comprehensive psychiatry*, *80*, 179-185.

Panagiotidi, M., Overton, P., & Stafford, T. (2017). Increased microsaccade rate in individuals with ADHD traits. *Journal of Eye Movement Research*, 10(1).

Panagiotidi, M., Overton, P. G., & Stafford, T. (2016). Attention-Deficit Hyperactivity Disorder-Like Traits and Distractibility in the Visual Periphery. Perception, 0301006616681313.

Panagiotidi, M., Overton, P. G., & Stafford, T. (2017). Co-Occurrence of ASD and ADHD Traits in an Adult Population. *Journal of Attention Disorders*, 1087054717720720. https://doi.org/10.1177/1087054717720720

Polner, B., Aichert, D., Macare, C., Costa, A., & Ettinger, U. (2015). Gently restless: association of ADHD-like traits with response inhibition and interference control. *European archives of psychiatry and clinical neuroscience*, 265(8), 689-699.

Quinn, P. O., & Madhoo, M. (2014). A review of attention-deficit/hyperactivity disorder in women and girls: uncovering this hidden diagnosis. *The primary care companion for CNS disorders*, *16*(3).

Reuter, M., Kirsch, P., & Hennig, J. (2006). Inferring candidate genes for attention deficit hyperactivity disorder (ADHD) assessed by the World Health Organization Adult ADHD Self-Report Scale (ASRS). *Journal of neural transmission*, *113*(7), 929-938.

Reynolds, S., Lane, S. J., & Gennings, C. (2010). The moderating role of sensory Overresponsivity in HPA activity: a pilot study with children diagnosed with ADHD. *Journal of Attention Disorders*, 13(5), 468–478. doi:10.1177/1087054708329906.

Robertson, A. E., & Simmons, D. R. (2013). The relationship between sensory sensitivity and autistic traits in the general population. *Journal of Autism and Developmental disorders*, 43(4), 775-784.

Romanos, M., Renner, T. J., Schecklmann, M., Hummel, B., Roos, M., von Mering, C., … Gerlach, M. (2008). Improved odor sensitivity in attention-deficit/hyperactivity disorder. *Biological Psychiatry*, 64(11), 938–940. doi:10.1016/j.biopsych.2008.08.013.

Rosen, S. (2003). Auditory processing in dyslexia and specific language impairment: Is there a deficit? What is its nature? Does it explain anything?. *Journal of phonetics*, *31*(3), 509-527.

Sable, J. J., Kyle, M. R., Knopf, K. L., Schully, L. T., Brooks, M. M., Parry, K. H., ... & Thompson, I. A. (2012). The Sensory Gating Inventory as a potential diagnostic tool for attention-deficit hyperactivity disorder. *ADHD Attention Deficit and Hyperactivity Disorders*, *4*(3), 141-144.

Schaaf, R. C., Benevides, T., Mailloux, Z., Faller, P., Hunt, J., van Hooydonk, E., ... & Kelly, D. (2014). An intervention for sensory difficulties in children with autism: A randomized trial. *Journal of Autism and Developmental Disorders*, *44*(7), 1493-1506.

Schultz, W. (2007). Multiple dopamine functions at different time courses. *Annu. Rev. Neurosci.*, *30*, 259-288.

Sergeant, J. A., Piek, J. P., & Oosterlaan, J. (2006). ADHD and DCD: A relationship in need of research. *Human movement science*, 25(1), 76-89.

Servan-Schreiber, D., Printz, H., & Cohen, J. D. (1990). A network model of catecholamine effects: gain, signal-to-noise ratio, and behavior. *Science*, *249*(4971), 892-895.

Shochat, T., Tzischinsky, O., & Engel-Yeger, B. (2009). Sensory hypersensitivity as a contributing factor in the relation between sleep and behavioral disorders in normal schoolchildren. *Behavioral Sleep Medicine*, *7*(1), 53-62.

Smolewska, K. A., McCabe, S. B., & Woody, E. Z. (2006). A psychometric evaluation of the Highly Sensitive Person Scale: The components of sensory-processing sensitivity and their relation to the BIS/BAS and "Big Five". *Personality and Individual Differences*, *40*(6), 1269-1279.

Sonuga-Barke, E. J., & Castellanos, F. X. (2007). Spontaneous attentional fluctuations in impaired states and pathological conditions: a neurobiological hypothesis. *Neuroscience & Biobehavioral Reviews*, *31*(7), 977-986.

Stevens, A. A., Maron, L., Nigg, J. T., Cheung, D., Ester, E. F., & Awh, E. (2012). Increased sensitivity to perceptual interference in adults with attention deficit hyperactivity disorder. *Journal of the International Neuropsychological Society*, *18*(3), 511-520.

Tian, L., Jiang, T., Liang, M., Zang, Y., He, Y., Sui, M., & Wang, Y. (2008). Enhanced resting-state brain activities in ADHD patients: a fMRI study. *Brain and Development*, *30*(5), 342-348.f

Tripp, G., & Wickens, J. R. (2009). Neurobiology of ADHD. *Neuropharmacology*, *57*(7-8), 579-589.