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Relating Sensory Sensitivity and Repetitive Behaviours in Autism Spectrum Disorders

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Abstract

The heterogenous expression of Autism Spectrum Disorder (ASD) complicates our etiological understanding of the disorder. By focusing on the most commonly-reported symptom of ASD, namely sensory processing dysfunction, this project attempts to determine the underlying factors of ASD-related restricted interests and repetitive behaviours (RRBs). The specific aims of this project are to examine the relationship between sensory sensitivity and RRBs and to compare current questionnaire measures of sensory processing issues to more objective measures, specifically, a psychophysical behavioural task of visual sensitivity. A positive relationship was found between sensitivity and RRBs in both autistic children and their TD peers. Furthermore, both behavioural and self-reported sensitivity are related to and predict RRBs in TD adults. Overall, the results suggest that sensitivity is related to RRBs but that our current measures of sensory sensitivity, namely questionnaire measures, may not be measuring sensitivity *per se*, but instead measure sensory reactivity.

Keywords

Autism, Autism Spectrum Disorder, ASD, restricted interests, repetitive behaviours, sensory processing, hypersensitivity, sensitivity.

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List of Abbreviations

Abbreviation	Meaning
°	Degrees
ADOS	Autism Diagnostic Observation Schedule
ASD	Autism Spectrum Disorder
CA	Chronological Age
CI	Confidence interval
CPD	Cycles per degree
CRI	Childhood Routines Inventory
DBC	Developmental Behaviour Checklist
E/I	Excitatory and inhibitory
F	F distribution value
GABA	gamma-Aminobutyric acid
Hz	Hertz
IQ	Intelligence Quotient
M	Mean
MA	Mental age
Mdn	Median
ms	Millisecond(s)
N	Number of participants
p	Probability
pr	Partial correlation
Q	Benjamini-Hochberg false discovery rate
r	Correlation coefficient
R^2	Correlation effect size
RBQ	Repetitive Behaviours Questionnaire
RBS	Repetitive Behaviours Scale
RDoC	Research Domain Criteria
RRBs	Restricted interests and repetitive behaviours

r_s	Correlation coefficient (Spearman Rank Order)
SD	Standard deviation
SP	Sensory Profile
SQ	Sensory Questionnaire
t	Student distribution value
TD	Typically-developing
U	Mann-Whitney value
VABS	Vineland Adaptive Behaviour Scale
WASI	Wechsler Abbreviated Scale of Intelligence
Z	Fisher transformation value
α	Alpha
β	Standardized coefficient
χ	Chi

Chapter 1

1 Introduction

A growing societal concern, the prevalence of Autism Spectrum Disorder (ASD) has nearly doubled in the past ten years. In 2008, the prevalence of ASD was estimated to be one in every 125 children, however, as of the 2018 Autism and Developmental Disabilities Monitoring Report, the number of children diagnosed with ASD has increased to one in every 59 (Baio et al., 2018). Although the prevalence of ASD appears to be continually increasing over the years, our knowledge of the disorder has not kept pace, specifically, we lack a clear understanding of the etiology of the disorder. The growing concern, coupled with the dearth of certainty about the origins of ASD symptomatology, has resulted in a significant push in the scientific community to determine the underlying causes of ASD. Autistic individuals can experience a wide variety of symptoms that have cascading effects throughout development. Deficits in social communication and social interaction often result in complications in educational settings and later occupational opportunities. In addition to problematic social-emotional reciprocity and interpreting nonverbal communication which ultimately result in difficulties developing and maintaining relationships, autistic individuals also display restricted interests and repetitive behaviours (RRBs; Honey, Leekam, Turner, & McConachie, 2007). RRBs vary among autistic children, but a few examples include head banging, full body rocking and twirling, strict routine requirements at school, and extreme interest in electric fans (APA, 2013). These RRBs can be the root of social stigma and exacerbate social interaction and communication difficulties for autistic individuals resulting in social isolation (Durand & Carr, 1987).

There is significant clinical heterogeneity among autistic individuals, further complicating the origin story and our current understanding of the disorder (Georgiades, Szatmari, & Boyle, 2013). Despite the general heterogeneity of the disorder, sensory processing issues are consistently reported in ASD. Indeed, disturbances in sensory processing were described in the first accounts of autism (Kanner, 1943) and currently 90%

of autistic individuals report prominent sensory processing issues (Tomchek & Dunn, 2007). Aligned with the heterogeneity of ASD, the sensory processing issues experienced by autistic individuals take many forms and extend to multiple sensory domains (Baum, Stevenson, & Wallace, 2015). Qualitatively, sensory processing issues in ASD have been described as both hypo and hypersensitivity, and also include both sensory seeking and sensory avoiding behaviours across sensory domains (Al-Heizan, AlAbdulwahab, Kachanathu, & Natho, 2015; Baranek, David, Poe, Stone, & Watson, 2006; Kern et al., 2007; Minshew & Hobson, 2008; Rogers, Hepburn, & Wehner, 2003). Here, hypersensitivity is defined as individual's enhanced ability to detect and perceive a sensory input. Hyposensitivity is an individua's diminished ability to detect and perceive a sensory input. Sensory seeking is any behaviour used to stimulate the senses such as chewing on inedible item, whereas sensory avoiding is any behaviour used to reduce sensory stimulation such as covering one's ears.

Quantitative studies have also reported variation in sensory processing between typically-developing (TD) and autistic participants. Differences have been observed in the simple perception of visual stimuli (Ashwin, Ashwin, Rhydderch, Howells, & Baron-Cohen, 2009; Bertone, Mottron, Jelenic, & Faubert, 2003, 2005; Mottron, Dawson, Soulieres, Hubert, & Burack, 2006; Plaisted, O'Riordan, & Baron-Cohen, 1998) and in the ability to detect slight differences in orientation of a visual stimuli (Bertone et al., 2005). Additionally, autistic individuals tend to perform better at visual search tasks which may suggest a focus on local details opposed to global details (de Jonge, Kemner, & van Engeland, 2006; Jolliffe & Baron-Cohen, 1997; Joseph, Keehn, Connolly, Wolfe, & Horowitz, 2009; Kemner, Van Ewijk, Van Engeland, & Hooge, 2008; O'Riordan & Plaisted, 2001). However, these differences in perception do not always result in better performance on visual tasks, deficits have been observed, most notably in the perception of motions (Bertone et al., 2003) and visuo-spatial processing (Bertone et al., 2005).

Some theories of ASD suggest that these differences in low-level visual processing may explain behavioural, cognitive, and social functioning in ASD, by way of bottom-up processing. Bottom-up processing is cognitive processing that is influenced by the

environment (Eysenck & Keane, 2013). Whereas most individuals appear to show some balance between bottom-up and top-down processing (whereby processing is influenced by prior experience and knowledge), autistic individuals seem to be biased towards bottom-up processing. The differences that occur in autistic individuals attributed to the bottom-up processing bias are captured in the Theory of Enhanced Perceptional Functioning which describes the outperformance of autistic individuals in the detection and discrimination of sensory stimuli compared to TD individuals (Mottron et al., 2006). This enhanced perceptual ability in the fine sensory details of the world may lead to deficits in the integration of this information into meaningful chunks.

Additional theories such as the Overarousal Hypothesis and the Perceptual Inconsistency Theory suggest that restricted interests and repetitive behaviours may be due to overwhelming sensory input to a hypersensitive sensory processing system (Hutt, Hutt, Lee, & Ounsted, 1964). According to these two theories, sensory processing issues may contribute many diagnostic aspects of ASD. The purpose of the current project is to test these theories and compare varying assessment methods of sensory processing in autistic and TD participants and relate these issues to RRBs. These aims were met through two subsequent studies, the first of which used qualitative reports of sensory processing and RRBs and correlated these two symptoms in autistic and TD children. The second project utilized quantitative measures of sensory processing to address the inherent limitations of qualitative data and compares these two methods in relation to RRBs in TD adults. Overall, this project aims to assess our current methods of measuring sensory processing and current understanding of these issues in ASD in relation to other autistic symptoms. This knowledge may in turn improve our knowledge of autistic symptomatology and how to treat sensory processing issues in ASD.

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Chapter 2

2 Experiment I – Sensory hypersensitivity predicts repetitive behaviours in autistic and typically-developing children

Autism Spectrum Disorder (ASD) is characterized by difficulties in social communication as well as restricted interests and repetitive behaviours (RRBs). RRBs are diagnostically defined as repetitive, non-functional movements or interests including self-injurious behaviours, stereotyped movements, behaviours involving objects, specific and obsessive interests, and repetitive use of language (Lewis & Bodfish, 1998). Also included under the umbrella of RRBs in the Diagnostic and Statistical Manual of Mental Disorders – Fifth Edition are atypical sensory issues, specifically hypo- and hypersensitivity to sensory input (APA, 2013). Although repetitive behaviours are a critical diagnostic characteristic of ASD, relatively few studies have attempted to account for the variance in these behaviours based on individual differences.

Previous research on repetitive behaviours in children with ASD, however, suggested a link between RRBs and atypical sensory processing, specifically hypersensitivity. Preliminary studies found increased RRBs with increased stimulation from novel toys, unfamiliar people (Hutt & Hutt, 1965), or flickering lights (Colman, Frankel, Ritvo, & Freeman, 1976). A recent series of studies have explored the connection between sensory processing and RRBs. The majority of these studies measured sensory processing with one of the many versions of the Sensory Profile (SP; (Dunn, 2014)) and related sensory processing to various parent-report measures of RRBs.

The first of these studies (Baker, Lane, Angley, & Young, 2008) related sensory processing issues in autistic children (aged 2 to 9 years) to a broad measure of maladaptive behaviours, including RRBs, using the Developmental Behaviour Checklist (DBC; (Brereton, Tonge, Mackinnon, & Einfeld, 2002)) and the Vineland Adaptive Behaviour Scale (VABS; (Perry & Factor, 1989)). Although, these studies used broad measures of sensory processing and maladaptive behaviours and did not specifically examine hypersensitivity or RRBs, the results displayed a positive relationship between

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dysfunctional sensory processing and maladaptive behaviours, in general, laying the necessary groundwork for future work to build upon and test more specific hypotheses on hypersensitivity and RRBs.

A follow-up study provided a more direct measure of RRBs by using the Repetitive Behaviours Scale (RBS; (Bodfish, Symons, & Lewis, 1999)) and compared it to overall sensory dysfunction in autistic children and adolescents aged three to nineteen years (Gabriels et al., 2008). In this study, a significant correlation was observed between the total RBS score and sensory processing such that greater sensory processing issues were associated with increased RRBs. Although this study did focus specifically on RRBs, there still remains the question as to whether the relationship between sensory processing and RRBs would differ if varying types of RRBs were considered individually.

Another study used the RBS to measure RRBs and utilized the subscales to compare specific types of RRBs to sensory processing as measured by the Sensory Questionnaire (SQ; (unpublished)). In a group of children with ASD, a relationship was observed between the SQ composite score and the RBS subscale of stereotypies and compulsions. Furthermore, the results suggested that the expression of RRBs was best predicted by group, age, SQ score, and behavioural regulation (Boyd, McBee, Holtzclaw, Baranek, & Bodfish, 2009). This study utilized a group of typically-developing (TD) controls, however, a direct, between-group comparison was not made, leaving unanswered the question of whether this relationship is specific to individuals with ASD.

These studies have provided further evidence for the relationship between sensory processing and RRBs. In addition to this line of research that began by broadly relating maladaptive behaviours and sensory issues in ASD, and eventually shifted the focus from maladaptive behaviours to RRBs more specifically, a second series of studies shifted from general sensory processing dysfunction towards sensory hypersensitivity. One such study differentiated atypical sensory processing patterns into hyposensitivity and hypersensitivity in autistic children between the ages of eight and sixteen (Chen, Rodgers, & McConachie, 2009). Measures of hypersensitivity, but not hyposensitivity, were significantly related to restricted interests, as measured by the Childhood Routines

Inventory (CRI; (Evans et al., 1997)). Furthermore, hypersensitivity significantly predicted the total number of items endorsed, as well as their frequency and intensity. In addition to isolating *hyper*sensitivity as a correlate of RRBs, this study also examined differences between sensory modalities. A relationship between tactile and auditory/visual sensitivity subscales and the number, frequency, and intensity of CRI items was observed, but no relationship was found with taste/smell sensitivity. This was one of the first studies to isolate hypersensitivity and relate it to restricted interests and laid the groundwork for future studies comparing these relationships in other clinical groups and in TD controls to determine if this relationship is specific to individuals with ASD.

A follow-up study also looked specifically at hypersensitivity and restricted interests and included a comparison between autistic children (mean chronological age was four years old) and children with developmental delays (Boyd et al., 2010). This study used an extensive battery of sensory measures, including not only the SP, but also additional reports and observational measures including the Sensory Experiences Questionnaire (Baranek et al., 2006), the Sensory Processing Assessment for Young Children (Baranek, 1999), and the Tactile Defensiveness and Discrimination Test (Baranek, 2010). From this battery, three sensory factors were isolated: hypersensitivity, hyposensitivity, and sensory seeking. When controlling for mental age, gender, and diagnostic group, hypersensitivity was significantly predictive of RRBs. More specifically, hypersensitivity was predictive of stereotypies, compulsions, and rituals or sameness behaviours, but contradictory to the previous study, not restricted interests. Notably, these two studies provide inconclusive results regarding which specific forms of RRBs are related to hypersensitivity. Additionally, while the Boyd et al.'s (2010) study improved upon the existing body of literature in that it compared results between two clinical samples, a direct, between-group comparison of the relationship between sensory issues and RRBs in various clinical and TD populations is still required.

To our knowledge, only one study has examined the specific relationship between sensory hypersensitivity and RRBs (specifically insistence on sameness) and directly compared this relationship with a group of TD controls. The results displayed a very strong

correlation between sensory hypersensitivity and insistence on sameness in a group of children with ASD between the ages of seven and seventeen years old. When this same relationship was examined in a group of TD children ages seven to eighteen, no relationship was found between variables, suggesting this relationship may be specific to ASD (Black et al., 2017).

To date, there is a strong convergence of evidence that sensory processing issues in ASD are directly related to RRBs. Of the few studies that have addressed the role of individual sensory modalities, or individual categories of RRBs, results have been mixed, however. Even more pressing, direct comparisons with mental-age-matched cohorts of TD children are much needed. As such, it is yet unknown whether this relationship between sensory processing and RRBs is specific to individuals diagnosed with ASD or if it is present in the general population. The current study aims to address these gaps in the literature with four objectives:

1) To confirm the relationship between hypersensitivity and RRBs in children with ASD;

2) To examine this relationship across the sensory modalities, including auditory, visual, tactile, and oral domains;

3) To determine whether this relationship varies across subdomains of RRBs, and;

4) To determine if the relationship is specific to ASD.

We hypothesize that the relationship between RRBs and sensory hypersensitivity will exist in both ASD and TD populations, with a stronger relationship apparent in the ASD group. We also expect this pattern to remain consistent across the sensory modalities and across the various types of RRBs.

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2.1 Methods

2.1.1 Participants

A total of 114 children and adolescents were recruited from schools and community ASD groups for this study. Their ages ranged from 6 to 20 years of age (M = 11.30, SD = 3.17) and 73 (64%) were male. Forty-nine of the participants were previously diagnosed with ASD by a clinician practitioner and each participant was further screened to confirm the diagnosis using the Autism Diagnostic Observation Schedule (ADOS; versions 1 or 2; (Lord, Rutter, Dilavore, & Risi, 2002)) administered by research-reliable clinicians. Sixty-five of the participants were TD; TD participants were excluded if they had a developmental disability or neuropsychiatric illness, or if they had a first-degree biological relative with ASD. Participants did not significantly differ on mental age (MA) across groups ($p = 0.97$, $t_{(93.74)} = 0.04$, $M_{ASD} = 11.44$, $SD_{ASD} = 3.92$, $M_{TD} = 11.49$, $SD_{TD} = 3.32$).

MA was calculated using chronological age (CA) and IQ [MA = CA*(IQ/100)], assessed using the two-subscale full IQ test score from the Wechsler Abbreviated Scale of Intelligence (WASI-2; (Wechsler, 2011)). Within these individual components of MA, ASD participants had a higher CA ($p < 0.01$, $t_{(104.62)} = 3.27$; $M_{ASD} = 12.37$, $SD_{ASD} = 3.00$, $Range_{ASD}$ = 7-20 years; $M_{TD} = 10.49$, $SD_{TD} = 3.07$, $Range_{TD}$ = 6-18 years), and a lower IQ ($p < 0.001$, $t_{(65.98)} = 4.83$; $M_{ASD} = 92.69$, $SD_{ASD} = 21.78$; $M_{TD} = 109.06$, $SD_{TD} = 10.72$). In line with population averages, the ASD group had a significantly higher portion of males ($p = 0.002$, $\chi^2_{(3)} = 9.03$; ASD = 39/49, TD = 34/65). While the aim here was to match on MA, given these differences in CA, IQ, and sex, each of these variables was controlled for in subsequent regression analyses.

Table 1: Demographics

	N	Males	Females	Chronological Age	IQ	Mental Age
ASD	49	39	10	12.37 (3.00)	92.69 (21.78)	11.44 (3.92)
TD	65	34	31	10.49 (3.07)	109.06 (10.72)	11.49 (3.32)
Total	114	73	41	11.30	101.90	11.46

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2.1.2 Materials & Procedures

The Sensory Profile-2 (SP-2) is an 86-item scale that assesses sensory function (Dunn, 2014). The child version is a caregiver report for children ages 3 to 14:11 years of age. For consistency, all parents completed the child version, even for individuals 15 and over (N = 19). For each item, parents were asked to describe their child's response to a sensory experience on a 5-point Likert scale ranging from "Almost Never" to "Almost Always". The SP-2 assesses sensory processing in six sensory domains including auditory, visual, touch, oral, movement, and body position, as well as three behavioural domains associated with sensory processing including conduct, social emotional, and attention. The scale provides a sensory profile based on four quadrants of sensory processing: sensitivity, sensory seeking, sensory avoiding, and low registration. Higher scores are associated with higher sensory dysfunction. The SP-2 has been normalized on a sample of 1791 children and includes individuals with ASD. The quadrants of the SP-2 for children have high internal consistency ranging from 0.85 to 0.90. The sensory domains ranged from 0.80 to 0.88 on internal consistency except for vision (0.60). The SP-2 has high test-retest reliability ranging from 0.87 to 0.97.

The Repetitive Behaviours Questionnaire, Second Edition (RBQ-2) is a 20-item measure of severity and frequency of repetitive behaviours, restricted interests, and insistence on sameness (Honey, McConachie, Turner, & Rodgers, 2012). All parents completed the child version. Each item was scored on a 3- or 4-point Likert Scale. For example, the item "Does your child insist that aspects of the daily routine must remain the same?" has three possible responses: never; mild or occasional (does not affect others); and marked or notable (affects others on a regular basis). Whereas the item "Does your child spin him/herself around and around?" is based strictly on the frequency of the behaviour and is rated on a four-point scale ranging from never or rarely to one or more times daily to 15 or more times daily (or at least once an hour) to 30 or more times daily (or twice an hour). Higher scores are associated with greater dysfunction and the scores are summarized into four factors including repetitive motor movements, rigidity and adherence to routine, preoccupation with restricted patterns of interest, and unusual sensory interest. Internal

consistency of the total RBQ-2 score is 0.85 based on a sample of 587 participants and ranges from 0.66 to 0.80 for each of the four factors (Leekam et al., 2007).

The parent of every participant provided informed, written consent, and every participant provided verbal assent and written assent if able. All procedures were approved by the local research ethics board.

2.1.3 Analysis

Missing data was accounted for through a fully-conditional Markov Chain Monte Carlo multiple imputation model with 10 iterations. Missing data constituted 2.22% of all values.

Each item on the SP-2 is categorized into the four quadrants of sensory processing, including a Sensitivity Quadrant. In order to create a hypersensitivity score for each sensory modality (auditory, visual, tactile, and oral) in an *a priori* manner, we added the items identified as part of the Sensitivity Quadrant in each sensory modality and reported it as a Hypersensitivity score for each sensory modality. For example, as part of the Auditory Processing section of the SP-2, 4 of 8 items are keyed as part of the Sensitivity Quadrant. The scores on those 4 Sensitivity Quadrant items were summed together and reported as Auditory Hypersensitivity. Thus, Auditory Hypersensitivity includes items such as “My child struggles to complete tasks when music or TV is on” which is part of the original Sensitivity Quadrant but excludes items such as “My child enjoys strange noises or makes noise(s) for fun” which is not part of the original Sensitivity Quadrant. Cronbach’s Alpha was calculated for the new Hypersensitivity scale in each sensory modality and internal consistency ranged from acceptable to excellent, including Visual ($\alpha = 0.724$), Tactile ($\alpha = 0.773$), Auditory ($\alpha = 0.887$), and Oral ($\alpha = 0.916$) Hypersensitivity.

Furthermore, the hypersensitivity in each of the sensory domains (auditory, visual, tactile, and oral) were added together to create a Sensory Hypersensitivity Score that is specific to *sensory* items. This measure of Sensory Hypersensitivity had an excellent internal consistency of $\alpha = 0.920$. The original Sensitivity Quadrant of the SP2 includes items from the behavioural domains *associated* with sensory processing, but not directly

referring to sensory processing itself. These items in the social emotional and attentional domains include, “My child struggles to interpret body language or facial expressions”, “My child looks away from tasks to notice all actions in the room”, and “My child gets lost easily”. Although these items factor onto the original Sensitivity Quadrant of the SP-2 and tangentially relate to sensory sensitivity, they are not direct measures of *sensory* sensitivity. Therefore, by excluding items from the behaviours domains, we adapted the Sensitivity Quadrant to be a more theoretically precise measure of *Sensory* Hypersensitivity. Thus, six measures were extracted from the SP-2 in total; the Sensitivity Quadrant score, Auditory, Visual, Tactile, and Oral Hypersensitivity, and Sensory Hypersensitivity.

The Kolmogorov-Smirnov Test was used to measure normality for each variable. In the TD sample, all of the variables displayed a non-normal distribution ($p \leq 0.002$). The ASD group displayed normal distribution in the Sensitivity Quadrant ($p = 0.20$), Sensitivity Hypersensitivity ($p = 0.63$), and Auditory Sensitivity ($p = 0.10$), however, the remainder of the measures displayed a non-normal distribution ($p \leq 0.045$). Due to the irregular distribution of data found in this sample, all analyses were conducted using non-parametric tests.

Total and subscale scores on the SP-2 and RBQ-2 were compared across ASD and TD groups using the Mann Whitney test. For the SP2, this included scores on the Sensitivity Quadrant; and scores from each sensory domain including Auditory Hypersensitivity, Visual Hypersensitivity, Tactile Hypersensitivity, and Oral Hypersensitivity; and the additional Sensory Hypersensitivity Score as described above. For the RBQ-2, ASD and TD groups were compared on the total Repetitive Behaviours Score and each of the four factors: Repetitive Motor Movements, Rigidity and Adherence to Routine, Preoccupation with Restricted Patterns of Interest, and Unusual Sensory Interests. Because the RBQ-2 questions unusual sensory interests in children, there is overlap in items when correlating the results with the SP-2. However, upon comparison of the results, both including and excluding the sensory interest items on the RBQ-2, no differences were observed, so all questions have been included in the total Repetitive Behaviours Score.

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Next, Spearman's Rank correlations were used to explore the relationships between repetitive behaviours and each sensory measure in both the ASD and TD groups. Because the Total Repetitive Behaviours Score was used in six correlations (Sensitivity Quadrant, Sensory Hypersensitivity, Auditory Hypersensitivity, Visual Hypersensitivity, Tactile Hypersensitivity, and Oral Hypersensitivity), the Bonferroni correction was used to adjust for multiple comparisons, resulting in a corrected α-value of 0.0083.

A three-model hierarchical regression predicting the total Repetitive Behaviours Score was conducted (it should be noted that residuals were normally distributed, allowing for parametric regression modelling). Model 1 accounted for demographic variables including IQ, age, and sex to control for group differences. Model 2 added the total Sensory Hypersensitivity score to explore the possibility that Sensory Hypersensitivity can predict RRBs above and beyond what the demographic variables explained. Lastly, Model 3 included diagnosis as a variable to determine whether diagnostic grouping could explain any significant variance beyond what demographic variables and Sensory Hypersensitivity could predict.

An identical analysis was conducted relating Sensory Hypersensitivity to individual repetitive behaviour subscales. Spearman Rank correlations were used to explore the relationships between Sensory Hypersensitivity and each of the four factors on the RBQ-2 in both the ASD and TD groups. Again, the Bonferroni correction was used to adjust for the multiple comparisons involving Sensory Hypersensitivity (Total Repetitive Behaviours, Repetitive Motor Movements, Rigidity and Adherence to Routine, Preoccupation with Restricted Patterns of Interest, and Unusual Sensory Interests). A Bonferonni-corrected α-value of 0.01 was used. Subsequently, the same three-model hierarchical regression described above was used to predict each individual factor on the RBQ-2.

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2.2 Results

2.2.1 Symptom Severity

Sensory hypersensitivity were exacerbated in ASD compared to the TD group in all SP-2 scales (Figure 1), including the Sensitivity Quadrant (Mdn_{ASD} = 50.00; Mdn_{TD} = 24.00; U = 247.00, $p < 0.01$), Sensory Hypersensitivity (Mdn_{ASD} = 35.00; Mdn_{TD} = 17.50; U = 362.00, $p < 0.01$), and Auditory (Mdn_{ASD} = 13.00; Mdn_{TD} = 6.00; U = 321.00, $p < 0.01$), Visual (Mdn_{ASD} = 4.00; Mdn_{TD} = 2.00; U = 793.00, $p < 0.01$), Tactile (Mdn_{ASD} = 6.00; Mdn_{TD} = 3.00; U = 673.00, $p < 0.01$), and Oral (Mdn_{ASD} = 12.00; Mdn_{TD} = 6.00; U = 886.00, $p < 0.01$) Hypersensitivities.

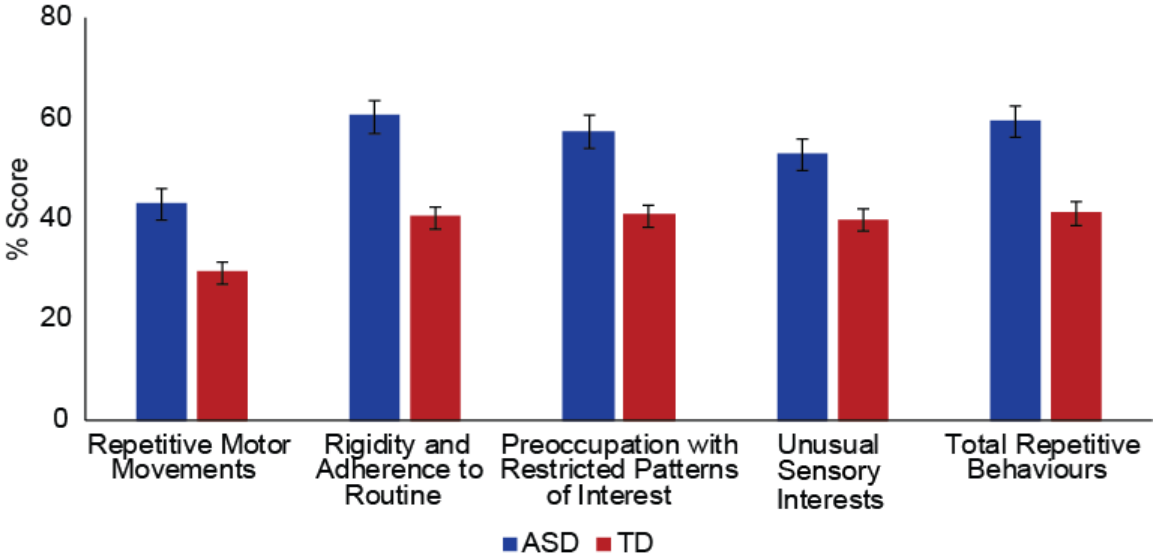

Figure 1: Comparison of RRBs severity between ASD and TD groups. The Y-axis represents the score on each subscale relative to the total possible score on each subscale. All differences were significant ($p < 0.01$). Error bars represent standard errors.

Likewise, all scales on the RBQ-2 were higher for the ASD sample compared to the TD sample (Figure 2), including Total Repetitive Behaviours (Mdn_{ASD} = 33.50; Mdn_{TD} = 22.90; U = 432.00, $p < 0.01$), Repetitive Motor Movements (Mdn_{ASD} = 7.00; Mdn_{TD} = 5.00; U = 802.50, $p < 0.01$), Rigidity and Adherence to Routine (Mdn_{ASD} = 12.00; Mdn_{TD} = 8.00; U = 506.50, $p < 0.01$), Preoccupation with Restricted Patterns of Interest (Mdn_{ASD} = 13.00; Mdn_{TD} = 8.00; U = 699.00, $p < 0.01$), and Unusual Sensory Interests (Mdn_{ASD} = 6.00; Mdn_{TD} = 4.00; U = 835.50, $p < 0.01$).

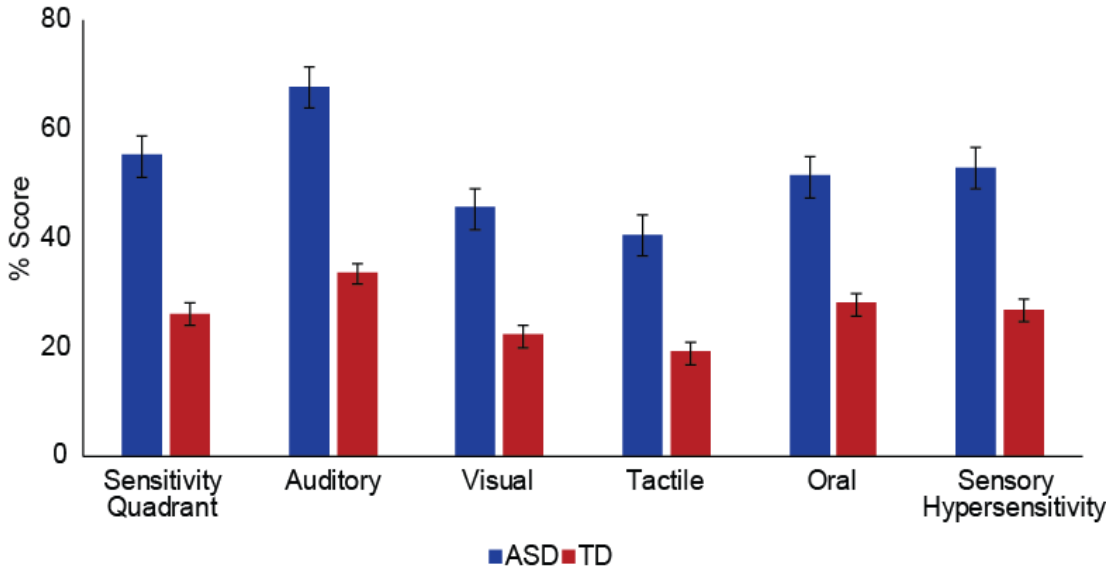

Figure 2: Comparison of sensory symptom severity between ASD and TD groups. The Y-axis represents the score on each subscale relative to the total possible score on each subscale. All differences were significant ($p < 0.01$). Error bars represent standard errors.

2.2.2 Relating Sensitivity and Total Repetitive Behaviours

The Sensitivity Quadrant was significantly correlated with Total Repetitive Behaviours (Figure 3A), in both ASD ($r_{s(47)} = 0.77$, $p < 0.01$) and TD ($r_{s(63)} = 0.47$, $p < 0.01$). In both groups, as sensitivity increased so did repetitive behaviours. While this positive relationship was significant for both groups, the correlations between the Sensitivity Quadrant and Total Repetitive Behaviours were significantly different between

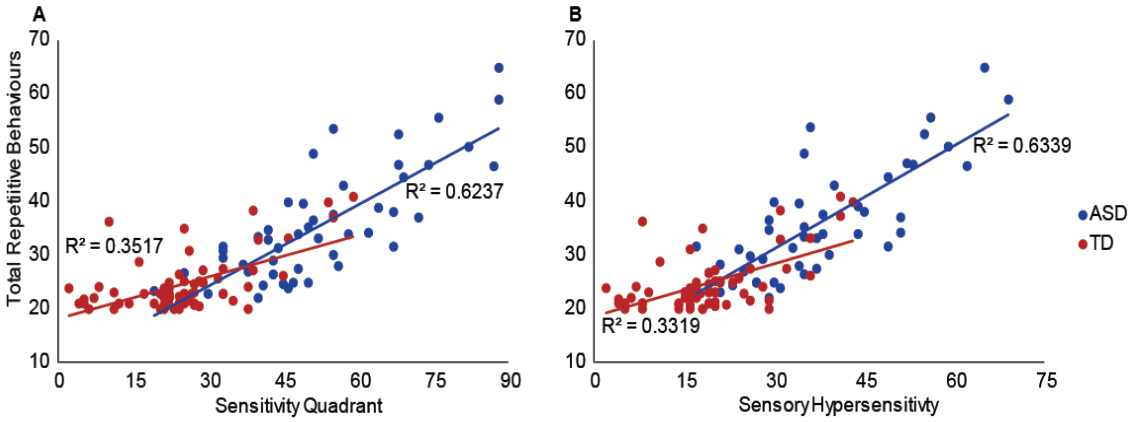

Figure 3: Correlations between Relating Total Repetitive Behaviours and (A) the SP-2 Sensitivity Quadrant and (B) Sensory Hypersensitivity. All correlations were significant ($p < 0.01$).

the ASD and TD groups ($z = 2.62$, $p < 0.01$), with a stronger relationship displayed by the ASD group.

The Total Repetitive Behaviours score was also significantly correlated with Sensory Hypersensitivity (Figure 3B) in ASD ($r_{s(47)} = 0.77$, $p < 0.01$) and TD ($r_{s(63)} = 0.44$, $p < 0.01$). As Sensory Hypersensitivity increased, so did Total Repetitive Behaviours. While this relationship was found in both groups, the correlation was significantly different between groups ($z = 2.79$, $p < 0.01$), with the ASD group displaying a stronger relationship.

In ASD, Total Repetitive Behaviours were significantly correlated with each individual sensory modality (Figure 4): Auditory ($r_{s(47)} = 0.37$, $p < 0.01$), Visual ($r_{s(47)} = 0.39$, $p < 0.01$), Tactile ($r_{s(47)} = 0.69$, $p < 0.01$), and Oral ($r_{s(47)} = 0.69$, $p < 0.01$)

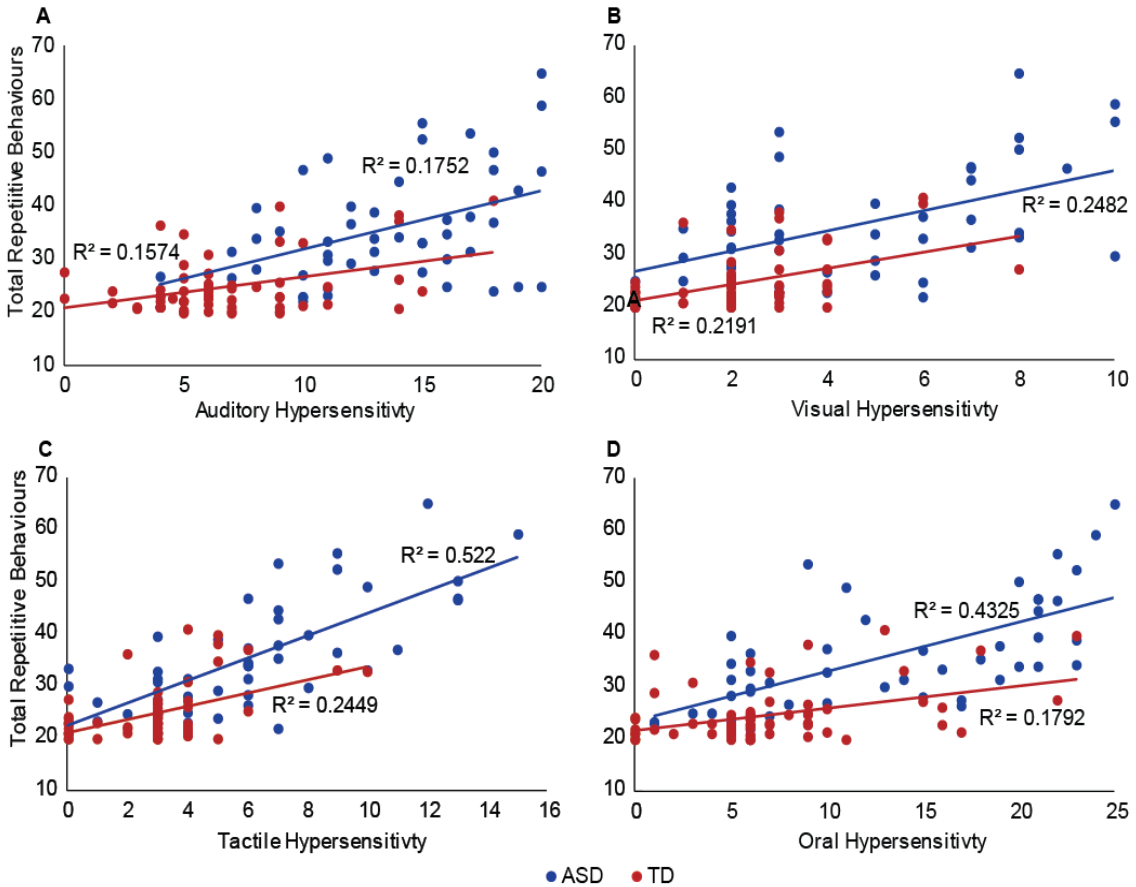

Figure 4: Correlations between Total Repetitive Behaviours and (A) Auditory Hypersensitivity, (B) Visual Hypersensitivity, (C) Tactile Hypersensitivity, and (D) Oral Hypersensitivity. All correlations were significant ($p < 0.01$).

Hypersensitivities. Hypersensitivity in each sensory modality was also significantly correlated to Total Repetitive Behaviours in TD (Figure 4): Auditory ($r_{s(63)}$ = 0.22, p = 0.07), Visual, ($r_{s(63)}$ = 0.40, p < 0.01), Tactile ($r_{s(63)}$ = 0.38, p < 0.01), and Oral ($r_{s(63)}$ = 0.38, p < 0.01). The correlations between ASD and TD were significantly different in the tactile (z = 2.32, p = 0.02) and oral (z = 2.28, p = 0.02) modalities but there were no group differences observed in the auditory (z = 0.83, p = 0.41) or visual (z = -0.09, p = 0.93) modalities.

2.2.3 Predicting Total Repetitive Behaviours

In the hierarchical regression predicting Total Repetitive Behaviours (see Table 2 for detailed statistics), Model 1 of the regression (demographic variables) was a significant predictor, primarily driven by intelligence. Model 2 (Sensory Hypersensitivity) was a significant predictor and intelligence remained significant, however, Sensory Hypersensitivity was the driving factor of Total Repetitive Behaviours. Finally, Model 3 (diagnosis) was not significant and Sensory Hypersensitivity was the only remaining significant predictor of Total Repetitive Behaviours. Thus, sensory hypersensitivity significantly predicted repetitive behaviours, and diagnostic group did not add any significant predictive abilities beyond Sensory Hypersensitivity.

Table 2: Hierarchical regression predicting Total Repetitive Behaviours

Predictor	Partial Correlation (pr)	P Value
Model 1: R^2 = 0.18, $F_{(3,108)}$ = 7.96, p < 0.01		
Intelligence	**-0.40**	**< 0.01**
Age	0.00	0.96
Sex	-0.11	0.26
Model 2: R^2 = 0.68, R^2-change = 0.50, $F\text{-change}_{(1,107)}$ = 170.91, p < 0.01		
Intelligence	**-0.19**	**0.05**
Age	-0.13	0.20
Sex	-0.03	0.76

Sensory Hypersensitivity	**0.78**	**< 0.01**
Model 3: R^2 = 0.69, R^2-change = 0.01, F-change$_{(1,106)}$ = 0.76, p = 0.39		
Intelligence	-0.16	0.09
Age	-0.14	0.14
Sex	0.00	> 0.99
Sensory Hypersensitivity	**0.71**	**< 0.01**
Diagnosis	0.08	0.39

2.2.4 Relating Sensory Hypersensitivity to the Repetitive Behaviour Subscales

In ASD, Sensory Hypersensitivity was significantly correlated with each of the individual factors on the RBQ-2 (Figure 5), including Repetitive Motor Movements ($r_{s(47)}$ = 0.44, p = 0.002), Rigidity and Adherence to Routine ($r_{s(47)}$ = 0.72, p < 0.01), Preoccupation with Restricted Patterns of Interests ($r_{s(47)}$ = 0.77, p < 0.01), and Unusual Sensory Interests ($r_{s(47)}$ = 0.76, p < 0.01). The patterns were similar in the TD group as well, with significant correlations between Sensory Hypersensitivity and each RBQ-2 factor (Figure 5), including Repetitive Motor Movements ($r_{s(63)}$ = 0.25, p = 0.04), Rigidity and Adherence to Routine ($r_{s(63)}$ = 0.40, p < 0.01), Preoccupation with Restricted Patterns of Interests ($r_{s(63)}$ = 0.43, p < 0.01), and Unusual Sensory Interests ($r_{s(63)}$ = 0.35, p < 0.01). The correlation between Repetitive Motor Movements and Sensory Hypersensitivity did not significantly differ between groups (z = 1.10, p = 0.27). However, the correlations between Sensory Hypersensitivity and Rigidity and Adherence to Routine (z = 2.54, p = 0.01), Preoccupation with Restricted Patterns of Interests (z = 2.87, p < 0.01), and Unusual Sensory Interests (z = 3.20, p < 0.01) were significantly stronger in ASD compared to TD.

2.2.5 Predicting RBQ-2 Factors

Using the same hierarchical regression models as above but predicting the individual factors of the RBQ-2, results were similar to the prediction of Total Repetitive Behaviours. Importantly, for predicting all subscales, including Repetitive Motor Movements, Rigidity and Adherence to Routine, Preoccupation with Restricted Patterns of Interest, and Unusual Sensory Interests, Sensory Hypersensitivity was a significant

predictor ($p < 0.01$) and diagnostic group was *not* significantly predictive (ps = 0.99, 0.20, 0.57, and 0.37, respectively).

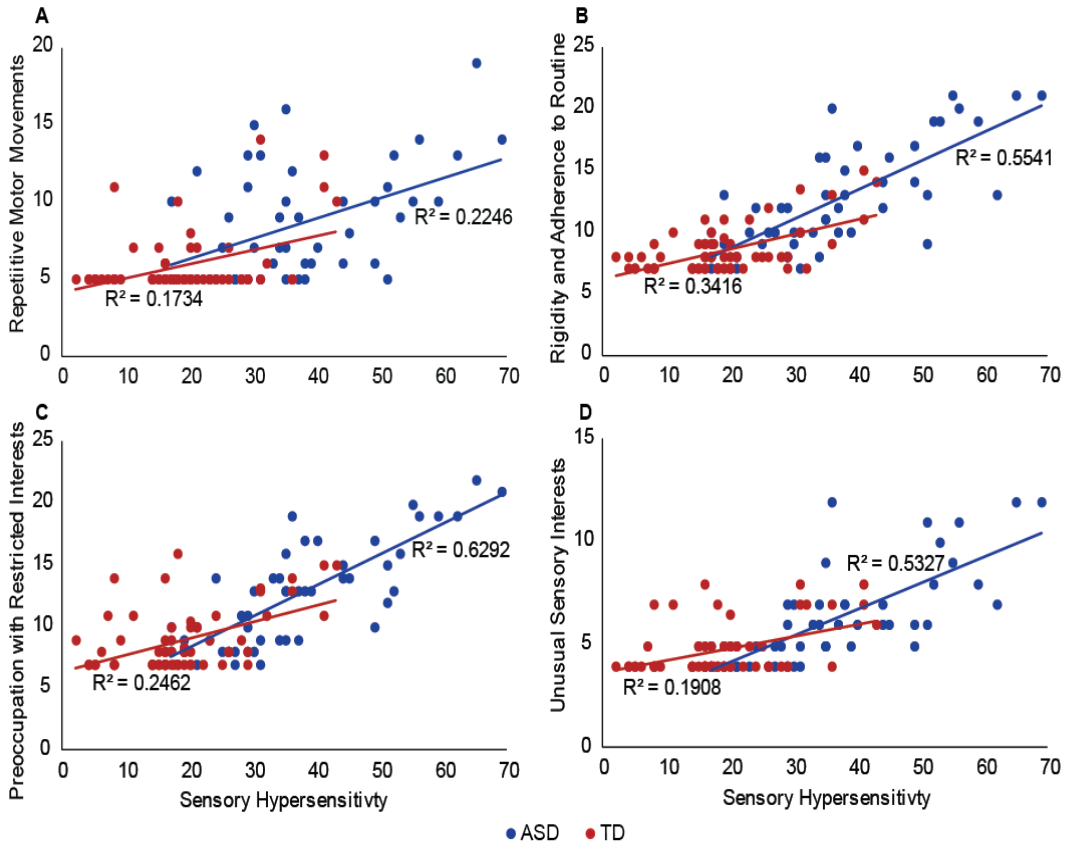

Figure 5: Correlations between Sensory Hypersensitivity and (A) Repetitive Motor Movements, (B) Rigidity and Adherence to Routine, (C) Preoccupation with restricted Interests, and (D) Unusual Sensory Interests. All correlations were significant ($p < 0.01$).

Intelligence was a significant predictor of all four factors in Model 1 (demographics, $p < 0.01$) and remained a significant predictor of Repetitive Motor Movements in Model 2 (Sensory Hypersensitivity, $p = 0.03$) and Model 3 (diagnosis, $p = 0.04$). Age was a significant predictor of Preoccupation with Restricted Patterns on Interest in Model 2 (Sensory Hypersensitivity, $p < 0.01$) and in Model 3 (diagnosis, $p < 0.01$).

Table 3: Hierarchical regression predicting RBQ-2 Factors.

	Repetitive Motor Movements		Rigidity and Adherence to Routine		Preoccupation with Restricted Patterns of Interest		Unusual Sensory Interests	
Predictor	Partial Correlation (pr)	P Value	Partial Correlation (pr)	P Value	Partial Correlation (pr)	P Value	Partial Correlation (pr)	P Value
Model 1	**R^2 = 0.17, $F_{(3,108)}$ = 7.10, p < 0.01**		**R^2 = 0.14, $F_{(3,108)}$ = 5.94, p < 0.01**		**R^2 = 0.12, $F_{(3,108)}$ = 4.98, p < 0.01**		**R^2 = 0.12, $F_{3,108)}$ = 5.12, p < 0.01**	
IQ	**-0.37**	**< 0.01**	**-0.36**	**< 0.01**	**-0.35**	**< 0.01**	**-0.34**	**< 0.01**
Age	0.05	0.58	0.02	0.83	-0.10	0.30	0.02	0.81
Sex	-0.16	0.10	-0.09	0.37	-0.02	0.82	-0.01	0.93
Model 2	**R^2 = 0.38, F-change$_{(1,107)}$ = 37.19, p < 0.01**		**R^2 = 0.64, F-change$_{(1,107)}$ = 147.91, p < 0.01**		**R^2 = 0.63, F-change$_{(1,107)}$ = 144.27, p < 0.01**		**R^2 = 0.50, F-change$_{(1,107)}$ = 80.75, p < 0.01**	
Intelligence	**-0.21**	**0.03**	-0.12	0.21	-0.10	0.31	-0.13	0.18
Age	-0.00	> 0.99	-0.09	0.35	**-0.27**	**< 0.01**	-0.06	0.54
Sex	-0.12	0.23	0.00	0.99	0.10	0.31	0.09	0.37
Sensory Hyper-sensitivity	**0.51**	**< 0.01**	**0.76**	**< 0.01**	**0.76**	**< 0.01**	**0.66**	**< 0.01**
Model 3	R^2 = 0.38, F-change$_{(1,106)}$ < 0.001, p > 0.99		R^2 = 0.65, F-change$_{(1,106)}$ = 1.77, p = 0.19		R^2 = 0.63, F-change$_{(1,106)}$ = 0.34, p = 0.56		R^2 = 0.51, F-change$_{(1,106)}$ = 0.80, p = 0.37	
Intelligence	**-0.20**	**0.04**	-0.08	0.41	-0.08	0.42	-0.15	0.13
Age	-0.001	>0.99	-0.12	0.21	**-0.27**	**< 0.01**	-0.04	0.71
Sex	-0.11	0.27	-0.08	0.41	0.11	0.25	0.05	0.58
Sensory Hyper-sensitivity	**0.44**	**< 0.01**	**0.68**	**< 0.01**	**0.68**	**< 0.01**	**0.61**	**< 0.01**
Diagnosis	0.001	>0.99	0.13	0.19	0.06	0.56	-0.09	0.37

2.3 Discussion

The objective of this study was to examine the relationship between sensory hypersensitivity and RRBs associated in both ASD and TD individuals. Results confirmed that sensory hypersensitivity is strongly related to the core ASD symptom of RRBs, but this relationship was not specific to ASD. In all children, both autistic and TD, RRBs significantly increased with sensory hypersensitivity, though stronger relationships were apparent in the ASD group. This positive relationship was observed across all sensory modalities in both groups. The strength of this relationship did not differ between groups in auditory and visual modalities, however, the ASD group exhibited a stronger relationship than the TD group in the tactile and oral modalities. Furthermore, overall sensory hypersensitivity was significantly related to RRBs in all participants, both ASD and TD, even when controlling for sex, chronological age, and IQ. Importantly, diagnosis did not add any predictive influence of RRBs above and beyond sensory hypersensitivity. Finally, when individual subdomains of RRBs were isolated, sensory hypersensitivity was significantly predictive in every subdomain, and diagnosis added no predictive ability above and beyond sensory hypersensitivity.

The results provide additional evidence to the existing literature that reports higher sensory hypersensitivity (Kern, Garver, et al., 2007; Rogers et al., 2003; Saulnier, 2002; Talay-Ongan & Wood, 2000; Tomchek & Dunn, 2007) and RRBs (Honey et al., 2007; Kim & Lord, 2010; MacDonald et al., 2007; Morgan, Wetherby, & Barber, 2008; Richler, Bishop, Kleinke, & Lord, 2007; Watt, Wetherby, Barber, & Morgan, 2008; Werner, Dawson, Munson, & Osterling, 2005) in autistic individuals compared to their TD counterparts. As RRBs are a core diagnostic feature and hypersensitivity is a common complaint among individuals with ASD, the differences in severity and frequency of these symptoms are well-documented in ASD and TD individuals.

Although there is a notable difference in symptom severity between groups, these data are congruent with previous lines of research suggesting that ASD symptoms fall on a spectrum that can be observed across the general population. In total, the vast majority of these studies show that autistic traits can be observed to varying degrees in TD

individuals, and that there is often not a qualitative, but only a quantitative shift in these traits between ASD and TD groups. These include (but are not limited to) studies of sensory processing differences associated with ASD traits in general (Horder, Wilson, Mendez, & Murphy, 2014; Robertson & Simmons, 2013), as well as studies that examine the relationship between specific sensory processing issues and ASD traits. For example, TD individuals who scored higher on the Autism Spectrum Quotient were better able to complete block design tasks providing evidence of differences in visuospatial reasoning linked to autistic traits (Stewart, Watson, Allcock, & Yaqoob, 2009), and autistic traits in TD individuals are related to differences in global and local processing (Stevenson et al., 2016; Sutherland & Crewther, 2010).

While there are quantitative shifts in both sensory hypersensitivity and repetitive behaviours between groups, a significant, positive relationship was found between sensory hypersensitivity and RRBs in both the ASD and TD groups. These results confirm and expand upon previous studies linking these symptoms in autistic individuals based on parent reports (Black et al., 2017; Boyd et al., 2010; Chen et al., 2009; Gabriels et al., 2008), and showing a possible overlap between the underlying neurobiology of these two symptoms (Joseph et al., 2009). However, to our knowledge, the current data is the first to provide evidence that the relationship between sensory hypersensitivity and RRBs is not restricted to ASD but is also apparent in the general population across sensory modalities.

The correlational findings in both ASD and TD groups were further bolstered by our results from a hierarchical regression predicting RRBs. In this regression, sensory hypersensitivity accounted for a significant amount of the variance displayed in RRBs, even when controlling for demographic variables including intelligence, chronological age, and sex. Importantly, diagnostic group did not account for variability in RRBs above and beyond sensory hypersensitivity. This novel finding implies that sensory hypersensitivity is strongly associated with RRBs and suggests that this association is not specific to ASD but extends to the general population as well.

The relationship between of RRBs and sensory hypersensitivity was not limited to the total repetitive behaviour score. Similar findings were observed for all four factors of

the RBQ-2. Repetitive motor movements, rigidity and adherence to routine, preoccupation with restricted patterns of interest, and unusual sensory interests, were all positively correlated with sensory hypersensitivity in both ASD and TD groups. Our initial correlational analysis also showed no group differences in the relationships between sensory hypersensitivity repetitive motor movements or rigidity and adherence to routine. Differences were observed relative to preoccupation with restricted patterns of interest and unusual sensory interests, in which the direction of the relationship was consistent, but the strength of the relationship was stronger in ASD. With that said, hierarchical regressions controlling for demographic variables showed that diagnosis itself did not provide any significant predictive information beyond sensory hypersensitivity in any of these subscales, again, suggesting that hypersensitivity influences RRBs not just in ASD, but in the general population. Therefore, these results provide original evidence for the relationship between sensory hypersensitivity and specific types of RRBs not only in autistic individuals but in TD individuals as well.

These data also provide a novel comparison of how the relationship between individual sensory modalities and RRBs may differ between autistic and TD groups. In both groups, the level of hypersensitivity in each sensory modality (audition, vision, tactile, and oral) was significantly related to levels of RRBs. Our data showed no group differences in how either auditory or visual sensitivities related to RRBs across diagnostic groups. However, the relationship between both tactile sensitivities and oral sensitivities and RRBs was significantly stronger in the ASD relative to the TD group. Though this is the first between-group comparison across individual sensory modalities, one study has previously described modality-specific relationships with RRBs within an ASD group (Chen et al., 2009). This previous study reported findings partially congruent with the current data in that repetitive behaviours increased with heightened tactile, visual, and auditory hypersensitivity, but not taste/smell sensitivity. This difference between the Oral subscale used in the current study and the taste/smell sensitivity scale used in the previous study may be the cause for this discrepancy, though work specific to taste and smell is an area for future work to consider.

A version of this paper has been accepted for publication (Schulz & Stevenson, *in press*).

2.3.1 Theoretical implications

The results confirm that there is a strong association between sensory hypersensitivity and repetitive behaviours, providing further evidence for the overarousal hypothesis. The overarousal hypothesis states that repetitive behaviours act to block out additional sensory input and are therefore more common in individuals who are more sensitive to their sensory environment. This hypothesis is based on a study of autistic individuals in varying environments. The study concluded that individuals with ASD displayed more stereotypies in more complex environments, involving novel toys and people (Hutt & Hutt, 1965). The complex environments are theorized to arouse the sensory system. These results provide further evidence for the overarousal hypothesis which specifically suggest that repetitive motor behaviours may be caused by the need to regulate one's sensory input from his or her environment. Additionally, the hypothesis claims that restricted interests and routine are employed to avoid novel situations, people, and objects that would provide additional stimulation (Hutt et al., 1964). Furthermore, these findings add novel evidence that suggests that the overarousal hypothesis may relate to multiple types of repetitive behaviours including repetitive motor movements, rigidity and adherence to routine, and preoccupation with restricted patterns of interest.

One of the most interesting new findings was that the relationship between sensory hypersensitivity and RRBs was not restricted to ASD individuals but was also observed in TD individuals. That is, while high symptom severity was specific to ASD, the pattern of increased RRBs with higher sensory hypersensitivity was not specific to ASD but was consistent across all individuals. Thus, while the overarousal hypothesis postulates that atypical sensory hypersensitivity in ASD may lead to RRBs, our results support a broader *arousal* hypothesis for the general population opposed to an *over*arousal hypothesis specific to ASD. While the *overarousal* hypothesis implies that a particular threshold of arousal must be surpassed before RRBs emerge, based on the results observed in this TD sample, it appears this relationship is apparent even at minimal degrees of these autistic traits. This relationship is continuous and was present in typical ranges of both sensory sensitivity and RRBs, suggesting that a more general *arousal* hypothesis may be more appropriate. An arousal hypothesis could also be used to describe not only the relationship

often observed in individuals with ASD where very severe RRBs are highly predicted by hypersensitivity but also the relationship observed in many TD individuals in which a lack of arousal that could also be related to a lack of RRBs. Therefore, regardless of how aroused or hypersensitive an individual is to their sensory environment, their engagement in RRBs can be predicted.

With that said, there is evidence that additional factors may impact the relationship between sensory sensitivity and RRBs. For example, RRBs have also been linked to mental age and intelligence in the past (Behrmann et al., 2006; Bertone et al., 2005; Black et al., 2017; Bonnel et al., 2010; De Jonge et al., 2007; Gabriels, Cuccaro, Hill, Ivers, & Goldson, 2005; Khalfa et al., 2004; Koh, Milne, & Dobkins, 2010; Militerni, Bravaccio, Falco, Fico, & Palermo, 2002). Intelligence/mental age has also been linked to hypersensitivity in both children with ASD and TD children (Milne, Scope, Pascalis, Buckley, & Makeig, 2009). Therefore, it has been hypothesized that these supposedly independent relationships, are not actually independent of one another. In line with the findings of the current study, previous work that has tested this hypothesis discovered that mental age/intelligence did not impact the relationship between sensory sensitivity and RRBs (Gabriels et al., 2008). While evidence to date has thus been equivocal, the current data suggest that the relationship between sensory hypersensitivity and RRBs is present even when accounting for any impact of mental age or intelligence.

While not measured in the current study, it is also important to note that anxiety may affect the relationship between hypersensitivity and RRBs. However, it is unclear in what way anxiety is related as some studies have found that anxiety mediated the relationship between sensory sensitivity and RRBs (Wigham, Rodgers, South, McConachie, & Freeston, 2015), while other studies have shown that sensory sensitivity mediates the relationship between anxiety and RRBs (Black et al., 2017; Lidstone et al., 2014). Inconclusive evidence in regard to how anxiety impacts the relationship between hypersensitivity and repetitive behaviours indicates the need for additional research on the impact of anxiety on ASD symptomatology.

A version of this paper has been accepted for publication (Schulz & Stevenson, *in press*).

2.3.2 Limitations

The current study, as well as most previous studies relating sensory processing and RRBs, utilized parent reports. Parent reports can be an excellent source of information on children's perceptions and behaviours, and indeed they have provided an important base of knowledge regarding the relationship between sensory issues and RRBs in ASD. With that said, there are a number of issues regarding the use of parent reports that should be noted. Firstly, it is possible that the correlations between the two parent-reported measures are strengthened due to general reporting bias. It is possible that the parents who are willing to report that their child has more severe issues in one area are more likely to report more willing to report severe issues in a second area. Secondly, parent reports do not allow for the ability to discriminate between hyper*sensitivity* and hyper*reactivity*. We define sensory *sensitivity* here as a child's physiological and perceptual representation of a stimulus and sensory *reactivity* as a child's behavioural response to a stimulus, irrespective of how the stimulus is physiologically perceived. Parents reporting sensory behaviours are necessarily contingent upon the observable reactions displayed by their child and are thus unable to distinguish between sensory *sensitivity* and sensory *reactivity*. Future studies should aim to use behavioural or neural measures of sensory sensitivity and/or reactivity to distinguish between the two and to reduce general reporting bias.

The SP-2 also has limitations regarding the measurement of sensory processing, specifically. The SP-2 measures six areas of sensory processing: audition, vision, touch, gustatory, proprioceptive, and vestibular, as well as three behavioural domains associated with sensory processing: conduct, attention, and social emotional. The scoring protocol profiles individuals based on four quadrants of sensory processing: sensitivity, registration, sensory seeking and sensory avoidance, however, because the behavioural domains are included in the scoring of the four quadrants resulting in processing scores that are not specifically "sensory". To combat this limitation, we reported a subset of the Sensory Quadrant items that was limited to sensory items specifically, which eliminated the items from the behavioural domains. Although this reduced any conflicts regarding the specificity of our results, it introduces subscales that have not been explicitly normalized in previous studies and should be replicated for validation purposes. Additionally, it should

be noted that the SP-2 child version was used for consistency across participants, but is only recommended for children up to the age of 14 years and 11 months (the RBQ child version was also used with all participants, though no age limit is specified for this measure).

While these results demonstrated a relationship between hypersensitivity and RRBs in accordance with overarousal hypothesis, it is important to look at sensitivity in its entirety before making any further claims about the possibility of an arousal hypothesis. That being the case, it would be interesting for future studies to examine the relationship between hyposensitivity and RRBs to determine if this relationship could also be important in explaining this phenomenon.

Furthermore, while these data demonstrate a relationship between sensory hypersensitivity and RRBs, this design is unable to assess whether sensory hypersensitivity is only related to RRBs or if sensory hypersensitivity is related to all ASD symptomatology. It would be particularly fruitful in future work to explore the relationship between sensory hypersensitivity and social and communication deficits, as such deficits have been linked to a number sensory processing issues (Hellendoorn et al., 2014; Miguel et al., 2017; R. A. Stevenson et al., 2015; R. A. Stevenson, Segers, Ferber, Barense, & Wallace, 2014; R. A. Stevenson et al., 2017; R. A. Stevenson, Siemann, et al., 2014; Ryan A Stevenson et al., 2017; for review, see Thye, Bednarz, Herringshaw, Sartin, & Kana, 2017; Wallace & Stevenson, 2014; Woynaroski et al., 2013).

Finally, it is important to note that this group of individuals was relatively high functioning and therefore, a similar study should be conducted in a more representative group of individuals before generalizing these results to all autistic individuals. Additionally, RRBs have been commonly reported in other neurodevelopmental disabilities as well, such as Obsessive-Compulsive Disorder and Intellectual Disabilities, thus future research should also examine this relationship between sensory processing issues and RRBs in other samples as well.

2.3.3 Conclusions

These results demonstrate a clear relationship between sensory hypersensitivity and RRBs that is apparent not only in autistic individuals, but also in their MA-matched, TD peers. Thus, while these findings confirm the relationship between sensory hypersensitivity and RRBs in ASD, they also suggest that this relationship is not specific to ASD but is observable in the general populations as well. With that said, all measures of sensory hypersensitivity and RRBs were more severe in ASD. Furthermore, previous findings, that were extended in that the current data, show that this relationship holds across specific sensory modalities (audition, vision, tactile, and oral) and specific categories of RRBs including repetitive motor movements, rigidity and adherence to routine, preoccupation with restricted patterns of interest, and unusual sensory interests. Importantly, the presence of RRBs, both in total and in specific subscales, was predicted by sensory hypersensitivity, with diagnosis providing no significant additional contribution, confirming correlational results that hypersensitivity is predictive of RRBs equally in ASD and TD individuals.

A version of this paper has been accepted for publication (Schulz & Stevenson, *in press*).

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Chapter 3

3 Experiment II – Differentiating between sensory sensitivity and sensory reactivity in relation to autism-related restricted interests and repetitive behaviours

Sensory processing issues in Autism Spectrum Disorder (ASD) have been the focus of intense research in previous years, resulting in its recent inclusion in the diagnostic criteria of ASD (APA, 2013). Indeed, sensory dysfunction is now recognized as the most commonly reported symptom in ASD (Rogers & Ozonoff, 2005), and spans the sensory modalities, including tactile, visual, auditory, gustatory, and olfactory processing (Baum et al., 2015; Clery et al., 2013). While sensory hyper/hyposensitivity is categorized as a subdomain of restricted interests and repetitive behaviours (RRBs) in the current diagnostic criteria, a growing body of research posits that sensory hypersensitivity may in fact contribute to RRBs in a causal manner (Black et al., 2017; Boyd et al., 2010; Boyd et al., 2009; Charlop, 1986; Chen et al., 2009; Colman et al., 1976; Gabriels et al., 2008; Hutt et al., 1964; Kinsbourne, 1980; Lovaas, Newsom, & Hickman, 1987; Repp, Felce, & Barton, 1988; Schulz & Stevenson, 2018; Zentall & Zentall, 1983) These findings can be encapsulated within the overarousal hypothesis, which posits that autistic individuals may use RRBs to cope with overwhelming sensory inputs (Hutt et al., 1964). Thus, RRBs may act as a homeostatic mechanism for sensory input in which individuals exert control over their sensory environment and potentially limit additional sensory input.

Sensory hypersensitivity has been reported quite broadly using behavioural psychophysics, including studies of audition (Bonnel et al., 2010; Jones et al., 2009; Khalfa et al., 2004; Kinsbourne, 1980), touch (Blakemore et al., 2006), taste and smell (Hrdlicka et al., 2011), and most germane to the current study, in studies of visual perception (Ashwin et al., 2009; Bertone et al., 2003; Caplette, Wicker, & Gosselin, 2016; Clery et al., 2013; Clery, et al., 2013; Clery, et al., 2013; McCleery, Allman, Carver, & Dobkins, 2007; Pellicano, Gibson, Maybery, Durkin, & Badcock, 2005). Visual perception, and specifically visual sensitivity, has been measured using a variety of behavioural,

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psychophysical tasks ranging from change detection, to visual acuity, to detection thresholds. Regardless of the task type, there appears to be a growing consensus that visual sensitivity is greater in autistic individuals compared to typically-developing individuals.

In a comparison of visual acuity, or the sharpness of vision, autistic individuals performed significantly better on Freiburg Visual Acuity and Contrast Test compared to their typically-developing (TD) peers (Ashwin et al., 2009). Another study found that autistic children were significantly better at finding a hidden figure in a picture (Pellicano et al., 2005). Also, change detection tasks have found that autistic individuals are more sensitive to minute changes in visual stimuli compared to their TD peers, a result that was consistent in both adults (Clery et al., 2013; Clery, Roux, et al., 2013) and children (Clery, Bonnet-Brilhault, et al., 2013). Comparable results have also been observed with neuroimaging techniques, which found that autistic participants showed greater activation in primary sensory cortical areas compared to TD controls when showed aversive visual stimuli (Green et al., 2013). All of these studies suggest that autistic individuals demonstrate atypical visual processing that can be attributed to visual hypersensitivity.

An additional line of work has used orientation-identification tasks to assess visual hypersensitivity. In the first of these studies, high-functioning autistic individuals displayed enhanced perception of simple, static stimuli compared to a group of TD controls. Autistic participants were better able to detect the orientation of a sinusoidal luminance grating that varied in contrast luminance in the simple stimuli condition but were worse at detecting more complex stimuli that also varied by texture (Bertone et al., 2005). In a follow-up study, similar methods were used to compare simple and complex visual stimuli across various frequencies. A comparison between high-functioning autistic individuals and typical controls showcased an increasing disparity between groups as frequency increased, with the autistic group exhibiting greater sensitivity (Kéïta, Guy, Berthiaume, Mottron, & Bertone, 2014). The difference in detection thresholds in general and witnessed at varying frequencies can be explained by current neurobiological hypothesis suggesting an imbalance between of excitatory and inhibitory (E/I) neurotransmitters (Kéïta et al., 2014). However, not all behavioural evidence points to greater sensitivity in autistic individuals.

A number of studies found that autistic individuals do not differ from TD individuals on measures of contrast sensitivity (Matson, Kiely, & Bamburg, 1997; Poustka & Lisch, 1993; Shafai, Armstrong, Iarocci, & Oruc, 2015; Thompson & Berkson, 1985).

Despite the conflicting evidence in behavioural measures of visual sensitivity, there is a strong consensus among parent/caregiver reports that hypersensitivity is in fact more severe in autistic individuals. Among parent/caregiver reports, the sensory profile is the most commonly used assessment of sensory processing in ASD, and sensitivity has been reported in a number of different populations ranging from infants and toddlers (Ben-Sasson, Cermak, Orsmond, & Tager-Flusberg, 2007; Dunn, Myles, & Orr, 2002), to children (Black et al., 2017; Schulz & Stevenson, 2018; Tomchek & Dunn, 2007), to adults (Crane, Goddard, & Pring, 2009; Kern et al., 2006). Sensitivity has also been measured by parents/caregivers who completed the Sensory Experiences Questionnaire (Baranek et al., 2006) and the Diagnostic Interview for Social and Communication Disorders (Leekam, Nieto, Libby, Wing, & Gould, 2007). Also, a review examining differences in sensory modulation between autistic individuals and TD individuals found resounding evidence pointing towards sensory hypersensitivity in autistic individuals (Ben-Sasson et al., 2009). Finally, in addition to the numerous reports of increased *sensory* sensitivity in autistic individuals, *visual* sensitivity, has also been specifically reported in parent reports (Black et al., 2017; Corbett, Schupp, Levine, & Mendoza, 2009; Schulz & Stevenson, 2018; Talay-Ongan & Wood, 2000).

One possible explanation for more inconsistency in behavioural paradigms compared to questionnaire measures of sensory sensitivity is that these two methodologies may measure distinct constructs. Here, we operationally define sensory sensitivity as an individual's ability to detect and perceive a sensory input. For example, a hypersensitive individual would be able to detect a weaker sensory input and would perceive a given input as stronger (brighter/louder) than a peer without hypersensitivity. Behavioural paradigms such as visual detection tasks are thus specifically designed to measure sensory sensitivity *per se*. Questionnaire measures, and in particular third-party reports such as parent/caregiver reports, do not directly measure sensory sensitivity, but instead rely on

observable behavioural responses to sensory stimuli, which we will refer to here as sensory *reactivity* or *responsivity*. When using these questionnaire measures as indices of sensitivity, one must rely upon the reasonable assumption that increases in sensory sensitivity would result in increased reactions to sensory inputs (e.g. if a child perceives a given sound as louder than their peers (*sensitivity*), they will be more likely to cover their ears to dampen the sensory input (*reactivity*)). With that said, while hypersensitivity may lead to hyperreactivity, a finding of hyperreactivity does not necessitate hypersensitivity, but may occur on its own. That is, an individual may be hyper*reactive* despite perceiving sensory inputs in a typical manner.

It is important to acknowledge the difference between sensory sensitivity and sensory reactivity and the impact this difference may have on autistic symptomatology, particularly when attempting to establish factors contributing to clinical symptomatology. Very early behavioural studies have attempted to determine the causal factors of autistic symptoms and linked hypersensitivity and RRBs by inducing RRBs with various sensory stimuli such as flickering lights (Colman et al., 1976), novel toys, and strangers (Hutt & Hutt, 1965). Since these first reports on the relationship between sensory hypersensitivity and RRBs, the majority of studies have utilized questionnaires to relate RRBs and hypersensitivity. Early questionnaire data provided evidence for the broader relationship between atypical sensory processing and maladaptive behaviours (Baker et al., 2008; Bodfish et al., 1999; Gabriels et al., 2008), and subsequently narrowed the focus and tested the correlations between sensory hypersensitivity and RRBs, specifically (Boyd et al., 2010; Chen et al., 2009; Schulz & Stevenson, 2018). This series of studies has suggested that sensory hypersensitivities are strongly correlated with the number, frequency, and intensity of RRBs. It is important to note, however, that these studies have all used parent/caregiver reports to index sensory hypersensitivity. There is consistency in the parent-reported measures of sensory sensitivity in relation to RRBs, but they are not able to distinguish between sensory *sensitivity* and sensory *reactivity*. Furthermore, there is a dearth of behavioural evidence in support of this relationship, which begs the question of whether caregiver reports and behavioural reports measure the same construct, and if not, which of these constructs is truly driving RRBs.

The aim of the current project is to relate RRBs to sensory sensitivity, assessing sensitivity using two methodologies including a well-established psychophysical behavioural detection paradigm and self-reported questionnaires. These two methodologies were further contrasted to determine if behavioural measures of sensitivity and self-reported measures of sensitivity assess like constructs. It was expected that correlations would show positive relationships between sensitivity and RRBs, regardless of the measurement type. It was also expected that the two measures of sensory processing would be positively related but that behavioural sensitivity and self-reported sensitivity would be shown to assess different constructs that impact RRBs independently.

3.1 Methods

3.1.1 Participants

A total of 103 participants were recruited for this study from a pool of undergraduate students at the University of Western Ontario. Data from four participants were excluded for failure to successfully complete all portions of the paradigm, and an additional nine were removed due to outliers (greater than three standard deviations away from the mean) or false alarm rates above 25%. Following exclusions, the final sample of 90 participants had an age range of 17-25 years (M = 18.5, SD = 1.05), and 45 (50%) were males. Participants reported normal or corrected-to-normal vision. Participants were recruited based upon the Research Diagnostic Criteria (RDoC) framework (Cuthbert & Insel, 2013; Insel et al., 2010), and thus were not required to have a formal ASD diagnosis.

3.1.2 Overview

Participants completed a visual detection task to measure behavioural sensitivity. Subsequently, participants completed a series of questionnaires reporting sensory processing issues (including hypersensitivity) and RRBs. The entire procedure took approximately one hour to complete. All study procedures were approved by the University of Western Ontario Research Ethics Board.

3.1.3 Stimuli

All stimuli were presented using MATLAB 2012b (Mathworks) software through

the Psychophysics Toolbox extension (Brainard, 1997) on a monitor with a refresh rate of 16.67 milliseconds (60 Hz). The visual detection task utilized sinusoidal luminance gratings (Gabor patches) in varying contrasts embedded in dynamic visual white noise. Noise was held constant at a 0.25 Michaelson contrast while Gabor patches were presented across a range of 8 contrasts (0.3, 0.2, 0.15, 0.1, 0.075, 0.05, 0.025, 0.01). Stimuli were presented at 2 different frequencies, 9 and 30 cycles per degree (CPD).

Each trial began with a white fixation cross on a grey screen. A 1330 milliseconds presentation of dynamic visual white noise was presented subtending 400-by-400 pixels (9.8° visual angle), with a sinusoidal luminance grating embedded randomly between 400 and 660 milliseconds following onset. Gabor patches were presented for 133 milliseconds. Null trials were identical, with the exception that no Gabor patch was embedded in the white noise.

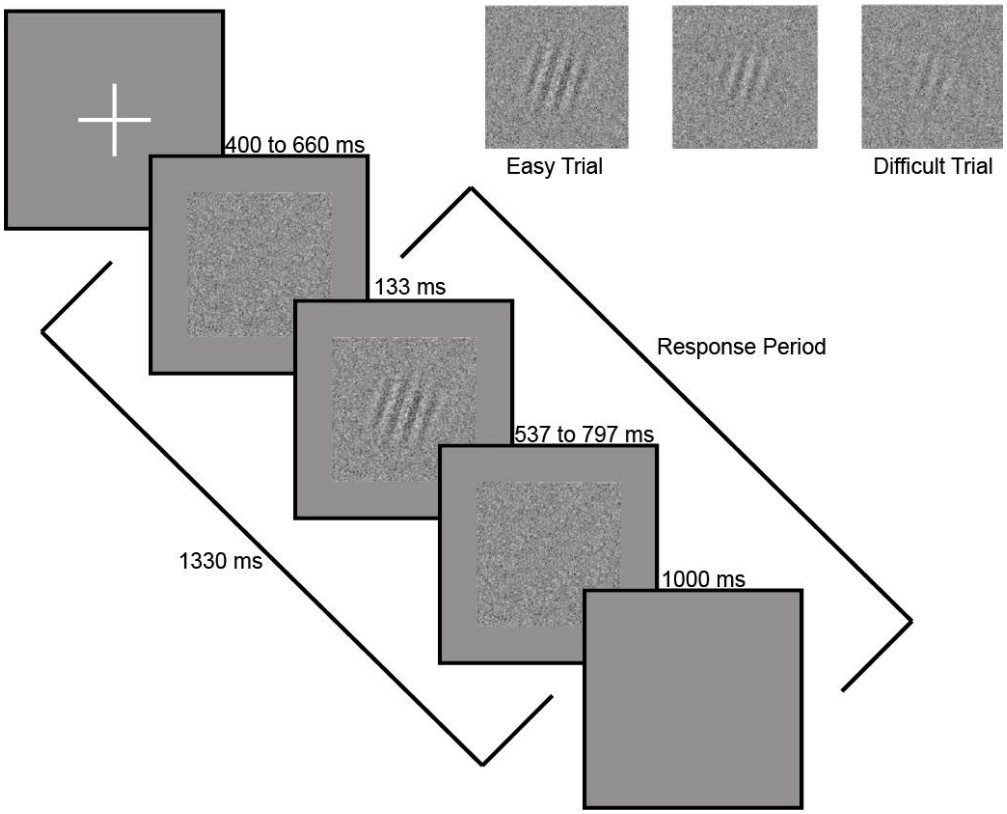

Figure 6: Experimental design including presentation times. An easy trial indicates a high-contrast visual stimulus, whereas a difficult trial indicates a low-contrast visual stimulus.

3.1.4 Procedure

Participants were seated in a dark, quiet room, at a desktop computer (Lenovo ThinkCentre M710s, model: 0037US), approximately 60 centimeters away from the computer monitor (Acer LCD Monitor, model: X223W). Participants were read the task instructions aloud by a research assistant and completed a practice trial to familiarize themselves with the task stimuli. Participants were instructed to indicate the presence of stimuli by pressing the space bar on the computer keyboard as quickly and as accurately as possible. The task consisted of ten trials at each of the 8 contrast levels and 80 null trials, resulting in a total of 160 trials. Trial order was randomized. Participants were allotted a short break halfway through the task, which lasted approximately 2 minutes.

3.1.5 Self-Report Questionnaires

Sensory Profile. The Sensory Profile - Adolescent/Adult (SP-2; W. Dunn, 2014) was used to assess sensory function based on six sensory domains including auditory, visual, touch, oral, movement, and body position, as well as three behavioural domains involved in sensory processing including conduct, social emotion, and attention. Values representing four aspects of sensory processing were calculated: seeking, avoiding, sensitivity, and low registration. These four quadrants have fairly strong internal consistency, with Cronbach's alphas of 0.60, 0.77, 0.78, and 0.78, respectively (Brown, Tollefson, Dunn, Cromwell, & Filion, 2001). This study is specifically concerned with the Visual Processing Score and the Sensitivity Quadrant Score. This 60-item scale included items such as "I am bothered by bright lights". Participants report their answers on a 5-point Likert Scale ranging from "Almost Always" to "Almost Never".

Repetitive Behaviours Questionnaire. The Repetitive Behaviours Questionnaire, Second Edition (RBQ-2; Honey et al., 2012) measures the frequency and severity of repetitive behaviours, restricted interests, and insistence on sameness. The adult version of this 20-item questionnaire includes items such as "Do you rock backwards and forwards, or side to side, either when sitting or standing?". The RBQ-2 assesses four main factors of repetitive behaviours including repetitive motor movements, rigidity and adherence to routine, preoccupation with restricted patterns of interest, and unusual sensory interests.

The RBQ-2 has an internal consistency of alpha = 0.83 for the total score (Barrett et al., 2015).

3.1.6 Analysis

A mean accuracy was calculated for each participant at each contrast level and frequency. These accuracies were then separately fit for each frequency with a psychometric curve using the *glmfit* function in MATLAB, from which, a 50% detection rate or threshold was extracted for each participant at each frequency. An individual's

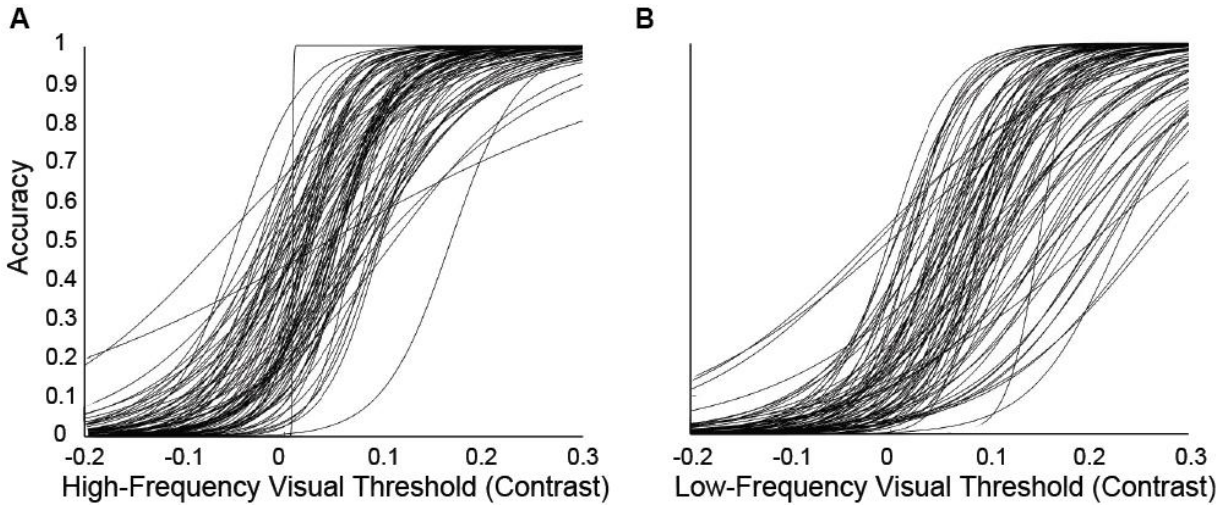

Figure 7:Visual threshold curves for each participant. (A) high-frequency stimuli. (B) low-frequency stimuli.

visual threshold is the contrast at which they are able to detect the stimuli half of the time, thus, lower thresholds are indicative of higher sensory sensitivity and *vice versa.*

To examine the relationships between behavioural sensitivity and self-reported sensory issues and RRBs, detection thresholds were related to all questionnaire measures of interest using Pearson Product-Moment Correlations. From the SP-2, this included the *Sensitivity Quadrant* Score and the *Visual Processing* Score, as well as the total score and all four subscales of the RBQ-2. To control for multiple comparisons, the Benjamini-Hochberg false discovery rate procedure was used (Q = 0.15).

To assess whether any differences between psychophysical and self-reported measures of sensory sensitivity had any potential impacts when explaining RRBs, two sets

of linear regression analyses were conducted predicting RBQ-2 scores. The predictor variables in the first set of analyses were high-frequency visual thresholds and SP-2 Visual Processing Scores. These predictors were used to predict the Total RBQ-2 Score as well as each RBQ-2 subscale. The second set of regressions matched the first set of regressions with the exception that the SP-2 Sensitivity Score was substituted in for the SP-2 Visual Processing Score. Thus, the total RBQ-2 score, as well as each of the four RBQ-2 subscales, were predicted by high-frequency visual thresholds and the SP-2 Sensitivity Score.

3.2 Results

Individual 50% visual detection thresholds were calculated for each participant for both high (M = 0.04 Michelson contrast, SD = 0.04) and low (M = 0.10 Michelson contrast, SD = 0.06) frequency stimuli. Mean scores were calculated for RBQ-2 Total and each of the RBQ-2 subscales, and all fell within the typical range (Barrett et al., 2015): Total RBQ-2 Score (M = 31.89, SD = 6.21), Repetitive Motor Movements (M = 9.49, SD = 2.86), Rigidity and Adherence to Routine (M = 10.51, SD = 2.68), Preoccupation with Restricted Patterns of Interests (M = 10.53, SD = 2.39), and Unusual Sensory Interests (M = 5.49, SD = 1.47). Average scores were also collected for the two subscales of interest on the SP-2, and both fell within the typical range: SP-2 Visual Processing (M = 22.55, SD = 4.60) and SP-2 Sensitivity Quadrant (M = 34.18, SD = 8.31).

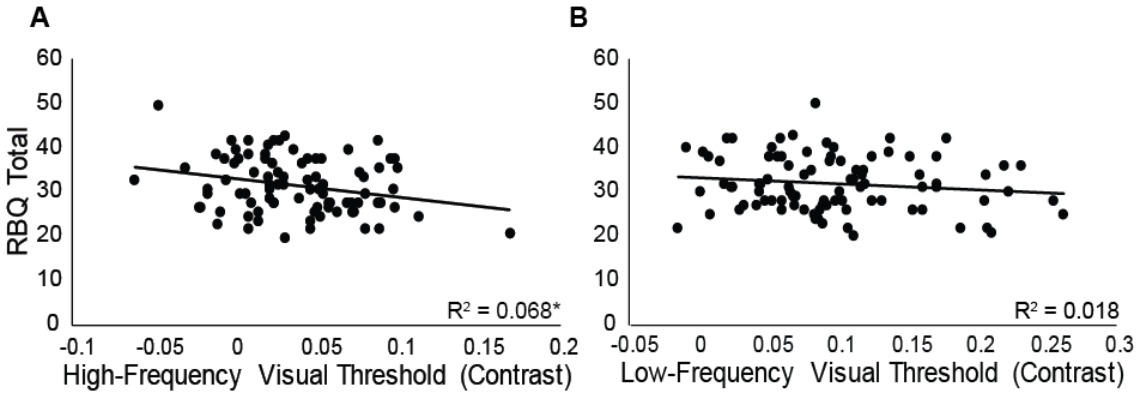

Figure 8: Correlations between Total Repetitive Behaviours Score and (A) high-frequency visual thresholds and (B) low-frequency visual thresholds. Note: Asterisks indicate FDR-corrected statistical significance.

3.2.1 Behavioural Sensitivity in Relation to RRBs

High-frequency visual thresholds were significantly, negatively correlated with Total Repetitive Behaviours ($r_{(88)}$ = -0.26, p = 0.01, $CI_{95\%}$ = 0.06 – 0.44), Preoccupation with Restricted Patterns of Interests ($r_{(88)}$ = -0.26, p = 0.01, $CI_{95\%}$ = -0.44 – -0.06), Unusual Sensory Interests ($r_{(88)}$ = -0.30, p = 0.005, $CI_{95\%}$ = -0.48 – 0.10), and Repetitive Motor Movements ($r_{(88)}$ = -0.20, p = 0.05, $CI_{95\%}$ = -0.39 – 0.01), but were not significantly correlated with Rigidity and Adherence to Routine ($r_{(88)}$ = -0.11, p = 0.32, $CI_{95\%}$ = -0.31 – 0.01). Therefore, as threshold values decrease, indicating higher sensitivity, total repetitive behaviours, repetitive motor movements, restricted interests, and unusual sensory patterns increased. Low-frequency visual thresholds were significantly related to high-frequency visual thresholds ($r_{(88)}$ = 0.56, p < 0.001, $CI_{95\%}$ = 0.40 – 0.69) but were not significantly related to any of the measures of RRBs: Total Repetitive Behaviours ($r_{(88)}$ = -0.13, p = 0.20, $CI_{95\%}$ = -0.33 – 0.08), Repetitive Motor Movements ($r_{(88)}$ = -0.05, p = 0.65, $CI_{95\%}$ = -0.25

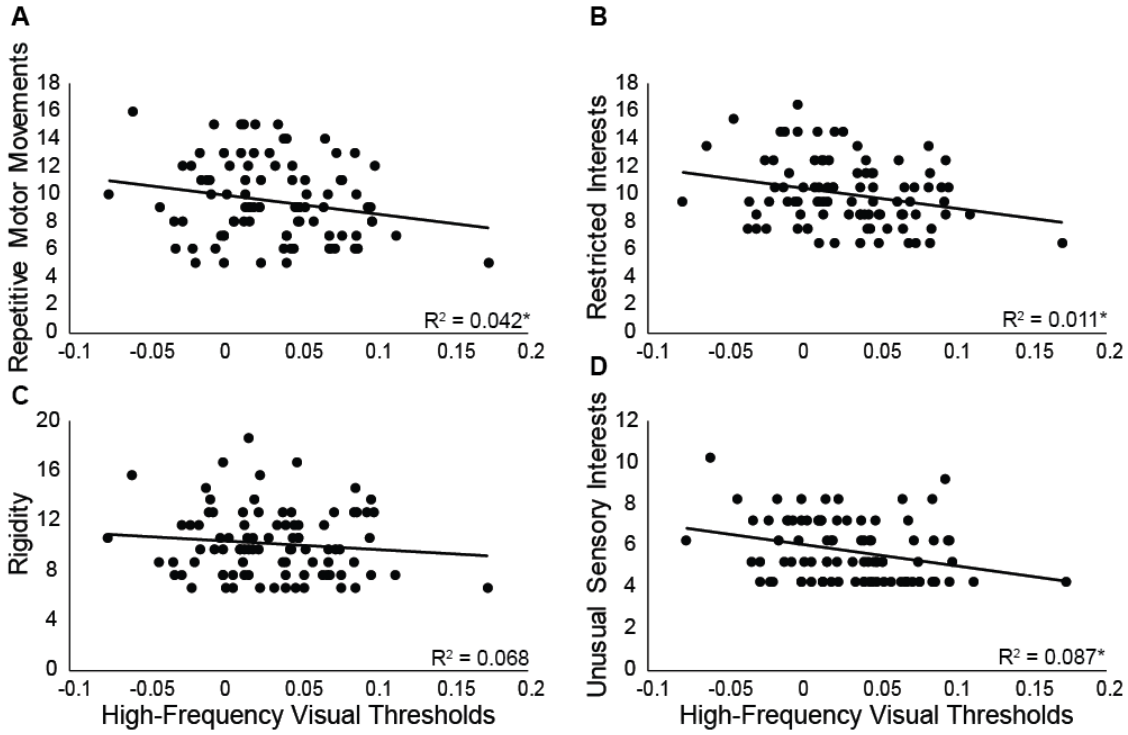

Figure 9: Correlations between high-frequency visual thresholds and RBQ-2 subscales, (A) Repetitive Motor Movements, (B) Rigidity, (C) Restricted Interests, and (D) Unusual Sensory Interests. Note: Asterisks indicate FDR-corrected statistical significance.

– 0.16), Rigidity and Adherence to Routine ($r_{(88)}$ = -0.11, p = 0.33, $CI_{95\%}$ = -0.31 – 0.10), Preoccupation with Restricted Patterns of Interests ($r_{(88)}$ = -0.18, p = 0.08, $CI_{95\%}$ = -0.37 – 0.03), and Unusual Sensory Interests ($r_{(88)}$ = -0.16, p = 0.14, $CI_{95\%}$ = -0.36 – 0.05).

3.2.2 Self-Reported Sensory Processing in Relation to RRBs

SP-2 Visual Processing score was significantly, positively correlated with all scales on the RBQ-2, Total Score ($r_{(88)}$ = 0.38, p < 0.001, $CI_{95\%}$ = 0.19 – 0.54), Repetitive Motor Movements ($r_{(88)}$ = 0.22, p = 0.04, $CI_{95\%}$ = 0.06 – 0.44), Rigidity ($r_{(88)}$ = 0.36, p < 0.001, $CI_{95\%}$ = 0.17 – 0.53), Restricted Interests ($r_{(88)}$ = 0.23, p = 0.03, $CI_{95\%}$ = 0.03 – 0.42), and Unusual Sensory Interests ($r_{(88)}$ = 0.33, p = 0.001, $CI_{95\%}$ = 0.13 – 0.50). Therefore, atypical visual processing is associated with all forms of repetitive behaviours by way of increased atypicality with increases in RRBs. A similar pattern was observed with relationships between the Sensitivity Quadrant Scale on the SP-2 and RBQ-2 scales except for the insignificant relationship with Repetitive Motor Movements ($r_{(88)}$ = 0.14, p = 0.20, $CI_{95\%}$ = -0.07 – 0.34). The remainder of the RBQ-2 scales were significantly related to the SP-2 Sensitivity Quadrant: Total RBQ-2 Score ($r_{(88)}$ = 0.33, p = 0.002, $CI_{95\%}$ = 0.13 – 0.50),

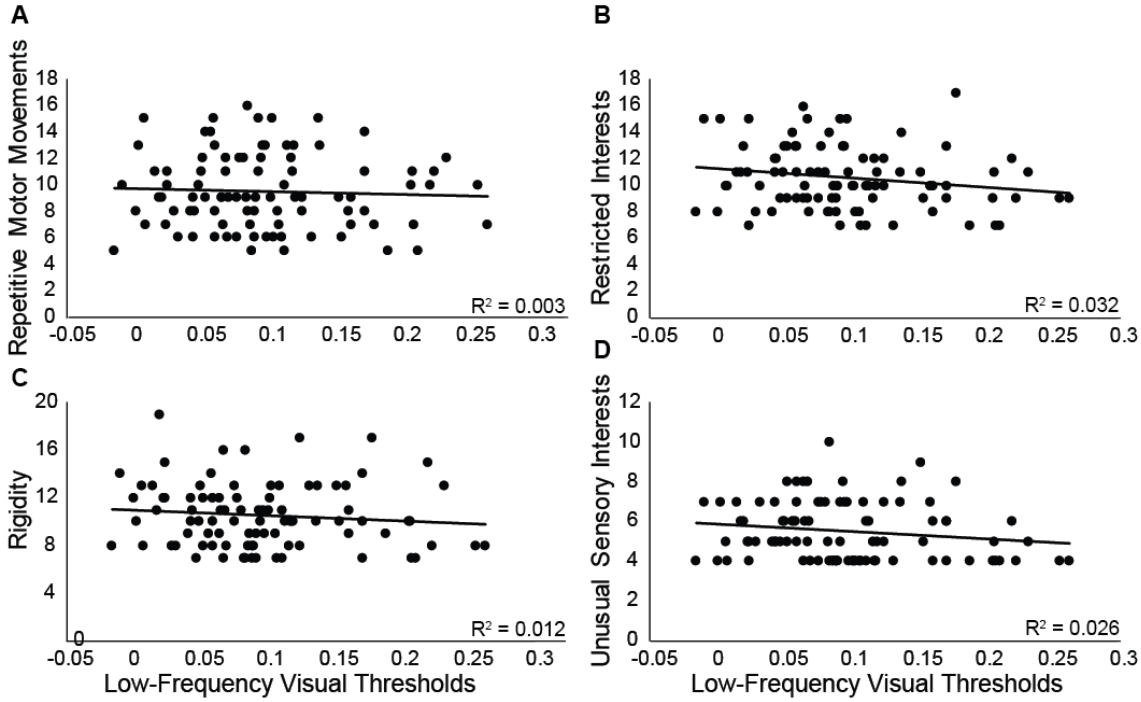

Figure 10: Correlations between low-frequency visual thresholds and RBQ-2 subscales, (A) Repetitive Motor Movements, (B) Rigidity, (C) Restricted Interests, and (D) Unusual Sensory Interests. No correlations reached statistical significance.

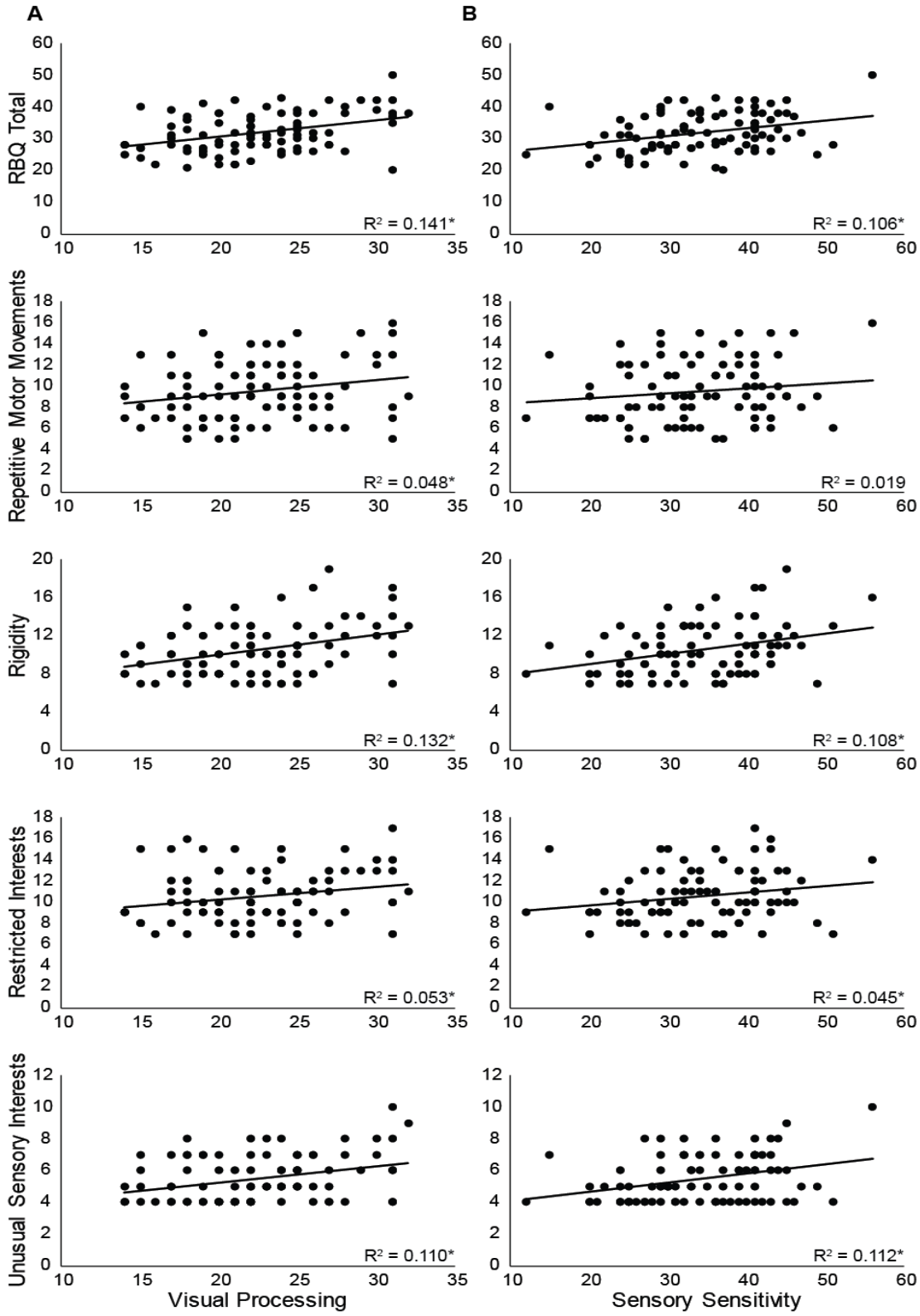

Figure 11: Correlations between RRBs Total Score/subscales scores and Panel (A) SP-2 Visual Processing Scale and Panel (B) SP-2 Sensory Sensitivity Quadrant.

Note: Asterisks indicate FDR-corrected significance.

Rigidity ($r_{(88)}$ = 0.33, p = 0.002, $CI_{95\%}$ = 0.13 – 0.50), Restricted Interests ($r_{(88)}$ = 0.21, p = 0.04, $CI_{95\%}$ = 0.004 – 0.40), and Sensory Interests ($r_{(88)}$ = 0.34, p = 0.001, $CI_{95\%}$ = 0.14 – 0.51). Again, this indicates that hypersensitivity is positively related to all forms of RRBs except repetitive motor movements.

3.2.3 Behavioural Sensitivity in Relation to Self-Reported Sensory Processing

The final correlational analyses examined the relationships between behavioural and self-reported sensitivity. Neither the SP-2 Visual Processing Scale ($r_{(88)}$ = -0.006, p = 0.96, $CI_{95\%}$ = -0.21 – 0.20) or the SP-2 Sensitivity Quadrant ($r_{(88)}$ = -0.14, p = 0.20, $CI_{95\%}$ = 0.34 – 0.07) were significantly related to high-frequency visual thresholds. Likewise, neither of the self-reported sensory measures, SP-2 Visual Processing ($r_{(88)}$ = -0.02, p = 0.82, $CI_{95\%}$ = 0.23 – 0.19) or SP-2 Sensitivity Quadrant ($r_{(88)}$ = -0.11, p = 0.29, $CI_{95\%}$ = 0.31 – 0.10), were related to low-frequency visual thresholds.

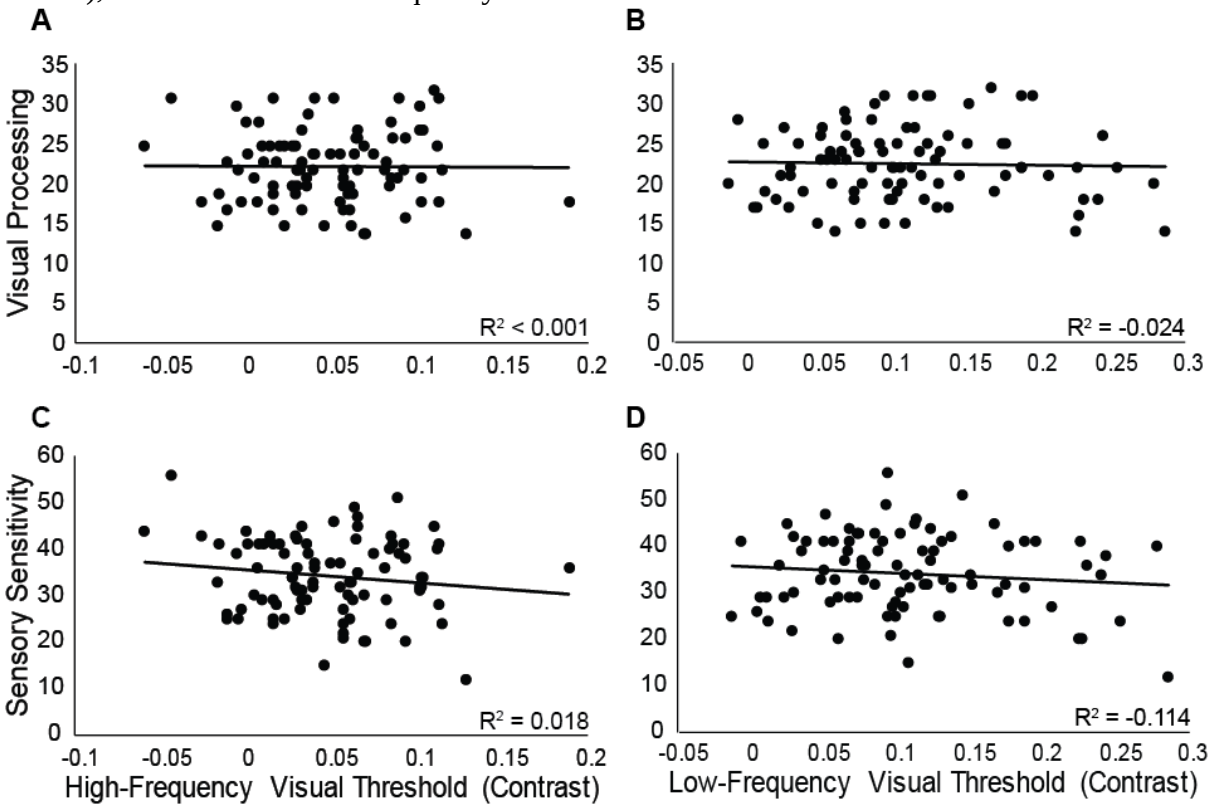

Figure 12: Correlations between SP-2 Visual Processing and (A) high-frequency and (B) low-frequency visual thresholds and SP-2 Sensory Sensitivity and (C) high-frequency visual thresholds and (D) low-frequency visual thresholds. No correlations reached statistical significance.

3.2.4 Predicting RRBs

Finally, to further differentiate between behavioural sensitivity and self-reported sensitivity, a series of regressions were conducted to determine if RRBs were affected independently by these differing measurement types. The first set of regressions predicted the Total Repetitive Behaviours Score and associated subscales of the RBQ-2 (Repetitive Motor Movements, Rigidity, Restricted Interests, and Unusual Sensory Interests) based on high-frequency visual thresholds and the SP-2 Visual Processing Score.

Table 4: Predicting RRBs by Visual Thresholds and SP-2 Visual Processing Score.

Predictor	β	t-value	Zero-Order Correlation (r)	Partial Correlation (pr)	P-Value
Model Predicting Total Repetitive Behaviours: R^2 = 0.21, F-change$_{(2,87)}$ = 11.36, p < 0.001*					
Visual Threshold	-0.26	-2.70	-0.26	-0.28	0.008*
SP-2 Vision	0.37	3.91	0.38	0.39	< 0.001*
Model Predicting Repetitive Motor Movements: R^2 = 0.09, F-change$_{(2,87)}$ = 4.23, p = 0.02*					
Visual Threshold	-0.20	-1.99	-0.20	-0.21	0.05*
SP-2 Vision	0.22	2.14	0.22	0.22	0.04*
Model Predicting Rigidity: R^2 = 0.14, F-change$_{(2,87)}$ = 7.29, p = 0.001*					
Visual Threshold	-0.10	-1.05	-0.11	-0.11	0.30
SP-2 Vision	0.36	3.67	0.36	0.37	< 0.001*
Model Predicting Restricted Interests: R^2 = 0.12, F-change$_{(2,87)}$ = 5.94, p = 0.004*					
Visual Threshold	-0.26	-2.58	-0.26	-0.27	0.01*
SP-2 Vision	0.23	2.27	0.23	0.24	0.03*
Model Predicting Unusual Sensory Interests: R^2 = 0.20, F-change$_{(2,87)}$ = 10.60, p < 0.001*					

Visual Threshold	-0.29	-3.05	-0.30	-0.31	0.003*
SP-2 Vision	0.33	3.43	0.33	0.35	0.001*

Note: Asterisk indicated FDR-corrected statistical significance.

Each model predicting the total or subscale scores of the RBQ-2 was significantly predicted by both visual thresholds and the SP-2 Visual Processing Scale. Upon examination of the partial correlations, in each model except when predicting Rigidity, it is apparent that both measures of sensory processing are accounting for distinct portions of the variance in RRBs. See Table 4 for detailed statistics.

A second set of regressions predicting RRBs was completed to determine whether behavioural sensitivity and the SP-2 Sensitivity subscale independently impact RRBs. All of the models, predicting Total Repetitive Behaviours, as well as each individual subscale, were significant, with the exception of the regression model predicting Repetitive Motor Movements. Again, strong partial correlations in the majority of these models suggest that both of the predictor variables are individually adding to the predictive ability of these models, with a few exceptions. Namely, the SP-2 Sensitivity Quadrant Scale does not add any explanation of variance to Restricted Interests whereas visual thresholds do not add any predictability above and beyond the Sensitivity Quadrant Scale in the prediction of Rigidity. See Table 5 for detailed statistics.

Table 5: Predicting RBBs by Visual Thresholds and SP-2 Sensitivity Quadrant Score.

Predictor	β	t-value	Zero-Order Correlation (r)	Partial Correlation (pr)	P-Value
Model Predicting Total Repetitive Behaviours: R^2 = 0.15, F-change$_{(2,87)}$ = 7.91, p = 0.001*					
Visual Threshold	-0.22	-2.21	-0.26	-0.23	0.03*
SP-2 Sensitivity	0.30	2.98	0.33	0.30	0.004*

Model Predicting Repetitive Motor Movements: R^2 = 0.05, F-change$_{(2,87)}$ = 2.48, p = 0.09					
Visual Threshold	0.19	-1.80	-0.20	-0.19	0.08*
SP-2 Sensitivity	0.11	1.06	0.14	0.11	0.29
Model Predicting Rigidity: R^2 = 0.11, F-change$_{(2,87)}$ = 5.47, p = 0.006*					
Visual Threshold	-0.63	-0.62	-0.11	-0.07	0.54
SP-2 Sensitivity	0.32	3.14	0.33	0.32	0.002*
Model Predicting Restricted Interests: R^2 = 0.10, F-change$_{(2,87)}$ = 4.85, p = 0.01*					
Visual Threshold	-0.24	-2.30	-0.26	-0.24	0.02*
SP-2 Sensitivity	0.18	1.77	-0.21	0.19	0.08*
Model Predicting Unusual Sensory Interests: R^2 = 0.18, F-change$_{(2,87)}$ = 9.26, p < 0.001*					
Visual Threshold	-0.25	-2.59	-0.30	-0.30	0.01*
SP-2 Sensitivity	0.30	3.06	0.34	0.34	0.003*

Note: Asterisk indicated FDR-corrected statistical significance.

3.3 Discussion

The purpose of this study was to provide a novel exploration into the relationship between RRBs and sensory sensitivities, measured both with behavioural psychophysics and questionnaires. The results confirmed a relationship between behavioural sensitivity and RRBs as well as the relationship between self-reported sensitivity and RRBs, suggesting that as sensitivity increases, the occurrence and severity of RRBs also increases. Strikingly, no significant correlation existed between behavioural and self-reported measures of sensitivity, and a regression analysis offered further confirmation that behavioural and self-reported measures account for different portions of the variance when

predicting RRBs. This suggests that these various measures of what are commonly referred to as sensory 'sensitivity' are in fact measuring discrete constructs.

The current study's hypothesis predicting that RRBs would increase with increasing sensory sensitivity are based on the prevailing evidence supporting this relationship in ASD (Boyd et al., 2010; Chen et al., 2009; Colman et al., 1976; Hutt & Hutt, 1965). The current results supported the hypothesis, conveying that sensory sensitivity, measured either behaviourally or through self-report, was significantly related to RRBs. It has been hypothesized that autistic individuals who are hypersensitive may exhibit an E/I imbalance in the cortex, with a tendency towards overexcitability, theoretically due to reduced levels of GABA (Rubenstein & Merzenich, 2003). It has been shown that autistic individuals have greater activation in the ventral visual stream when exposed to visual stimuli (Green et al., 2013). This excitatory neuronal state may result in a perceptually overwhelming state, and RRBs such as restricted interests, adherence to routine, and repetitive motor movements, may act as a homeostatic mechanism to control incoming sensory input and reduce exposure to novel stimuli and therefore limit any additional excitation (Green et al., 2013).

This E/I imbalance may also explain the discrepancy in the correlations between high and low frequency stimuli. Individuals who displayed higher levels of autistic traits in the form of RRBs demonstrated enhanced visual detection of high-frequency visual stimuli, but not low-frequency visual stimuli. This result is aligned with previous research suggesting that autistic individuals manifest greater issues with high-frequency stimuli compared to low-frequency stimuli (Kéïta et al., 2014). The theory of E/I imbalance is thought to disrupt lateral inhibition in early visual cortex, which would differentially impact perception of high-frequency stimuli compared to low-frequency stimuli (Kéïta et al., 2014).

In addition to providing behavioural evidence of the possible E/I imbalance, the current study is the first that we are aware of that documents the positive relationship between *behavioural* sensitivity and RRBs. The majority of the previous work exploring the relationship between sensory sensitivity and RRBs employs caregiver-reports of

sensitivity (Boyd et al., 2009; Chen et al., 2009; Schulz & Stevenson, 2018). Although these studies laid the foundational base upon which the current study was built, the current study makes a novel contribution by attempting to discriminate between behavioural and self-reported sensitivity in relation to autistic traits. Despite that both measures of sensory sensitivity were related to RRBs, the two measures themselves were not significantly correlated. Furthermore, both behavioural and self-reported sensitivity significantly contributed to the prediction of RRBs, and yet the results of the regression suggest that these two measures differentially predict RRBs. In other words, behavioural and self-reported 'sensitivity' account for distinct portions of the variance in RRBs, and consequently, may actually measure two distinct constructs. We hypothesize that these different constructs may reflect measurements of sensory *sensitivity* and sensory *reactivity*. That is, the behavioural task in this study reflects how (or whether) a participant perceived a visual sensory input. Specifically, the behavioural measure can be used to determine the threshold of each participant or at what intensity a participant is able to detect a given sensory input. On the other hand, questionnaire measures, particularly when reported by third parties, reflect behavioural responses, or *reactivity*, to a perceived sensory input. For the RBQ-2 specifically, many of the questions regarding sensitivity provide examples of reactions to sensory stimuli as part of the question to aid in the determination of the presence of a certain symptom. For example, one item reads "I like to keep the shades down during the day when I am at home." These types of questionnaires measure atypical, overt behaviours in response to a given sensory input that may or may not be perceived similarly to that of the average individual.

Differentiating sensory sensitivity and sensory reactivity may aid in the discovery of the contributing factors of RRBs by potentially differentiating between phenotypes. In some individuals RRBs may be due to atypical sensory sensitivity whereas in others, RRBs may simply be atypical behavioural reactions in the absence of sensory sensitivity. This has implications in areas of assessment and treatment if we wish to determine and treat underlying factors contributing to RRBs, resulting in improved, individualized treatment for autistic symptomatology. For example, if RRBs are a result of sensory sensitivities, sensitivity should be considered when planning treatments to reduce RRBs. In terms of

specific treatment for sensory sensitivity, one approach could be to reduce sensory input from the environment. On the other hand, if RRBs are a result of hyperreactivity rather than hypersensitivity, other therapy options may prove to be more fruitful, such as consequence and antecedent-based behavioural interventions or cognitive behavioural interventions.

In addition to differentiating between sensory sensitivity and sensory reactivity, the use of behavioural measures also addresses a common methodological concern with the practice of relating multiple self- or parent/caregiver reports which may culminate in general reporting bias as individuals who are willing to report more severe issues in one area are more likely to be willing to report more severe issues in another area as well.

In conclusion, behavioural sensitivity and self-reported sensory processing are both positivity related to RRBs. Furthermore, behavioural and self-reported sensitivity are uniquely predictive in the model of RRBs. This suggests that behavioural sensitivity and self-reported sensory processing may reflect distinct constructs, namely, sensitivity and reactivity, respectively. Understanding the distinction between sensory sensitivity and sensory reactivity and their implications on autistic symptoms may compel novel and personalized remediation of symptoms.

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4 Discussion

The objectives of this project were to relate sensory sensitivities to RRBs in ASD and to further differentiate between sensory sensitivity and sensory reactivity. The results suggest that as sensitivity increases so do repetitive behaviours in both autistic and TD children. However, the method of assessing sensitivity matters. The results displayed unique patterns of predictive ability of RRBs between self-reported measures of sensitivity and behavioural measures of sensitivity. These results have important implications for all aspects of ASD research from causes, to diagnosis, to intervention.

4.1 Causes

This work supports the theory of bottom-up processing in ASD. There are noticeable differences in low-level sensory processing in autistic individuals that can successfully predict the behavioural symptoms of ASD, specifically, hypersensitivity predicts RRBs. In accordance with the Enhanced Perceptual Functioning theory proposed by Bertone and colleagues (2005) and more specifically the Overarousal Hypothesis proposed by Hutt and colleagues (1964), this work provides potential evidence for a causal role of hypersensitivity on RRBs in ASD. Future research should use experimental studies to strengthen the argument of the causal role that hypersensitivity may play in the occurrence and severity of RRBs.

Furthermore, the different constructs measured by questionnaire and behavioural assessments may highlight differences in neurological functioning among autistic individuals. Sensory reactivity may occur regardless of perception and therefore may take place independently of perception (Sinclair, Oranje, Razak, Siegel, & Schmid, 2017). Whereas, sensory sensitivity is inherently a byproduct of perception. Further neurological studies should be conducted to determine if differences can be observed between autistic individuals in terms perception of versus reaction to sensory stimuli.

4.2 Diagnosis

Thus far, we have observed differences in symptomatology in autistic individuals attributed to unique differences in reactivity and sensitivity, yet, we see similar patterns of traits in individuals with and without ASD. This conflicting evidence in the consistency of symptomatology suggests a need to re-evaluate the diagnostic framework. This work supports an Research Domain Criteria (RDoC) framework which uses a dimensional scale of psychological constructs to classify dysfunction (Cuthbert & Insel, 2013). Thus, instead of classifying individuals on the autism spectrum, the domain of cognitive systems would have been analyzed in this study and participants would receive a report including varying perceptual issues, however, there would be separation between reactivity measured by self-report measures and sensitivity measured by behavioural measures. These distinct constructs could then be treated accordingly.

4.3 Intervention

The final piece of the puzzle is intervention, to treat autistic symptoms by treating the underlying contributing factors. Firstly, symptoms occur on a spectrum of severity, as can be seen by the wide variation in symptom severity among autistic individuals and the autistic traits observed in TD individuals to a lesser extent. Therefore, we should offer a range of intervention options for this range of symptom severities. Secondly, this discrepancy between sensory sensitivity and sensory reactivity and their impact on RRBs in crucial for interventions in autistic populations. Importantly, we must aim to intervene on the causes of autistic symptomatology rather than the symptoms themselves. Thus, clinicians should assess both sensory reactivity and sensory sensitivity when attempting to reduce RRBs and intervene accordingly. Future research should aim to develop practical tools for assessing both sensory sensitivity and sensory reactivity.

A version of this paper has been submitted for publication (Schulz & Stevenson, *submitted*).

4.4 References

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Appendix A

Ethics Approval

Western Research

Research Ethics

Western University Non-Medical Research Ethics Board
NMREB Delegated Initial Approval Notice

Principal Investigator: Prof. Ryan Stevenson
Department & Institution: Social Science\Psychology,Western University

NMREB File Number: 108105
Study Title: Linking sensory perception and communication, social competency, and personality traits

NMREB Initial Approval Date: June 27, 2016
NMREB Expiry Date: June 27, 2017

Documents Approved and/or Received for Information:

Document Name	Comments	Version Date
Western University Protocol	Received June 9, 2016	
Revised Assent		2016/06/09
Letter of Information & Consent	Parent Survey Only - Online	2016/06/09
Letter of Information & Consent	Adult Behavioural	2016/06/09
Letter of Information & Consent	Child Behavioural from Parent	2016/06/09
Letter of Information & Consent	Adult Survey Online	2016/06/09
Advertisement	SONA with EEG	2016/06/09
Advertisement	SONA no EEG	2016/06/09
Advertisement	Flyer Received June 9, 2016	
Other	Stimulus examples Received June 9, 2016	
Instruments	WASI-KBIT items - Received June 9, 2016	
Instruments	AQ - Received June 9, 2016	
Instruments	BAPQ - Received June 9, 2016	
Instruments	EQ2 - Received June 9, 2016	2016/06/09
Instruments	Glassgow Sensory Scale - Received June 9, 2016	
Instruments	MSCS - Received June 9, 2016	
Instruments	RBQ - Received June 9, 2016	
Instruments	SCQ - Received June 9, 2016	
Instruments	SEQ - Received June 9, 2016	
Instruments	Social Responsiveness Scales - Received June 9, 2016	
Instruments	SP - Received June 9, 2016	
Instruments	Vineland Scan Bank - Received June 9, 2016	
Instruments	SQ - Received June 9, 2016	
Advertisement	Email - Adult Behavioural	2016/06/09
Advertisement	Email - Adult Survey	2016/06/09
Advertisement	Email - Parent Behavioural	2016/06/09
Advertisement	Email - Parent Survey	2016/06/09
Advertisement	Email Reminder - Adult Behavioural	2016/06/09
Advertisement	Email Reminder - Adult Survey	2016/06/09
Advertisement	Email Reminder - Parent Survey	2016/06/09
Advertisement	Email Reminder - Parent Behavioural	2016/06/09
Advertisement	Telephone Script	2016/06/09

The Western University Non-Medical Research Ethics Board (NMREB) has reviewed and approved the above named study, as of the NMREB Initial Approval Date noted above.

NMREB approval for this study remains valid until the NMREB Expiry Date noted above, conditional to timely submission and acceptance of NMREB Continuing Ethics Review.

The Western University NMREB operates in compliance with the Tri-Council Policy Statement Ethical Conduct for Research Involving Humans (TCPS2), the Ontario Personal Health Information Protection Act (PHIPA, 2004), and the applicable laws and regulations of Ontario.

Members of the NMREB who are named as Investigators in research studies do not participate in discussions related to, nor vote on such studies when they are presented to the REB.

The NMREB is registered with the U.S. Department of Health & Human Services under the IRB registration number IRB 00000941.

Western Research

Research Ethics

Western University Non-Medical Research Ethics Board
NMREB Delegated Initial Approval Notice

Date: 7 June 2018
To: Prof. Ryan Stevenson
Project ID: 109024
Study Title: Sensory Processing in development and in autism
Application Type: Continuing Ethics Review (CER) Form
Review Type: Delegated
REB Meeting Date: June 19, 2018
Date Approval Issued: 07/Jun/2018
REB Approval Expiry Date: 07/Jun/2019

Dear Prof. Ryan Stevenson,

The Western University Research Ethics Board has reviewed the application. This study, including all currently approved documents, has been re-approved until the
expiry date noted above.

REB members involved in the research project do not participate in the review, discussion or decision.

Western University REB operates in compliance with, and is constituted in accordance with, the requirements of the TriCouncil Policy Statement: Ethical Conduct for
Research Involving Humans (TCPS 2); the International Conference on Harmonisation Good Clinical Practice Consolidated Guideline (ICH GCP); Part C, Division 5
of the Food and Drug Regulations; Part 4 of the Natural Health Products Regulations; Part 3 of the Medical Devices Regulations and the provisions of the Ontario
Personal Health Information Protection Act (PHIPA 2004) and its applicable regulations. The REB is registered with the U.S. Department of Health & Human Services
under the IRB registration number IRB 00000940.

Please do not hesitate to contact us if you have any questions.

Sincerely,

[redacted]

Appendix B

Experiment I – Letter of Information

Western

Sensory Processing in development and in autism

Information letter – Parent

Prof. Ryan Stevenson
Department of Psychology
Western University
[redacted]

1. Invitation to participate

You're child is invited to participate in a study investigating how sensory processing influences how we interact with the world, how that changes as you grow up, and where there are differences in individuals with autism. There will be two groups of participants recruited, individuals with and without autism spectrum disorder, with 800 individuals recruited in total, ranging in age from 4 to 65.

2. Purpose of the Study

The purpose of the study is to understand how people use the things they hear and see, how they put what they hear and see together, and how this processes develops to impact how people interact with the world, particularly those with autism. Almost everything people do in the world depends on how we perceive the world. Little is known about difference in how each one of us as individuals see, hear, and feel the world around us impact our communicative abilities, social abilities, and personalities. This study seeks to explore these relationships. This project is for research only, there is no clinical therapy element involved.

3. How long will you be in the study?

The study will take from 1-4 hours, depending on which portion of the experiment your child is participating in today. Behavioural, eye tracking, EEG, fMRI, and questionnaire portions will last no longer that 2 hours to complete. If you would like to complete multiple portions of the experiment, you can. Each portion will be described individually below.

4. **What are the study procedures?**

All Participants

In order to participate, individuals must: a) normal or corrected-to-normal hearing and vision; and b) no known neurological issues (epilepsy, brain injury, etc.). If you have an ASD diagnosis, we will also ask you to bring verification of diagnosis, and you or your child to participant in a diagnostic verification task. This study will take place at four possible locations on the campus of the University of Western Ontario:

1. Westminster Hall
2. Natural Sciences Centre
3. Western Interdisciplinary Research Building
4. Robarts Research Institute

Questionnaires:

You will be asked to complete several questionnaires about a range of your child's personal skills and characteristics on paper or computer-based forms, and will be asked to complete a problem solving task and vocabulary test. This portion of participation may last up to two hours. Participation will take place at Western Universities London campus or online.

Behavioural:

Your child will be asked to look at pictures, listen to sounds, feel gentle taps, and watch some short videos that have been created specifically to understand how people attend to and understand what they see and what they hear. During the session, their eye movements will be recorded and tracked using eye-tracking equipment.

EEG:

If your child is volunteering to participated in an EEG session, they will be asked to wear a soft, damp net over your head while they attend to the presentations that will allow us to non-invasively record your child's brain's activity. We will ask them to not wear makeup to an EEG session, and hair products (i.e. a hair dryer, shampoo, towels) will be provided following the EEG. This portion of participation may last up to two hours.

fMRI:

If your child is volunteering to participated in an fMRI session, in order to participate, they will be screened for exclusionary criteria of the MRI itself, including:

1) Age outside of 4-65 years old
2) Weight more than 300 pounds due to scanner table limitations.
3) Significant medical illness (for example, cancer, HIV) or neurological illness (stroke, brain
   tumor, multiple sclerosis, epilepsy)
4) Active substance abuse or dependence in the last 3 months, excluding caffeine and nicotine
5) Head injury that has resulted in loss of consciousness for over 30 minutes
6) Pregnancy/possibility of pregnancy
7) Presence of any metal implant or shrapnel in the body
8) Claustrophobia
9) Breathing problems or motion disorders
8) Body piercing/tattoos
9) Permanent makeup
10) Dentures
11) Radiation seeds/implants
12) Pacemakers or implantable stimulation systems

Because the scanner environment is very unusual and potentially uncomfortable they will have the choice to first participate in a training program designed to familiarize you with the MRI scanning machine. In this case, participation will involve coming to Western on two occasions. On the first visit, your child would practice participating in the MRI experiment in a special training facility and complete standardized tests. This includes lying on a “mock scanner” bed with a replica head coil, and being placed into an MRI scanner. You will be able to hear the noises the scanner will make, and experience what it will be like to be in the scanner.On the second visit, you will participate in the actual imaging procedure. If they are comfortable participating in the actual MRI on the first visit, that is also possible. The MRI training facility is located in room 221 of the Westminster Hall, which is located at 361 Windermere Rd. (near the corner of Windermere Rd. and Richmond St.). The actual MRI scanner is located in the Robarts Research Institute right beside the London Health Sciences Centre – University Campus on Perth Drive, just off Windermere Road in London Ontario.

Magnetic resonance imaging is a non-invasive technique that does not involve injections, x- rays, or radiation.

5. What are the risks and harms of participating?

All studies, including this study, pose the possibility of confidentiality risks. These risks will be minimized in every way possible, detailed in section 8 of this document.

fMRI only: There are no known biological risks associated with MR imaging. Some people cannot have an MRI because they have some type of metal in their body. For instance, if you have a heart pacemaker, artificial heart valves, metal implants such as metal ear implants, bullet pieces, chemotherapy or insulin pumps or any other metal such as metal clips or rings, they cannot have an MRI. During this test, you will lie in a small closed area inside a large magnetic tube. Some people may get scared or anxious in small places (claustrophobic). An MRI may also cause possible anxiety for people due to the loud banging made by the machine and the confined space of the testing area. You will be given either ear plugs or specially designed headphones to help reduce the noise.

6. What are the benefits of participating in this study?

Your child may not directly benefit from participating in this study but information gathered may provide benefits to society as a whole which include understanding the role that sensory perception plays in typical development, which may lead to theories and practices to help individuals who exhibit impaired sensory perception, such as those with autism.

7. Can participants choose to leave the study?

Participation is completely voluntary, *your child can withdraw from the study at any time*. If they decide to stop participating, they will still be eligible to receive the promised compensation for agreeing to be in this project. In the event they withdraw from the study, all associated data collected will be immediately destroyed wherever possible.

8. How will participants' information be kept confidential?

All information obtained during the study will be held in strict confidence to the fullest extent possible by law. While we do our best to protect your child's information there is no guarantee that we will be able to do so. The inclusion of your child's name, contact information, and date of birth may allow someone to link the data and identify them. To mitigate this risk to the greatest extent possible, all data will be de-identified immediately following collection and labelled with a Participant ID, and the file linking your identifying information and Participant ID will be kept under lock and key. Only study team will have access to study-related information, and representatives of The Western University Health Sciences Research Ethics Board may require access to your study-related records to monitor the conduct of the research. The experimental data acquired in this study may, in an anonymized form that cannot be connected to your child, be used for teaching purposes, be presented at meetings, published, shared with other scientific researchers or used in future studies. Your child's name or other identifying information will not be

used in any publication or teaching materials without your specific permission. Study materials will be archived for 5 years following the completion of the study, analysis, and publication.

9. **Are participants compensated to be in this study?**

Compensation will be $5.00 for every 30 minutes of participation. If travelling from outside of London, travel expenses will be reimbursed.

10. **What are the Rights of Participants?**

Your child's participation in this study is voluntary. Your child may decide not to be in this study. Even if you consent to your child's participate you have the right to not answer individual questions or to withdraw from the study at any time.

We will give you new information that is learned during the study that might affect your child's decision to stay in the study.

You do not waive any legal right by signing this consent form.

11. **Whom do participants contact for questions?**

If you have questions about this research study please contact: Prof. Ryan Stevenson at the Department of Psychology, Western University, [redacted].

If you have any questions about your rights as a research participant or the conduct of this study, you may contact The Office of Research Ethics (519) 661-3036, email: ethics@uwo.ca.

Thank you for your interest and participation in this study, it is greatly appreciated!

This letter is yours to keep for future reference.

Appendix C

Experiment I – Consent Form

Sensory Processing in development and in autism

INFORMED CONSENT FORM

Prof. Ryan Stevenson
Department of Psychology
Western University
[redacted]

I have read the Letter of Information, have had the nature of the study explained to me and I agree to participate. All questions have been answered to my satisfaction.

Questionnaires:	☐ Yes	☐ No
Behavioural:	☐ Yes	☐ No
EEG:	☐ Yes	☐ No
fMRI:	☐ Yes	☐ No

Name (please print): _____

Signature: _____

Date: _____

Name of Person Obtaining Consent_____

Signature of Person Obtaining Consent_____

Date for Person Obtaining Consent_____

Appendix D

Experiment I – Child Letter of Information

Western

Sensory Processing in development and in autism

Assent form

Prof. Ryan Stevenson
Department of Psychology
Western University
[redacted]

1. Why are you here?

Dr. Stevenson wants to tell you about a study that will look at how children see, hear, and feel the world around them.

2. Why are they doing this study?

Dr. Stevenson wants see if how children see, hear, and feel the world changes how they grow up, and if every kid feel the world differently.

3. What will happen to you?

If you want to be in the study, we may do a couple different things.

1. We may do a few puzzles and word games.

2. We may do some computer activities where you'll see things on the screen, hear things through the speakers, or feel gentle taps on your hand or arm. While you do that, the researchers will watch where your looking on the screen.

EEG: ☐ Yes ☐ No
The researchers may also look at what your brain is doing. If you want to do that, they'll put a cap on your head that will be a little bit wet.

fMRI: ☐ Yes ☐ No

The researchers will also take pictures of your brain while you do the computer activity. The brain camera is a pretty big camera, and you'll lay down on a bed with your head in a helmet to help the camera get really good pictures. You'll have to lay really still, and the camera is quite noisy, so we'll give you ear plugs and headphones so it's not uncomfortable.

4. **Will there be any tests?**

There won't be any tests or grade as a part of this study.

5. **Will the study help you?**

This study will not help you directly, but in the future, it might help children who hear, see, and feel the world differently.

6. **Do you have to be in the study?**

You do not have to be in the study. No one will be mad at you if you do not want to do this. If you do not want to be in the study, tell Dr. Stevenson or your parents. Even if you say yes, you can change your mind later. It is up to you.

7. **What if you have any questions?**

You can ask questions at any time, now or later. You can talk to your family or Dr. Stevenson.

This letter is yours to keep for future reference.

Appendix E

Experiment I – Assent Form

Sensory Processing in development and in autism

Assent form

Prof. Ryan Stevenson
Department of Psychology
Western University
[redacted]

I want to participate in this study.

Print Name of Child _____

Date_____

Age _____

Name of Person Obtaining Consent_____

Signature of Person Obtaining Consent_____

Date for Person Obtaining Consent_____

Appendix F

Experiment II – Letter of Information

Western

Sensory Processing in development and in autism

Information letter – Adult

Prof. Ryan Stevenson
Department of Psychology
Western University
[redacted]

8. Invitation to participate

You're invited to participate in a study investigating how sensory processing influences how we interact with the world, how that changes as you grow up, and where there are differences in individuals with autism. There will be two groups of participants recruited, individuals with and without autism spectrum disorder, with 800 individuals recruited in total, ranging in age from 4 to 65.

9. Purpose of the Study

The purpose of the study is to understand how people use the things they hear and see, how they put what they hear and see together, and how this processes develops to impact how people interact with the world, particularly those with autism. Almost everything people do in the world depends on how we perceive the world. Little is known about difference in how each one of us as individuals see, hear, and feel the world around us impact our communicative abilities, social abilities, and personalities. This study seeks to explore these relationships. This project is for research only, there is no clinical therapy element involved.

10. How long will you be in the study?

The study will take from 1-4 hours, depending on which portion of the experiment you are participating in today. Behavioural, eye tracking, EEG, fMRI, and questionnaire portions will last no longer that 2 hours to complete. If you would like to complete multiple portions of the experiment, you can. Each portion will be described individually below.

11. **What are the study procedures?**

All Participants

In order to participate, individuals must: a) normal or corrected-to-normal hearing and vision; and b) no known neurological issues (epilepsy, brain injury, etc.). If you have an ASD diagnosis, we will also ask you to bring verification of diagnosis, and participant in a diagnostic verification task.

This study will take place at four possible locations on the campus of the University of Western Ontario:

1. Westminster Hall
2. Natural Sciences Centre
3. Western Interdisciplinary Research Building
4. Robarts Research Institute

Questionnaires:

You may be asked to complete several questionnaires about a range of personal skills and characteristics on paper or computer-based forms, and will be asked to complete a problem solving task and vocabulary test. This portion of participation may last up to two hours. Participation will take place at Western Universities London campus or online.

Behavioural:

You will be asked to look at pictures, listen to sounds, feel gentle taps, and watch some short videos that have been created specifically to understand how people attend to and understand what they see and what they hear. During the session, your eye movements will be recorded and tracked using eye-tracking equipment.

EEG:

If you are volunteering to participated in an EEG session, you will be asked to wear a soft, damp net over your head while you attend to the presentations that will allow us to non-invasively record your brain's activity. We will ask you to not wear makeup to an EEG session, and hair products (i.e. a hair dryer, shampoo, towels) will be provided following the EEG. This portion of participation may last up to two hours.

fMRI:

If you are volunteering to participated in an fMRI session, in order to participate, you will be screened for exclusionary criteria of the MRI itself, including:

1) Age outside of 4-65 years old
2) Weight more than 300 pounds due to scanner table limitations.
3) Significant medical illness (for example, cancer, HIV) or neurological illness (stroke, brain
   tumor, multiple sclerosis, epilepsy)
4) Active substance abuse or dependence in the last 3 months, excluding caffeine and nicotine
5) Head injury that has resulted in loss of consciousness for over 30 minutes
6) Pregnancy/possibility of pregnancy
7) Presence of any metal implant or shrapnel in the body
8) Claustrophobia
9) Breathing problems or motion disorders
8) Body piercing/tattoos
9) Permanent makeup
10) Dentures
11) Radiation seeds/implants
12) Pacemakers or implantable stimulation systems

Because the scanner environment is very unusual and potentially uncomfortable you will have the choice to first participate in a training program designed to familiarize you with the MRI scanning machine. In this case, participation will involve coming to Western on two occasions. On the first visit, you would practice participating in the MRI experiment in a special training facility and complete standardized tests. This includes lying on a “mock scanner” bed with a replica head coil, and being placed into an MRI scanner. You will be able to hear the noises the scanner will make, and experience what it will be like to be in the scanner. On the second visit, you will participate in the actual imaging procedure. If you are comfortable participating in the actual MRI on the first visit, that is also possible. The MRI training facility is located in room 221 of the Westminster Hall, which is located at 361 Windermere Rd. (near the corner of Windermere Rd. and Richmond St.). The actual MRI scanner is located in the Robarts Research Institute right beside the London Health Sciences Centre – University Campus on Perth Drive, just off Windermere Road in London Ontario.

Magnetic resonance imaging is a non-invasive technique that does not involve injections, x- rays, or radiation.

12. **What are the risks and harms of participating?**

All studies, including this study, pose the possibility of confidentiality risks. These risks will be minimized in every way possible, detailed in section 8 of this document.

fMRI only: There are no known biological risks associated with MR imaging. Some people cannot have an MRI because they have some type of metal in their body. For instance, if you have a heart pacemaker, artificial heart valves, metal implants such as metal ear implants, bullet pieces, chemotherapy or insulin pumps or any other metal such as metal clips or rings, they cannot have an MRI. During this test, you will lie in a small closed area inside a large magnetic tube. Some people may get scared or anxious in small places (claustrophobic). An MRI may also cause possible anxiety for people due to the loud banging made by the machine and the confined space of the testing area. You will be given either ear plugs or specially designed headphones to help reduce the noise.

13. **What are the benefits of participating in this study?**

You may not directly benefit from participating in this study but information gathered may provide benefits to society as a whole which include understanding the role that sensory perception plays in typical development, which may lead to theories and practices to help individuals who exhibit impaired sensory perception, such as those with autism.

14. **Can participants choose to leave the study?**

Participation is completely voluntary, *you can withdraw from the study at any time*. If you decide to stop participating, you will still be eligible to receive the promised compensation for agreeing to be in this project. In the event you withdraw from the study, all associated data collected will be immediately destroyed wherever possible.

15. **How will participants' information be kept confidential?**

ALL INFORMATION OBTAINED DURING THE STUDY WILL BE HELD IN STRICT CONFIDENCE TO THE FULLEST EXTENT POSSIBLE BY LAW. WHILE WE DO OUR BEST TO PROTECT YOUR INFORMATION THERE IS NO GUARANTEE THAT WE WILL BE ABLE TO DO SO. THE INCLUSION OF YOUR NAME, CONTACT INFORMATION, AND DATE OF BIRTH MAY ALLOW SOMEONE TO LINK THE DATA AND IDENTIFY YOU. TO MITIGATE THIS RISK TO THE GREATEST EXTENT POSSIBLE, ALL DATA WILL BE DE-IDENTIFIED IMMEDIATELY FOLLOWING COLLECTION AND LABELLED WITH A PARTICIPANT ID, AND THE FILE LINKING YOUR IDENTIFYING INFORMATION AND PARTICIPANT ID WILL BE KEPT UNDER LOCK AND KEY. ONLY STUDY TEAM WILL HAVE ACCESS TO STUDY-RELATED INFORMATION, AND REPRESENTATIVES OF THE WESTERN UNIVERSITY HEALTH SCIENCES RESEARCH ETHICS BOARD MAY REQUIRE ACCESS TO YOUR STUDY-RELATED RECORDS TO MONITOR THE CONDUCT OF THE RESEARCH. THE EXPERIMENTAL DATA ACQUIRED IN THIS STUDY MAY, IN AN ANONYMIZED FORM THAT CANNOT BE CONNECTED TO YOU, BE USED FOR TEACHING PURPOSES, BE PRESENTED AT MEETINGS, PUBLISHED, SHARED WITH OTHER SCIENTIFIC RESEARCHERS OR USED IN FUTURE STUDIES. YOUR NAME OR OTHER IDENTIFYING INFORMATION WILL NOT BE USED IN ANY PUBLICATION OR TEACHING MATERIALS WITHOUT YOUR SPECIFIC PERMISSION. STUDY

MATERIALS WILL BE ARCHIVED FOR 5 YEARS FOLLOWING THE COMPLETION OF THE STUDY, ANALYSIS, AND PUBLICATION.

16. **Are participants compensated to be in this study?**

Yes. Participants from the SONA system will be compensated with 1 research credit per hour toward PSYC1000 for participating in this study. If you are enrolled in a course other than Psych 1000, your compensation will be based on your course outline. If you have any questions about the time or compensation, please feel free to contact the investigators before you consider signing the consent. Otherwise, compensation will be $5.00 for every 30 minutes of participation, and if travelling from outside of London, travel expenses will be reimbursed..

17. **What are the Rights of Participants?**

Your participation in this study is voluntary. You may decide not to be in this study. Even if you consent to participate you have the right to not answer individual questions or to withdraw from the study at any time. If you choose not to participate or to leave the study at any time it will have no effect on your academic standing if you are a student.

We will give you new information that is learned during the study that might affect your decision to stay in the study.

You do not waive any legal right by signing this consent form.

18. **Whom do participants contact for questions?**

If you have questions about this research study please contact: Prof. Ryan Stevenson at the Department of Psychology, Western University, [redacted]

If you have any questions about your rights as a research participant or the conduct of this study, you may contact The Office of Research Ethics (519) 661-3036, email: ethics@uwo.ca.

Thank you for your interest and participation in this study, it is greatly appreciated!

This letter is yours to keep for future reference.

Appendix G

Experiment II – Consent Form

Sensory Processing in development and in autism

INFORMED CONSENT FORM

Prof. Ryan Stevenson
Department of Psychology
Western University
[redacted]

I have read the Letter of Information, have had the nature of the study explained to me and I agree to participate. All questions have been answered to my satisfaction.

Questionnaires:	☐ Yes	☐ No
Behavioural:	☐ Yes	☐ No
EEG:	☐ Yes	☐ No
fMRI:	☐ Yes	☐ No

Name (please print): _____

Signature: _____

Date: _____

Name of Person Obtaining Consent_____

Signature of Person Obtaining Consent_____

Date for Person Obtaining Consent_____

Appendix H

Experiment I – Questionnaires

Sensory Sensitivities and RRBs

Demographics

- ○ Date of Birth (dd/mm/yy) _____
- ○ Current age (in years) _____
- ○ Gender (M/F) _____
- ○ Right or Left-Handed? _____
- ○ Primary Diagnosis _____
- ○ Any other diagnoses/impairments? If yes, please list _____
- ○ First language _____
- ○ Most frequently used language _____

By the age of 3, was your child's language as developed as their peers?

- ○ Yes
- ○ No

My child's hearing:

- ○ Has not been tested
- ○ Has been tested and no problems were found
- ○ Has been tested and difficulties were found

Estimated date of child's last hearing test (mm/yyyy)

_____

The following difficulties were found when my child's hearing was tested:

_____

Is your child currently participating in any kind of treatment or therapy services? _____

Please specify:

- ○ Type of treatment or service(s) _____
- ○ For how long? _____

Has your child received any kind of treatment or therapy services in the past?

- ○ Yes
- ○ No

Please specify:

- ○ Type of treatment or service(s) _____
- ○ For how long? _____
- ○ Any specific reason(s) for terminating?

_____

What is your highest level of education?

- ○ Less than high school diploma or equivalent
- ○ High school diploma or equivalency certificate
- ○ Trade certificate or diploma
- ○ College, CEGEP or other non-university diploma
- ○ Bachelors degree
- ○ Advanced degree (masters or doctorate)
- ○ Prefer not to say

What is your relationship to the child?

- ○ Mother
- ○ Father
- ○ Grandparent
- ○ Aunt/Uncle
- ○ Brother/Sister
- ○ Other: _____

What is your annual household income?

- ○ Less than $25,000
- ○ $25,000 to $39,999
- ○ $40,000 to $59,999
- ○ $60,000 to $79,999
- ○ $80,000 to $99,999
- ○ $100,000 or more
- ○ Prefer not to say

You may belong to one or more racial or cultural groups on the following list. Are you (check all that apply):

- ☐ White
- ☐ Black
- ☐ South Asian (e.g. East Indian, Pakistani, Sri Lankan)
- ☐ Chinese

- [ ] Filipino
- [ ] First Nations, Métis or Inuk (Inuit)
- [ ] Latin American
- [ ] Arab
- [ ] Southeast Asian (E.g. Vietnamese, Cambodian, Malaysian, Laotian)
- [ ] West Asian (e.g., Iranian, Afghan)
- [ ] Korean
- [ ] Japanese
- [ ] Other - Specify
- [ ] Prefer not to to say

Does your child identify with a different racial or cultural group than the one(s) selected above?

- ○ Yes
- ○ No

Please specify the racial or cultural group(s) your child identifies with:

_____

Do you have a preference regarding the terminology “individuals with autism” or “autistic individuals”?

- ○ Yes, I prefer “individuals with autism”
- ○ Yes, I prefer “autistic individuals”
- ○ No, I don’t mind either way
- ○ I don’t know
- ○ Other _____

Does your child have a preference regarding the terminology “individuals with autism” or “autistic individuals”?

- ○ Yes, my child prefers “individuals with autism”
- ○ Yes, my child prefers “autistic individuals”
- ○ No, my child doesn't mind either way
- ○ I don’t know if my child has a preference
- ○ Other _____

RBQ

Children often repeat the same behaviour over and over again, and some children are more repetitive than others. Please rate the repetitive behaviours your child has shown over the last month and rate the most usual ways he/she displays this behaviour.

	Never or Rarely	One or more times daily	15 or more times daily (or at least once an hour)	30 or more times daily (or twice an hour)
1. Arrange toys or other items in rows or patterns?	○	○	○	○
2. Repetitively fiddle with toys or other items? E.g. Spin, twiddle, bang, tap, twist, or flick anything repeatedly	○	○	○	○
3. Spin him/herself around and around?	○	○	○	○
4. Rock backwards and forwards, or side to side, either when sitting or when standing?	○	○	○	○
5. Pace or move around repetitively?	○	○	○	○
6. Make repetitive hand and/or finger movements? E.g. Flap, wave, or flick his/her hands or fingers repetitively	○	○	○	○

Does your child:	Never or rarely	Mild or occasional	Marked or notable
7. Have a fascination with specific objects? (e.g. trains, road signs or other things?)	○	○	○
8. Like to look at objects from particular or unusual angles?	○	○	○
9. Have a special interest in the smell of people or objects?	○	○	○
10. Have a special interest in the feel of different surfaces?	○	○	○
11. Have any special objects he/she likes to carry around? (e.g. a teddy, a blanket, a book, or a stick?)	○	○	○
12. Collect or hoard items of any sort?	○	○	○
13. Insist on things at home remaining the same? (e.g. furniture staying in the same place, things being kept in certain places, or arranged in certain ways?)	○	○	○
14. Get upset about minor changes to objects (e.g. flecks of dirt on his clothes, minor scratches on toys)	○	○	○
15. Insist that aspects of daily routine must remain the same?	○	○	○
16. Insist on doing things in a certain way or re- doing things until they are “just right”?	○	○	○
17. Play the same music, game or video, or read the same book repeatedly?	○	○	○
18. Insist on wearing the same clothes or refuse to wear new clothes?	○	○	○

19. Insist on eating the same foods, or a very small range of foods, at every meal?	○	○	○

	A range of different and flexible self- chosen activities	Some varied and flexible interests but commonly chooses the same activities	Almost always chooses from a restricted range of repetitive activities
20. Will your child choose if they are left to occupy themselves?	○	○	○

SP2	Almost Always	Frequently	Half the Time	Occasionally	Almost Never	Does Not Apply
1. Reacts strongly to unexpected or loud noises (for example, sirens, dog barking, hair dryer).	○	○	○	○	○	○
2. Holds hands over ears to protect them from sound.	○	○	○	○	○	○
3. Struggles to complete tasks when music or TV is on.	○	○	○	○	○	○
4. Is distracted when there is a lot of noise around.	○	○	○	○	○	○
5. Becomes unproductive with background noise (for example, fan, refrigerator).	○	○	○	○	○	○
6. Tunes me out or seems to ignore me.	○	○	○	○	○	○
7. Seems not to hear when I call his or her name (even though hearing is OK).	○	○	○	○	○	○
8. Enjoys strange noises or makes noise(s) for fun.	○	○	○	○	○	○
9. Prefers to play or work in low lighting.	○	○	○	○	○	○
10. Prefers bright colors or patterns for clothing.	○	○	○	○	○	○
11. Enjoys looking at visual details in objects.	○	○	○	○	○	○
12. Needs help to find objects that are obvious to others.	○	○	○	○	○	○
13. Is more bothered by bright lights than other same-aged children.	○	○	○	○	○	○

14. Watches people as they move around the room.	○	○	○	○	○	○
15. Is bothered by bright lights (for example, hides from sunlight through car window).	○	○	○	○	○	○
16. Shows distress during grooming (for example, fights or cries during haircutting, face washing, fingernail cutting).	○	○	○	○	○	○
17. Becomes irritated by wearing shoes or socks.	○	○	○	○	○	○
18. Shows an emotional or aggressive response to being touhed.	○	○	○	○	○	○
19. becomes anxious when standing close to others (for example, in a line).	○	○	○	○	○	○
20. Rubs or scratches a part of the body that has been touched.	○	○	○	○	○	○
21. Touches people or objects to the point of annoying others.	○	○	○	○	○	○
22. Displays need to touch toys, surfaces, or textures (for example, wants to get the feeling of everything).	○	○	○	○	○	○
23. Seems unaware of pain.	○	○	○	○	○	○
24. Seems unaware of temperature changes.	○	○	○	○	○	○
25. Touches people and objects more than same-aged children.	○	○	○	○	○	○
26. Seems oblivious to messy hands or face.	○	○	○	○	○	○
27. Pursues movement to the point it interferes with daily routines (for example, can't sit still, fidgets).	○	○	○	○	○	○

28. Rocks in chair, on floor, or while standing.	○	○	○	○	○	○
29. Hesitates going up or down curbs or steps (for example, is cautious, stops before moving).	○	○	○	○	○	○
30. Becomes excited during movement tasks.	○	○	○	○	○	○
31. Takes movement or climbing risks that are unsafe.	○	○	○	○	○	○
32. Looks for opportunities to fall with no regard for own safety (for example, falls down on purpose).	○	○	○	○	○	○
33. Loses balance unexpectedly when walking on an uneven surface.	○	○	○	○	○	○
34. Bumps into things, failing to notice objects or people in the way.	○	○	○	○	○	○
35. Moves stiffly	○	○	○	○	○	○
36. Becomes tired easily, especially when standing or holding the body in one position.	○	○	○	○	○	○
37. Seems to have weak muscles.	○	○	○	○	○	○
38. Props to support self (for example, holds head in hands, leans against a wall).	○	○	○	○	○	○
39. Clings to objects, walls or banisters more than same-aged children.	○	○	○	○	○	○
40. Walks loudly as if feet are heavy.	○	○	○	○	○	○
41. Drapes self over furniture or on other people.	○	○	○	○	○	○
42. Needs heavy blankets to sleep.	○	○	○	○	○	○

43. Gags easily from certain food textures or food utensils in mouth.	○	○	○	○	○	○
44. Rejects certain tastes or food smells that are typically part of children's diets.	○	○	○	○	○	○
45. Eats only certain tastes (for example, sweet, salty).	○	○	○	○	○	○
46. Limits self to certain food textures.	○	○	○	○	○	○
47. Is a picky eater, especially about food textures.	○	○	○	○	○	○
48. Smells nonfood objects.	○	○	○	○	○	○
49. Shows a strong preference for certain tastes.	○	○	○	○	○	○
50. Craves certain foods, tastes or smells.	○	○	○	○	○	○
51. Puts objects in mouth (for example, pencil, hands).	○	○	○	○	○	○
52. Bites tongue or lips more than same-aged children.	○	○	○	○	○	○
53. Seems accident-prone.	○	○	○	○	○	○
54. Rushes through coloring, writing or drawing.	○	○	○	○	○	○
55. Takes excessive risks (for example, climbs high into a tree, jumps off tall furniture) that compromise own safety.	○	○	○	○	○	○
56. Seems more active than same-aged children.	○	○	○	○	○	○

57. Does things in a harder way than is needed (for example, wastes time, moves slowly).	○	○	○	○	○	○
58. Can be stubborn and uncooperative.	○	○	○	○	○	○
59. Has temper tantrums.	○	○	○	○	○	○
60. Appears to enjoy falling.	○	○	○	○	○	○
61. Resists eye contact from me or others.	○	○	○	○	○	○
62. Seems to have low self-esteem (for example, difficulty liking self).	○	○	○	○	○	○
63. Needs positive support to return to challenging situations.	○	○	○	○	○	○
64. Is sensitive to criticisms.	○	○	○	○	○	○
65. Has definite, predictable fears.	○	○	○	○	○	○
66. Expresses feeling like a failure.	○	○	○	○	○	○
67. Is too serious.	○	○	○	○	○	○
68. Has strong emotional outbursts when unable to complete a task.	○	○	○	○	○	○
69. Struggles to interpret body language or facial expression.	○	○	○	○	○	○
70. Gets frustrated easily.	○	○	○	○	○	○
71. Has fears that interfere with daily routines.	○	○	○	○	○	○

72. Is distressed by changes in plans, routines, or expectations.	○	○	○	○	○	○
73. Needs more protection from life than same-aged children (for example, defenseless physically or emotionally).	○	○	○	○	○	○
74. Interacts or participates in groups less than same-aged children.	○	○	○	○	○	○
75. Has difficulty with friendships (for example, making or keeping friends).	○	○	○	○	○	○
76. Misses eye contact with me during everyday interactions.	○	○	○	○	○	○
77. Struggles to pay attention.	○	○	○	○	○	○
78. Looks away fro tasks to notice all actions in the room.	○	○	○	○	○	○
79. Seems oblivious within an active environment (for example, unaware of activity).	○	○	○	○	○	○
80. Stares intensively at objects.	○	○	○	○	○	○
81. Stares intensively at people.	○	○	○	○	○	○
82. Watches everyone when they move around the room.	○	○	○	○	○	○
83. Jumps from one thing to another so that it interferes with activities.	○	○	○	○	○	○
84. Gets lost easily.	○	○	○	○	○	○
85. Has a hard time finding objects in competing backgrounds (for example, shoes in a messy room, pencil in "junk drawer").	○	○	○	○	○	○

86. Seems unaware when people come into the room.	○	○	○	○	○	○

Appendix I

Experiment II – Questionnaires

Sensory Sensitivities and RRBs

Demographics

- Date of Birth (dd/mm/yyyy) (1) _____
- Current age (in years) (2) _____
- Gender (M/F/other) (3) _____
- Right or Left-Handed? (4) _____
- First language (5) _____
- Most frequently used language (6) _____

To your knowledge, did you have a language delay as a child?

- I did not have a language delay (1)
- I did have a language delay (2)
- I don't know (3)

Does anyone in your immediate biological family (parents, siblings, or children) have an autism spectrum disorder diagnosis?

- Yes (1)
- No (2)

Do you have an autism spectrum disorder diagnosis?

- ○ Yes (1)
- ○ No (2)

Do you have any other diagnosis (for example ADHD, OCD, etc)?

- ○ Yes (1)
- ○ No (2)

If so, what was the diagnosis or diagnoses?

_____

What is your highest level of education?

- ○ Less than high school diploma or equivalent
- ○ High school diploma or equivalency certificate
- ○ Trade certificate or diploma
- ○ College, CEGEP or other non-university diploma
- ○ Bachelors degree
- ○ Advanced degree (masters or doctorate)
- ○ Prefer not to say

What is your annual household income?

- ○ Less than $25,000 (1)
- ○ $25,000 to $39,999 (2)
- ○ $40,000 to $59,999 (3)
- ○ $60,000 to $79,999 (4)
- ○ $80,000 to $99,999 (5)
- ○ $100,000 or more (6)
- ○ Prefer not to say (99)

You may belong to one or more racial or cultural groups on the following list. Are you (check all that apply):

- ☐ White (1)
- ☐ Black (2)
- ☐ South Asian (e.g. East Indian, Pakistani, Sri Lankan) (3)
- ☐ Chinese (4)
- ☐ Filipino (5)
- ☐ First Nations, Métis or Inuk (Inuit) (6)
- ☐ Latin American (7)
- ☐ Arab (8)

- [ ] Southeast Asian (E.g. Vietnamese, Cambodian, Malaysian, Laotian) (9)
- [ ] West Asian (e.g., Iranian, Afghan) (10)
- [ ] Korean (11)
- [ ] Japanese (12)
- [ ] Other - Specify (13)
- [ ] Prefer not to to say (99)

Do you identify with a different racial or cultural group than the one(s) selected above?

- ○ Yes (1)
- ○ No (2)
- ○ Other

Please specify the racial or cultural group(s) you identify with:

_____

Do you have a preference regarding the terminology “individuals with autism” or “autistic individuals”?

- ○ Yes, I prefer “individuals with autism”
- ○ Yes, I prefer “autistic individuals”
- ○ No, I don’t mind either way
- ○ I don’t know
- ○ Other _____

RBQ

Please rate the repetitive behaviors you have experienced over the last month.

DO YOU…	**Never** or **Rarely**	**One** or more times daily	**15** or more times daily (or at least once an hour)	**30** or more times daily (or twice an hour)
1. like to arrange personal belongings or other items in rows or patterns?	○	○	○	○
2. Repetitively fiddle with personal belongings or other items? E.g. spin, twiddle, bang, tap, twist, or flick any objects repeatedly	○	○	○	○
3. Spin yourself around and around?	○	○	○	○
4. Rock backwards and forwards, or side to side, either when sitting or when standing?	○	○	○	○
5. Pace or move around repetitively? E.g. walk to and from across a room, or around the same path in a garden	○	○	○	○
6. Make repetitive hand and/or finger movements? *E.g. Flap, wave, or flick hands or fingers repetitively*	○	○	○	○

DO YOU…	**Never** or r**arely**	**Mild** or **occasional**	**Marked** or **notable**
7. Have a fascination with specific objects? E.g. trains, road signs, computers	○	○	○
8. Like to look at objects from particular or unusual angles?	○	○	○
9. Have a special interest in the smell of people or objects?	○	○	○
10. Have a special interest in the feel of different surfaces?	○	○	○
11. Have any special objects you like to carry around?	○	○	○
12. Collect or hoard items of any sort?	○	○	○
13. Insist on things at home remain the same? E.g. furniture staying in the same place or arranged in certain ways?	○	○	○
14. Get upset about minor changes to objects. E.g. flecks of dirt on your clothes, minor scratches on your belongings	○	○	○
15. Insist that aspects of your daily routine must remain the same?	○	○	○
16. Always do things in a certain way or redo things until they are “just right”?	○	○	○
17. Play the same music, game or video, or read the same book repeatedly?	○	○	○

18. Insist on wearing the same clothes or refuse to wear new clothes?	○	○	○
19. Insist on eating the same foods, or a very small range of foods, at every meal?	○	○	○

	A **range** of different and flexible self-chosen activities	**Some** varied and flexible interests but commonly chooses the same activities	**Almost always** chooses from a restricted range of repetitive activities
20. What sort of activity will you choose if you're by yourself?	○	○	○

SP-2	Almost Always	Frequently	Half the Time	Occasionally	Almost Never	Does Not Apply
1. I leave or move to another section when I smell a strong odor in a store (for example, bath products, candles, perfume).	○	○	○	○	○	○
2. I add spice to my food.	○	○	○	○	○	○
3. I don't smell things that other people say they smell.	○	○	○	○	○	○
4. I enjoy being close to people who wear perfume or cologne.	○	○	○	○	○	○
5. I only eat familiar foods.	○	○	○	○	○	○
6. Many foods taste bland to me (in other words, food tastes plain or does not have a lot of flavour).	○	○	○	○	○	○
7. I don't like strong tasting mints or candies (for example, hot/cinnamon or sour candy).	○	○	○	○	○	○
8. I go over to smell fresh flowers when I see them.	○	○	○	○	○	○
9. I'm afraid of heights.	○	○	○	○	○	○

10. I enjoy how it feels to move about (for example, dancing, running).	○	○	○	○	○	○
11. I avoid elevators and/or escalators because I dislike the movement.	○	○	○	○	○	○
12. I trip or bump into things.	○	○	○	○	○	○
13. I dislike the movement of riding in a car.	○	○	○	○	○	○
14. I choose to engage in physical activities.	○	○	○	○	○	○
15. I am unsure of footing when walking on stairs (for example, after bending over, getting up too fast).	○	○	○	○	○	○
16. I become dizzy easily (for example, after bending over, getting up too fast).	○	○	○	○	○	○
17. I like to go to places that have bright lights and that are colourful.	○	○	○	○	○	○
18. I keep the shades down during the day when I come home.	○	○	○	○	○	○
19. I like to wear colourful clothing.	○	○	○	○	○	○

20. I become frustrated when trying to find something in a crowded drawer in my messy room.	○	○	○	○	○	○
21. I miss the street, building, or room signs when trying to go somewhere new.	○	○	○	○	○	○
22. I am bothered by unsteady or fast moving visual images on TV.	○	○	○	○	○	○
23. I don't notice when people come into a room.	○	○	○	○	○	○
24. I choose to shop in smaller stores because I'm overwhelmed in large stores.	○	○	○	○	○	○
25. I become bothered when I see lots of movement around me (for example, at a busy mall, parade, or carnival).	○	○	○	○	○	○
26. I limit distractions when I am working (for example, I close the door, or turn off the TV).	○	○	○	○	○	○
27. I dislike having my back rubbed.	○	○	○	○	○	○
28. I like how it feels to get my hair cut.	○	○	○	○	○	○
29. I avoid wearing gloves during activities that will make my hands messy.	○	○	○	○	○	○

30. I touch others when I'm talking (for example, I put my hand on their shoulder or shake hands).	○	○	○	○	○	○
31. I am bothered by the feeling in my mouth when I wake up in the morning.	○	○	○	○	○	○
32. I like to go barefoot.	○	○	○	○	○	○
33. I'm uncomfortable wearing certain fabrics (for example, wool, silk, corduroy, tags in clothing).	○	○	○	○	○	○
34. I don't like particular food textures (for example, peaches with skin, applesauce, cottage cheese, chunky peanut butter).	○	○	○	○	○	○
35. I move away when others get too close to me.	○	○	○	○	○	○
36. I don't seem to notice when my face or hands are dirty.	○	○	○	○	○	○
37. I get scrapes or bruises but I don't remember how I got them.	○	○	○	○	○	○
38. I avoid standing in lines or standing too close to other people because I don't like to get too close to others.	○	○	○	○	○	○

39. I don’t seem to notice when someone touches my arm or back.	○	○	○	○	○	○
40. I work on more than two tasks at the same time.	○	○	○	○	○	○
41. It takes me more time to wake up in the morning.	○	○	○	○	○	○
42. I do things on the spur of the moment (in other words, I do things without making a plan ahead of time).	○	○	○	○	○	○
43. I find time to get away from my busy life and spend time by myself.	○	○	○	○	○	○
44. I rRejects certain tastes or food smells that are typically part of other's diets.	○	○	○	○	○	○
45. I don’t get jokes as quickly as others.	○	○	○	○	○	○
46. I stay away from crowds.	○	○	○	○	○	○
47. I find activities to perform in front of others (for example, music, sports, acting, public speaking, and answering questions in class).	○	○	○	○	○	○
48. I find it hard to concentrate for the whole time when sitting in a long class or meeting.	○	○	○	○	○	○

49. I avoid situations where unexpected things might happen (for example, going to unfamiliar places or being around people I don't know).	○	○	○	○	○	○
50. I hum, whistle, sing, or make other noises.	○	○	○	○	○	○
51. I startle easily at unexpected or loud noises (for example, vacuum cleaner, dog barking, telephone ringing).	○	○	○	○	○	○
52. I have trouble following what people are saying when they talk fast or about unfamiliar topics.	○	○	○	○	○	○
53. I leave the room when others are watching TV, or I ask them to turn it down.	○	○	○	○	○	○
54. I am distracted if there is a lot of noise around.	○	○	○	○	○	○
55. I don't notice when my name is called.	○	○	○	○	○	○
56. I use strategies to drown out sound (for example, close my door, cover my ears, wear ear plugs).	○	○	○	○	○	○
57. I stay away from noisy settings.	○	○	○	○	○	○
58. I like to attend events with a lot of music.	○	○	○	○	○	○

59. I have to ask people to repeat things.	○	○	○	○	○	○
60. I find it difficult to work with background noise (for example, fan, radio).	○	○	○	○	○	○

Curriculum Vitae

Name: Samantha Schulz

Post-secondary Education and Degrees:
University of Waterloo
Waterloo, Ontario, Canada
2011 – 2016 B.Sc (Health Science)

The University of Western Ontario
London, Ontario, Canada
2016 – Present M.Sc. (Psychology)

Honours and Awards:
University of Waterloo President's Scholarship
2011

Scholar Athlete Award
2016 – 2018

Dr. Benjamin Goldberg Award
2017 – 2018

C. Kingsley Allison Research Grant
2018 – 2019

Ontario Graduate Scholarship
2018 – 2019

Related Work Experience
Teaching Assistant
The University of Western Ontario
2016 – Present

Publications:

Schulz, S. E., & Stevenson, R. A. (*submitted*). Differentiating between sensory sensitivity and sensory reactivity in relation to autism-related restricted interests and repetitive behaviours. *Autism* (Aut-18-0249)

Schulz, S. E., & Stevenson, R. A. *(in press)* Sensory hypersensitivity predicts repetitive behaviours in autistic and typically developing children. *Autism*. doi: 10.1177/1362361318774559

Stevenson, R. A., Toulmin, J., Youm, A., Besney, R., Schulz, S. E., Barense, M., & Ferber, S. (2017) Increases in the autistic trait of attention to detail are associated with decreased multisensory temporal adaptation. *Nature: Scientific Reports*. DOI 10.1038/s41598-017-14632-1

Presentations:

Schulz, S. E., & Stevenson, R. A. (2018, May). *Comparing assessments of sensory sensitivity in relation to Autistic traits.* Developmental Disabilities Research Day 2018, London, ON.

Schulz, S. E., & Stevenson, R. A. (2018, May). *Relating sensory hypersensitivity and Autistic traits in typically-developed adults.* 2018 International Meeting for Autism Research, Rotterdam, NL.

Lauzon, S. A., Schulz, S. E., & Stevenson, R. A. (2018, May). *Multisensory integration and Autistic traits.* 2018 International Meeting for Autism Research, Rotterdam, NL.

Schulz, S. E., & Stevenson, R. A. (2018, February). *Comparing measures of sensitivity in relation to Autistic traits.* Lake Ontario Visionary Establishment, Niagara Falls, ON.

Jasim, S., Schulz, S. E., & Stevenson, R. A. (2018, February). *Auditory and visual discrimination tasks relate to Autistic traits.* Lake Ontario Visionary Establishment, Niagara Falls, ON.

Lauzon, S. A., Cohen, Z. L. Schulz, S. E., & Stevenson, R. A. (2018, February). *Multisensory integration and Autistic traits.* Lake Ontario Visionary Establishment, Niagara Falls, ON.

Schulz, S. E. & Stevenson, R. A. (2017, November). *Hypersensitivity and repetitive behaviours in Autism Spectrum Disorder.* Annual Division of Child and Adolescent Psychiatry Research Half Day, London, ON.

Schulz, S. E., & Stevenson, R. A. (2017, June). *Sensory hypersensitivity and repetitive behaviours in Autism and typically-developed children.* International Conference on Vision in the Real World, Toronto, ON.

Toulmin, J. K., Stevenson, R. A., Youm, A., Schulz, S. E., Barense, M. D., & Ferber, S. (2017, June). *Attention to detail predicts adaptation of statistics of sensory environment.* International Multisensory Research Forum, Nashville, TN.

Schulz, S. E., Segers, M., Ncube, B. L., Bebko, J. M., & Stevenson, R. A. (2017, May). *Sensory hypersensitivity and the predictability of repetitive behaviours in Autism Spectrum Disorder.* International Meeting for Autism Research, San Francisco, CA.

Stevenson, R. A., Toumlin, J., Youm, A., Schulz, S. E., & Ferber, S. (2017, May). *The relationship between audiovisual statistical learning and Autistic traits.* International Meeting for Autism Research, San Francisco, CA.

Schulz, S. E., Segers, M., Ncube, B. L., Bebko, J. M., & Stevenson, R. A. (2017, February). *Sensory sensitivity and repetitive motor movements in Autism compared to typical development.* Lake Ontario Visionary Establishment, Niagara Falls, ON.

Besney, R., Morden, E., Schulz, S. E., Sadler, T., & Stevenson, R. A. (2017, February). *Audiovisualstatistical learning and Autistic traits: An ERP study.* Lake Ontario Visionary Establishment, Niagara Falls, ON.

Sadler, T., Schulz, S. E., Besney, R., Morden, E., & Stevenson, R. A. (2017, February). *Auditory and visual sensory thresholds as predictive measure of Autism-related social difficulties.* Lake Ontario Visionary Establishment, Niagara Falls, ON.

Morden, E., Besney, R., Schulz, S. E., Sadler, T., & Stevenson, R. A. (2017, February). *The impact of synchrony perception on audiovisual integration.* Lake Ontario Visionary Establishment, Niagara Falls, ON.