Differentiating between sensory sensitivity and sensory reactivity in relation to restricted interests and repetitive behaviours

Samantha E Schulz and Ryan A Stevenson

Abstract
Recent studies have suggested that individuals who exhibit heightened sensitivity also exhibit higher rates and severity of restricted interests and repetitive behaviours. This line of research has been conducted almost exclusively through caregiver reports of sensitivity. Here, a more rigorous psychophysics paradigm was applied to assess sensory sensitivity and relate hypersensitivity to restricted interests and repetitive behaviours. In addition, commonly used questionnaire measures of sensory sensitivity were collected to determine if self-reported measures accurately reflect behavioural measures of sensory sensitivity. In all, 90 typically developing participants completed a visual detection task, a questionnaire measure of sensory processing and a measure of restricted interests and repetitive behaviours. Visual sensitivity, measured both behaviourally and with questionnaires, is positively related to restricted interests and repetitive behaviours. Surprisingly, visual sensitivity as measured behaviourally and through self-report are unrelated. Furthermore, a regression analysis suggests that while restricted interests and repetitive behaviours can be predicted based on both behaviourial and self-reported sensitivity, these two predictors account for different portions of the variance in restricted interests and repetitive behaviours. Thus, while these results provide evidence supporting the contribution of sensory sensitivity to restricted interests and repetitive behaviours, these results also indicate that behavioural and questionnaire measures of sensory sensitivity are measuring two distinct constructs. We hypothesize that behavioural measures are measuring sensory sensitivity, while questionnaires measures are in fact measuring sensory reactivity.

Keywords
adults, autism spectrum disorders, behavioural measurement, reactivity, repetitive behaviours and interests, sensitivity, sensory impairments

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 (American Psychiatric Association (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, Stevenson, & Wallace, 2015; Clery, Andersson, 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, McBee, Holtzclaw, Baranek, & Bodfish, 2009; Charlop, 1986; Chen, Rodgers, & McConachie, 2009; Colman, Frankel, Ritvo, & Freeman, 1976; Gabriels et al., 2008; Hutt, Hutt, Lee, & Ounsted, 1964; Kinsbourne, 1980; Lovaas, Newsom, & Hickman, 1987; Repp, Felce, & Barton, 1988; Schulz & Stevenson, 2019; 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

Western University, Canada

Corresponding author:
Samantha E Schulz, Western Interdisciplinary Research Building, Western University, 1151 Richmond Street, London, ON N6A 5B7, Canada.
Email: sschulz@uwo.ca
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 this study, in studies of visual perception (Ashwin, Ashwin, Rhydderch, Howells, & Baron-Cohen, 2009; Bertone, Mottron, Jelenic, & Faubert, 2003; Caplette, Wicker, & Gosselin, 2016; Clery, Andersson, et al., 2013; Clery, Bonnet-Brilhault, et al., 2013; Clery, Roux, 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, 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 (TD) 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 developed 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, Andersson, 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, Mottron, Jelenic, & Faubert, 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 a current neurobiological hypothesis, suggesting an imbalance 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 typically-developed individuals on measures of contrast sensitivity (Matson, Kiely, & Bamburg, 1997; Poustka & Lisch, 1993; Shafai, Armstrong, Iarocci, & Oruc, 2015; T. J. 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, 2019; 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, David, Poe, Stone, & Watson, 2006) and the Diagnostic Interview for Social and Communication Disorders (Leeakam, 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, specifically, has also been reported in parent reports (Black et al., 2017; Corbett, Schupp, Levine, & Mendoza, 2009; Schulz & Stevenson, 2019; Talay-Ongan & Wood, 2000).

One possible explanation for more consistency in questionnaire measures compared to behavioural paradigms regarding 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. Questionnaire measures, and particularly 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 on the assumption that increased reactions to sensory inputs are caused by increases in sensory sensitivity – an assumption that may not hold. While hypersensitivity may lead to hyperreactivity, a finding of hyperreactivity does not necessitate hypersensitivity. That is, an individual may be hyperreactive despite perceiving sensory inputs in a typical manner. For example, a child with auditory hypersensitivity may perceive a noise as being louder than their peers (hypersensitivity), and subsequently cover their ears. On the other hand, a child may perceive the same noise similarly to their peers, yet still exhibit the behavioural response of covering their ears (hyperreactivity). Importantly, while these two examples have distinct etiologies of the behaviour, from the standpoint of a third-party observer, they would be identical.

It is important to acknowledge the difference between sensory sensitivity and sensory reactivity and the impact this difference may have on autistic symptomatology. This issue is further convoluted because these terms are often used interchangeably, for example, the Sensory Experiences Questionnaire measures ‘hyperresponsivity’, whereas the Sensory Profile assesses ‘hypersensitivity’, but there is substantial overlap between items in these sections of their respective questionnaires. It is particularly important to distinguish between these two potentially different constructs 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, Lane, Angley, & Young, 2008; Bodfish, Symons, & Lewis, 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, 2019). This series of studies has suggested that sensory hypersensitivities are strongly correlated with the number, frequency and intensity of repetitive behaviours. 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 this project is to relate RRBs to sensory sensitivity. Furthermore, the aim is to compare two different methodologies of assessing sensory sensitivity, including a well-established psychophysical behavioural detection paradigm and self-reported questionnaires. These two assessment methodologies were contrasted to determine if behavioural measures of sensitivity and self-reported measures of sensitivity assess like constructs and are related to RRBs in a similar manner. We hypothesize that the results will show a positive relationship 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.

**Methods**

**Participants**

A total of 103 TD participants were recruited for this study. Participants were recruited from a database of undergraduate students enrolled in psychology courses at the University of Western Ontario. Previous research has found autistic traits distributed throughout the population, ranging from clinically relevant in autistic individuals to mild and non-distressing in the general population, including sensory issues (Baron-Cohen, Wheelwright, Hill, Raste, & Plumb, 2001; Baron-Cohen, Wheelwright, Skinner, Martin, & Clubley, 2001; Constantino & Todd, 2003; Hoekstra, Bartels, Verweij, & Boomsma, 2007; Horder, Wilson, Mendez, & Murphy, 2014; Jobe & White, 2007; Robertson, 2012; Robertson & Simmons, 2013; Ruzich et al., 2015; Scheeren & Stauder, 2008; Schulz & Stevenson, 2019; Stevenson et al., 2018; Stevenson et al., 2017). Thus, inferences can be made about clinical populations from TD participants as the distribution of autistic traits, specifically sensory sensitivity and RRBs, extends into the general population.

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.

**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 1h to complete. All study procedures were approved by the University of Western Ontario Research Ethics Board.
All stimuli were presented using MATLAB 2012b (Mathworks) software through the Psychophysics Toolbox extension (Brainard & Vision, 1997) on a monitor with a refresh rate of 16.67 ms (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 Michelson contrast, while Gabor patches were presented across a range of eight contrasts (0.3, 0.2, 0.15, 0.1, 0.075, 0.05, 0.025, 0.01). Stimuli were presented at two different frequencies, 9 (low-frequency) and 30 (high-frequency) cycles per degree (CPD). Each trial began with a white fixation cross on a grey screen (Figure 1). A 1330 ms presentation of dynamic visual white noise was presented subtending 400 × 400 pixels (9.8° visual angle), with a sinusoidal luminance grating embedded randomly between 400 and 660 ms following onset. Gabor patches were presented for 133 ms. Null trials were identical, with the exception that no Gabor patch was embedded in the white noise.

Procedure
Participants were seated in a quiet, dark room, at a desktop computer (Lenovo ThinkCentre M710s, model: 0037US), approximately 60 cm 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 10 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 min.

Self-report questionnaires
Sensory profile. The Sensory Profile – Adolescent/Adult (SP2; 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. The Visual

Figure 1. Experimental design (high-contrast visual stimuli), including presentation times.
Processing Score is one of the Sensory Section Summary Scores, which is commonly reported in Sensory Profile – 2 for children, and it is a summary score of all visual processing issues, with higher scores indicating greater visual processing dysfunction (Dunn, 2014). The Sensitivity Quadrant is a summary score which accounts for sensitivity in all sensory modalities. This 60-item scale included items such as ‘I am bothered by bright lights’. Participants report their answers on a 5-point Likert-type Scale ranging from ‘Almost Always’ to ‘Almost Never’.

Repetitive behaviours questionnaire. The Repetitive Behaviours Questionnaire, Second Edition (RBQ-2; Honey, McConachie, Turner, & Rodgers, 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 Adult Scale has an internal consistency of alpha = 0.83 for the total score (Barrett et al., 2015).

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 (Figure 2). An individual’s 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 Benjamin–Hochberg false discovery rate procedure was used (Q = 0.15).

To assess whether any differences between psycho-physical 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 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.

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 scores fell within the typical range for the average item score, ranging from 1 to 2.55 (Barrett et al., 2015). The average item score for participants ranged from 1 to 2.5 (M = 1.59, SD = 0.31), 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, 2.68), preoccupation with restricted patterns of interests (M = 10.53, SD = 2.39), and unusual sensory interests (M = 5.49, 1.47). The scores on the SP-2 varied greatly, with scores on the Visual Processing domain ranging from 12 to 56 (M = 22.55, SD = 4.60) and the scores on the Sensitivity Quadrant ranging from 14 to 32 (M = 34.18, SD = 8.31). Although some of these scores would be interpreted as ‘more than most people’ or ‘much more than most people’, the scores were still normally distributed as expected in a typically developed population (Brown & Dunn, 2002).

**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; Figure 3), Preoccupation with Restricted Patterns of Interests ($r(88) = -0.26$, $p = 0.01$, CI$_{95\%} = -0.44$ to −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) (Figure 4). 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; Figure 3), repetitive motor movements ($r(88) = -0.05$, $p = 0.65$, CI$_{95\%} = -0.25$–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; Figure 5).

**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 (Figure 6).

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 ($r(88) = 0.43$, $p = 0.002$, CI$_{95\%} = 0.13$–0.50), 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 unusual 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 (Figure 6).

**Behavioural sensitivity in relation to self-reported sensory processing**

The final correlational analyses examined the relationships between behavioural and self-reported sensitivity (Figure 7). Neither the SP-2 Visual Processing Scale ($r(88) = -0.06$, $p = 0.96$, 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...
Figure 4. Correlations between high-frequency visual thresholds and RBQ-2 subscales. (a) Repetitive motor movements. (b) Rigidity. (c) Restricted interests. (d) Unusual sensory interests.
*FDR-corrected statistical significance.

Figure 5. Correlations between low-frequency visual thresholds and RBQ-2 Subscales. (a) Repetitive motor movements. (b) Rigidity. (c) Restricted interests. (d) Unusual sensory interests.
No correlations reached statistical significance.
Figure 6. Correlations between self-reported sensory processing and RRBs. (a) SP-2 Visual Processing Scale related to total RBQ-2 Score and all RBQ-2 Subscales. (b) SP-2 sensory sensitivity quadrant related to total RBQ-2 Score and all RBQ-2 Subscales.

*FDR-corrected statistical significance.
Quadrant ($r_{88} = -0.11, p = 0.29, \text{CI}_{95\%} = 0.31-0.10$), were related to low-frequency visual thresholds.

**Predicting RRBs through regressions**

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 Scale. 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 1 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 2 for detailed statistics.

**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 increase. 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.

This study’s hypothesis predicting that RRBs would increase with increasing sensory sensitivity is 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). It is important to note that this study examined autistic traits in TD adults and not autistic individuals themselves; however, many studies have displayed the extension of autistic symptoms in the general population. Therefore, it is likely that these findings are generalizable to the autistic population if interpreted with caution, and further studies should examine this relationship in autistic individuals (Baron-Cohen, Wheelwright, Hill, et al., 2001; Baron-Cohen, Wheelwright, Skinner, et al., 2001; Constantino & Todd, 2003; Hoekstra et al., 2007; Horder et al., 2014; Robertson, 2012; Robertson & Simmons, 2013; Ruzich et al., 2015; Stevenson et al., 2018; Stevenson et al., 2017). 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 primary sensory cortical areas, with a tendency towards overexcitability, theoretically due to reduced levels of gamma-aminobutyric acid (GABA; Rubenstein & Merzenich, 2003). Although further research is required to examine GABA levels in TD individuals who exhibit

### Table 1. Predicting repetitive behaviours by visual thresholds and SP-2 Visual Processing Score.

<table>
<thead>
<tr>
<th>Predictor</th>
<th>β</th>
<th>t value</th>
<th>Zero-order correlation (r)</th>
<th>Partial correlation (pr)</th>
<th>p value</th>
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<td>Visual threshold</td>
<td>−0.29</td>
<td>−3.05</td>
<td>−0.30</td>
<td>−0.31</td>
<td>0.003*</td>
</tr>
<tr>
<td>SP-2 vision</td>
<td>0.33</td>
<td>3.43</td>
<td>0.33</td>
<td>0.35</td>
<td>0.001*</td>
</tr>
</tbody>
</table>

*FDR (false discovery rate)-corrected statistical significance.

### Table 2. Predicting RRBs by visual thresholds and SP-2 Sensitivity Quadrant Score.

<table>
<thead>
<tr>
<th>Predictor</th>
<th>β</th>
<th>t-value</th>
<th>Zero-order correlation (r)</th>
<th>Partial correlation (pr)</th>
<th>p value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Model predicting total repetitive behaviours: $R^2 = 0.15$, F-change$^{(2,87)} = 7.91$, $p = 0.001^{*}$</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Visual threshold</td>
<td>−0.22</td>
<td>−2.21</td>
<td>−0.26</td>
<td>−0.23</td>
<td>0.03*</td>
</tr>
<tr>
<td>SP-2 Sensitivity</td>
<td>0.30</td>
<td>2.98</td>
<td>0.33</td>
<td>0.30</td>
<td>0.004*</td>
</tr>
<tr>
<td>Model predicting repetitive motor movements: $R^2 = 0.05$, F-change$^{(2,87)} = 2.48$, $p = 0.09$</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Visual threshold</td>
<td>0.19</td>
<td>−1.80</td>
<td>−0.20</td>
<td>−0.19</td>
<td>0.08*</td>
</tr>
<tr>
<td>SP-2 Sensitivity</td>
<td>0.11</td>
<td>1.06</td>
<td>0.14</td>
<td>0.11</td>
<td>0.29</td>
</tr>
<tr>
<td>Model predicting rigidity: $R^2 = 0.11$, F-change$^{(2,87)} = 5.47$, $p = 0.006^{*}$</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Visual threshold</td>
<td>−0.63</td>
<td>−0.62</td>
<td>−0.11</td>
<td>−0.07</td>
<td>0.54</td>
</tr>
<tr>
<td>SP-2 Sensitivity</td>
<td>0.32</td>
<td>3.14</td>
<td>0.33</td>
<td>0.32</td>
<td>0.002*</td>
</tr>
<tr>
<td>Model predicting restricted interests: $R^2 = 0.10$, F-change$^{(2,87)} = 4.85$, $p = 0.01^{*}$</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Visual threshold</td>
<td>−0.24</td>
<td>−2.30</td>
<td>−0.26</td>
<td>−0.24</td>
<td>0.02*</td>
</tr>
<tr>
<td>SP-2 Sensitivity</td>
<td>0.18</td>
<td>1.77</td>
<td>−0.21</td>
<td>0.19</td>
<td>0.08*</td>
</tr>
<tr>
<td>Model predicting unusual sensory interests: $R^2 = 0.18$, F-change$^{(2,87)} = 9.26$, $p &lt; 0.001^{*}$</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Visual threshold</td>
<td>−0.25</td>
<td>−2.59</td>
<td>−0.30</td>
<td>−0.30</td>
<td>0.01*</td>
</tr>
<tr>
<td>SP-2 Sensitivity</td>
<td>0.30</td>
<td>3.06</td>
<td>0.34</td>
<td>0.34</td>
<td>0.003*</td>
</tr>
</tbody>
</table>

RRB: restricted interests and repetitive behaviours.

*FDR (false discovery rate)-corrected statistical significance.
higher levels of autistic traits, this study provides novel evidence for the continuum of autistic traits in the general population and a starting point for future research directions. In autistic individuals however, greater neural response in both primary auditory and visual areas has been demonstrated (among others, including amygdala and prefrontal cortex; Green et al., 2013). Furthermore, this study found that neural activation in primary sensory cortex, particularly visual cortex, was associated with parent-report based measures of sensory hyperreactivity. 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 in the primary sensory cortical areas (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. In relation to visual processing, 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. In relation to visual processing, the 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 in the primary sensory cortical areas (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. In addition to providing behavioural evidence of the possible E/I imbalance, this 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, 2019). Although these studies laid the foundational base upon which this study was built, this study makes a novel contribution by attempting to discriminate between behavioural and self-reported sensitivity in relation to autistic traits. Despite both measures of sensory sensitivity being 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 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, respectively. 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 explanation of the contributing factors of RRBs, which could possibly suggest an autistic phenotype in which some sensory issues are due to atypical sensory sensitivity, whereas others may 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. These results must be interpreted with caution as the TD participants of this study may have greater insight into their own behaviours and perceptions than autistic individuals (Mitchell & O’Keefe, 2008; T. Thompson, 2008) and again, these relationships should be examined in a clinical population in future research.

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. Although this issue is controlled for using a behavioural paradigm, there are other limitations in this study regarding the questionnaire data and sample. For example, RBQ-2 has only been validated in children and thus future studies are required to validate this questionnaire in an adult sample. Finally, while the sample included an equal number of males and females, this is not equivalent to the gender ratio in autism, which is more prevalent in males, potentially affecting the ability to generalize the results to the autistic population.
In conclusion, behavioural sensitivity and self-reported sensory processing are both positively 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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**References**


