Introduction

Autism spectrum disorder (ASD) is characterized by difficulties in social communication as well as restricted interests and repetitive behaviours. Repetitive behaviours 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 and Bodfish, 1998). Also included under the umbrella of repetitive behaviours and restricted interests in the Diagnostic and Statistical Manual of Mental Disorders (5th ed.; DSM-5) are atypical sensory issues, specifically hypo- and hypersensitivity to sensory input (American Psychological Association (APA), 2013; Baum et al., 2015). 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 (Szatmari et al., 2006).

Previous research on repetitive behaviours in children with ASD, however, suggested a link between repetitive behaviours and atypical sensory processing, specifically hypersensitivity. Preliminary studies found increased repetitive behaviours with increased stimulation from novel toys, unfamiliar people (Hutt and Hutt, 1965) or...

Sensory hypersensitivity predicts repetitive behaviours in autistic and typically-developing children

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Abstract

The objective of this study was to examine the relationship between sensory hypersensitivity and restricted interests and repetitive behaviours associated with autism spectrum disorder and their typically-developing peers. Furthermore, the aims included the examination of the relationship across sensory modalities and various types of restricted interests and repetitive behaviours. Data were collected from the parents of 114 children: 49 of whom were diagnosed with autism spectrum disorder and 65 typically-developing children. Parents completed the Sensory Profile 2 – Child Version and the Repetitive Behaviours Questionnaire, Second Edition. The results suggested that sensory hypersensitivity is strongly related to the core autism spectrum disorder symptom of repetitive behaviours. This relationship was not specific to autism spectrum disorder; repetitive behaviours significantly increased with sensory hypersensitivity in typically-developing individuals as well. This effect was consistent across all modalities in both autism spectrum disorder and typically developing groups; group differences were observed in the oral and tactile modalities. Furthermore, sensory hypersensitivity was significantly predictive of repetitive behaviours in all participants, autism spectrum disorder and typically-developing, and importantly, autism spectrum disorder diagnosis did not add any predictive influence above and beyond sensory hypersensitivity. Finally, sensory hypersensitivity was significantly predictive of all subdomains of repetitive behaviours, including repetitive motor movements, rigidity and adherence to routine, preoccupation with restricted patterns of interest and unusual sensory interests, and diagnosis added no predictive ability beyond sensory hypersensitivity.

Keywords

autism spectrum disorder, repetitive behaviours, restricted interests, sensory hypersensitivity, sensory processing
flickering lights (Colman et al., 1976). A recent series of
studies have explored the connection between sensory pro-
cessing and repetitive behaviours. 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-reported
measures of repetitive behaviours.

The first of these studies (Baker et al., 2008) related
sensory processing issues in autistic children (aged
2–9 years) to a broad measure of maladaptive behaviours,
including repetitive behaviours, using the Developmental
Behaviour Checklist (DBC; (Brereton et al., 2002) and the
Vineland Adaptive Behaviour Scale (VABS; (Perry and
Factor, 1989)). Although neither hypersensitivity nor
repetitive behaviours were isolated in this study, the results
displayed a relationship between dysfunctional sensory
processing and maladaptive behaviours, in general, laying
the necessary groundwork for future work to build upon
and test more specific hypotheses.

A follow-up study provided a more direct measure of
repetitive behaviours by using the Repetitive Behaviour
Scale (RBS; Bodfish et al., 1999) and compared it to over-
all sensory dysfunction in autistic children and adolescents
aged 3 to 19 years (Gabriels et al., 2008). In this study, a
significant correlation was observed between the total
RBS score and sensory processing such that greater sen-
sory processing issues were associated with increased
repetitive behaviours. Although this study did focus spe-
cifically on restricted interests and repetitive behaviours,
there still remains the question as to whether the relation-
ship between sensory processing and restricted interests
and repetitive behaviours would differ if varying types of
restricted interests and repetitive behaviours were consid-
ered individually.

Another study used the RBS to measure repetitive behav-
ours and utilized the subscales to compare specific types of
restricted interests and repetitive behaviours to sensory pro-
cessing as measured by the Sensory Questionnaire (SQ;
unpublished). In a group of children with ASD, a relation-
ship was observed between the SQ composite score and the
RBS subscale of stereotypies and compulsions. Furthermore,
the results suggested that the expression of repetitive behav-
ious was best predicted by group, age, SQ score, and
behavioural regulation (Boyd et al., 2009). This study uti-
ized a group of typically-developing (TD) controls; how-
ever, a direct, between-group comparison was not made,
leaving unanswered the question of whether this relation-
ship is specific to individuals with ASD.

A follow-up study also looked specifically at hypersen-
sitivity and restricted interests and included a comparison
between autistic children (mean chronological age (CA)
was 4 years) and children with development delays
(Boyd et al., 2010). This study used an extensive battery of
sensory measures, including not only the SP but also addi-
tional 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, hy-
persensitivity and sensory seeking. When controlling for
mental age (MA), gender, and diagnostic group, hypersen-
sitivity was significantly predictive of repetitive behav-
ious. More specifically, hypersensitivity was predictive of
stereotypies, compulsions, and rituals or sameness behav-
ours, but contradictory to the previous study, not restricted
interests. Notably, these two studies provide inconclusive
results regarding which specific forms of restricted inter-
ests and repetitive behaviours are related to hypersensitiv-
ity. In addition, 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 repetitive behaviours in various clinical
and TD populations is still required.

To our knowledge, only one study has examined the
specific relationship between sensory hypersensitivity and
restricted interests and repetitive behaviours (specifically
insistence on sameness) and directly compared this rela-
tionship with a group of TD controls. The results displayed
a very strong correlation between sensory hypersensitivity
shifted from general sensory processing dysfunction
towards sensory hypersensitivity. One such study differen-
tiated atypical sensory processing patterns into hyposensitiv-
ty and hypersensitivity in autistic children between the
ages of 8 and 16 years (Chen et al., 2009). Measures of
hypersensitivity, but not hyposensitivity, were signifi-
cantly 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 hypersensitivity as a
correlate of repetitive behaviours, 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 rela-
tionships in other clinical groups and in TD controls to
determine whether this relationship is specific to individu-
als with ASD.
and insistence on sameness in a group of children with ASD between the ages of 7 and 17 years. When this same relationship was examined in a group of TD children ages 7–18 years, 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 repetitive behaviours. However, of the few studies that have addressed the role of individual sensory modalities, or individual categories of repetitive behaviours, results have been mixed. Even more pressing, direct comparisons with metal-age-matched cohorts of TD children are much needed. As such, it is yet unknown whether this relationship between sensory processing and repetitive behaviours is specific to individuals diagnosed with ASD or if it is present in the general population. This study aims to address these gaps in the literature with four objectives:

1. To confirm the relationship between hypersensitivity and repetitive behaviours 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 repetitive behaviours;
4. To determine whether the relationship is specific to ASD.

We hypothesize that the relationship between repetitive behaviours 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 repetitive behaviours.

Methods

Participants

A total of 114 children and adolescents were recruited from schools and community autism groups for this study. Their ages ranged from 6 to 20 years (M = 11.30 years, standard deviation (SD) = 3.17 years) and 73 (64%) were male. Of the participants, 49 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; version 2; Lord et al., 2012) administered by research-reliable clinicians. Of the participants, 65 were TD: TD participants were excluded if they had a developmental disability or neuropsychiatric illness or if they had a first-order biological relative with ASD. Participants were well matched on 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 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 = 0.001, 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 = 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.

Materials and procedures

The Sensory Profile 2 (SP2) is an 86-item scale that assesses sensory function (Dunn, 2014). The child version is a caregiver report for children aged 3 to 14:11 years of age. For consistency, all parents completed the child version, even for individuals 15 years and above (N = 19). For each item, parents were asked to describe their child’s response to a sensory experience on a 5-point Likert-type scale ranging from ‘Almost Never’ to ‘Almost Always’. The SP2 assesses sensory processing in six sensory domains including auditory, visual, 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: hypersensitivity, sensory seeking, sensory, avoiding and low registration. Higher scores are associated with higher sensory dysfunction. The SP2 has been normalized on a sample of 1791 children and includes individuals with ASD. The quadrants of the SP2 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 SP2 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 et al., 2012). All parents completed the child version. Each item was scored on a 3- or 4-point Likert-type 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 4-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.

**Analysis**

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

Each item on the SP2 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 SP2, 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 (α = 0.724), Tactile (α = 0.773), Auditory (α = 0.887) and Oral (α = 0.916) Hypersensitivity.

Furthermore, the hypersensitivity score 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 α = 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 SP2 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 SP2 in total: the Sensitivity Quadrant score, Auditory Hypersensitivity, Visual Hypersensitivity, Tactile Hypersensitivity, 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 ≤ 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 ≤ 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 SP2 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 include 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 SP2. 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.

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 intelligence, 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 repetitive behaviours above and beyond what the demographic variables explained. Finally, 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. Pearson 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 Bonferroni-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.

Results

Symptomatic differences between diagnostic groups

Sensory hypersensitivity were exacerbated in ASD compared to the TD group in all SP2 scales (Figure 1), including the Sensitivity Quadrant (Mdn_{ASD} = 50; Mdn_{TD} = 24; U = 247.00, p < 0.001), Sensory Hypersensitivity (Mdn_{ASD} = 35; Mdn_{TD} = 17.5; U = 362.00, p < 0.001) and Auditory (Mdn_{ASD} = 13; Mdn_{TD} = 6; U = 321.00, p < 0.001), Visual (Mdn_{ASD} = 4; Mdn_{TD} = 2; U = 793.00, p < 0.001), Tactile (Mdn_{ASD} = 6; Mdn_{TD} = 3; U = 673.00, p < 0.001) and Oral (Mdn_{ASD} = 12; Mdn_{TD} = 6; U = 886.00, p < 0.001) Hypersensitivities.

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} = 33.5; Mdn_{TD} = 22.9; U = 432.00, p < 0.001), Repetitive Motor Movements (Mdn_{ASD} = 7; Mdn_{TD} = 5; U = 802.50, p < 0.001), Rigidity and Adherence to Routine (Mdn_{ASD} = 12; Mdn_{TD} = 8; U = 506.50, p < 0.001), Preoccupation with Restricted Patterns of Interest (Mdn_{ASD} = 13; Mdn_{TD} = 8; U = 699.00, p < 0.001), and Unusual Sensory Interests (Mdn_{ASD} = 6; Mdn_{TD} = 4; U = 835.50, p < 0.001).

Relating sensitivity and total repetitive behaviours

The Sensitivity Quadrant was significantly correlated with Total Repetitive Behaviours (Figure 3(a)), in both ASD (r_{47} = 0.77, p < 0.001) and TD (r_{63} = 0.47, p < 0.001). 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 the ASD and TD groups (z = 2.62, p = 0.009), with a stronger relationship displayed by the ASD group.

The Total Repetitive Behaviours score was also significantly correlated with Sensory Hypersensitivity (Figure 3(b)) in ASD (r_{47} = 0.77, p < 0.001) and TD (r_{63} = 0.44, p < 0.001). 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 = 0.005), with the ASD group displaying a stronger relationship.
In ASD, Total Repetitive Behaviours were significantly correlated with each individual sensory modality (Figure 4): Auditory ($r_{47} = 0.37$, $p = 0.009$), Visual ($r_{47} = 0.39$, $p = 0.006$), Tactile ($r_{47} = 0.69$, $p < 0.001$), and Oral ($r_{47} = 0.69$, $p < 0.001$) Hypersensitivities. Hypersensitivity in each sensory modality was also significantly correlated to Total Repetitive Behaviours in TD (Figure 4): Auditory ($r_{63} = 0.22$, $p = 0.073$), Visual, ($r_{63} = 0.40$, $p = 0.001$), Tactile ($r_{63} = 0.38$, $p = 0.002$), and Oral ($r_{63} = 0.38$, $p = 0.002$). 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.

**Predicting total repetitive behaviours**

In the hierarchical regression predicting Total Repetitive Behaviours (see Table 1 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).
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 ($r_{s(47)}=0.72$, $p<0.001$), Preoccupation with Restricted Patterns of Interests ($r_{s(47)}=0.77$, $p<0.001$), and Unusual Sensory Interests ($r_{s(47)}=0.76$, $p<0.001$). 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 ($r_{s(63)}=0.40$, $p=0.001$), Preoccupation with Restricted Patterns of Interests ($r_{s(63)}=0.43$, $p<0.001$), and Unusual Sensory Interests ($r_{s(63)}=0.35$, $p<0.001$). 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 ($z=2.87$, $p=0.004$)
### Table 2. Hierarchical regression predicting total repetitive behaviours.

<table>
<thead>
<tr>
<th>Predictor</th>
<th>Partial correlation (pr)</th>
<th>p value</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Model 1:</strong> $R^2 = 0.18$, $F(3, 108) = 7.96$, $p &lt; 0.001$</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Intelligence</td>
<td>$-0.40$</td>
<td>$&lt;0.001$</td>
</tr>
<tr>
<td>Age</td>
<td>0.00</td>
<td>0.96</td>
</tr>
<tr>
<td>Sex</td>
<td>-0.11</td>
<td>0.26</td>
</tr>
<tr>
<td><strong>Model 2:</strong> $R^2 = 0.68$, $R^2$-change $= 0.50$, $F$-change $(1, 107) = 170.91$, $p &lt; 0.001$</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Intelligence</td>
<td>$-0.19$</td>
<td>0.05</td>
</tr>
<tr>
<td>Age</td>
<td>-0.13</td>
<td>0.20</td>
</tr>
<tr>
<td>Sex</td>
<td>-0.03</td>
<td>0.76</td>
</tr>
<tr>
<td>Sensory Hypersensitivity</td>
<td>0.78</td>
<td>$&lt;0.001$</td>
</tr>
<tr>
<td><strong>Model 3:</strong> $R^2 = 0.69$, $R^2$-change $= 0.01$, $F$-change $(1, 106) = 0.76$, $p = 0.39$</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Intelligence</td>
<td>-0.16</td>
<td>0.09</td>
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<tr>
<td>Age</td>
<td>-0.14</td>
<td>0.14</td>
</tr>
<tr>
<td>Sex</td>
<td>0.00</td>
<td>$&gt;0.99$</td>
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<tr>
<td>Sensory Hypersensitivity</td>
<td>0.71</td>
<td>$&lt;0.001$</td>
</tr>
<tr>
<td>Diagnosis</td>
<td>0.08</td>
<td>0.39</td>
</tr>
</tbody>
</table>

Relating sensory hypersensitivity to the repetitive behaviour subscales.

and Unusual Sensory Interests ($z=3.20$, $p=0.001$) were significantly stronger in ASD compared to TD.

### 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 ($p<0.001$) and diagnostic group was not significantly predictive ($ps=0.995, 0.1986, 0.5659, and 0.372$, respectively).

Intelligence was a significant predictor of all four factors in Model 1 (demographics, $p<0.001$) 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, $p=0.005$) and in Model 3 (diagnosis, $p=0.005$) (Table 3).

### Discussion

The objective of this study was to examine the relationship between sensory hypersensitivity and repetitive behaviours associated with ASD and their TD peers. Results confirmed that sensory hypersensitivity is strongly related to the core ASD symptom of repetitive behaviours, but this relationship was not specific to ASD. In all children, both autistic and TD, repetitive behaviours 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 repetitive behaviours in all participants, both ASD and TD, even when controlling for sex, CA, and IQ. Importantly, diagnosis did not add any predictive influence of repetitive behaviours above and beyond sensory hypersensitivity. Finally, when individual subdomains of repetitive behaviours 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 et al., 2007; Rogers et al., 2003; Saulnier, 2002; Talay-Ongan and Wood, 2000; Tomchek and Dunn, 2007) and repetitive behaviours (Honey et al., 2007; Kim and Lord, 2010; MacDonald et al., 2007; Morgan et al., 2008; Richler et al., 2007; Watt et al., 2008; Werner et al., 2005) in autistic individuals compared to their TD counterparts. As repetitive behaviours 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 autism 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 et al., 2014; Robertson and 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 (AQ) were better able to complete block design tasks providing evidence of differences in visuospatial reasoning linked to autistic traits (Stewart et al., 2009), and autistic traits in TD individuals are related to differences in global and local processing (Stevenson et al., 2016; Sutherland and 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 repetitive behaviours 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 (Wolff et al., 2017). However, to our knowledge, the current data are the first to provide evidence that the relationship between sensory hypersensitivity and repetitive behaviours is not restricted to autism 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 using sensory hypersensitivity to account for variability in repetitive behaviours. The results display that sensory hypersensitivity accounts for a significant portion of the variability in repetitive behaviours even when controlling for demographic variables including intelligence, CA, and sex. Importantly, diagnostic group did not account for variability in repetitive behaviours above and beyond sensory hypersensitivity. This novel finding implies that sensory hypersensitivity is strongly associated with repetitive behaviours and suggests that this association is not specific to autism but extends to the general population as well.

The relationship between repetitive behaviours 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 repetitive behaviours not just in autism, but in the general population. Therefore, these results provide original evidence for the relationship between sensory hypersensitivity and specific types of repetitive behaviours not only in autistic individuals but also in TD individuals as well.

These data also provide a novel comparison of how the relationship between individual sensory modalities and repetitive behaviours 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 repetitive behaviours. Our data showed no group differences in how either auditory or visual sensitivities related to repetitive behaviours across diagnostic groups. However, the relationship between both tactile sensitivities and oral sensitivities and repetitive behaviours 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 repetitive behaviours 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 this 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.

**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 Autism displayed more stereotypes in more complex environments, involving novel toys and people (Hutt and...
Hutt, 1965). The complex environments are theorized to arouse the sensory system. These results provide further evidence for the overarousal hypothesis which specifically suggests that repetitive motor behaviours may be caused by the need to regulate one’s sensory input from his or her environment. In addition, 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 repetitive behaviours was not only 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 repetitive behaviours 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 autism may lead to repetitive behaviours, our results support a broader arousal hypothesis for the general population opposed to an overarousal hypothesis specific to ASD. While the overarousal hypothesis implies that a particular threshold of arousal must be surpassed before repetitive behaviours emerge, based on the results observed in this TD sample, it appears that 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 repetitive behaviours, 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 repetitive behaviours and restricted interests 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 repetitive behaviours. Therefore, regardless of how aroused or hypersensitive an individual is to their sensory environment, their engagement in restricted interests and repetitive behaviours can be predicted.

With that said, there is evidence that additional factors may impact the relationship between sensory sensitivity and repetitive behaviours. For example, repetitive behaviours and restricted interests have also been linked to MA and intelligence in the past (Bartak and Rutter, 1976; Bishop et al., 2006; Bodfish et al., 2000; Carcani-Rathwell et al., 2006; Gabriels et al., 2005; Matson et al., 1997; Militerni et al., 2002; Poustka and Lisch, 1993; Thompson and Berkson, 1985). Intelligence/MA has also been linked to hypersensitivity in both children with autism and TD children (Baranek et al., 2007). Therefore, it has been hypothesized that these supposedly independent relationships are not actually independent of one another. In line with the findings of this study, previous work that has tested this hypothesis discovered that MA/intelligence did not impact the relationship between sensory sensitivity and repetitive behaviours (Gabriels et al., 2008). While evidence to date has thus been equivocal, the current data suggest that the relationship between sensory hypersensitivity and repetitive behaviours is present even when accounting for any impact of MA or intelligence.

While not measured in this study, it is also important to note that anxiety may affect the relationship between hypersensitivity and restricted interests and repetitive behaviours. However, it is unclear in what way anxiety is related as some studies have found that anxiety mediated the relationship between sensory sensitivity and restricted interests and repetitive behaviours (Wigham et al., 2015), while other studies have shown that sensory sensitivity mediates the relationship between anxiety and restricted interests (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 autism symptomatology.

**Future directions**

This study, as well as most previous studies relating sensory processing and repetitive behaviours, 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 repetitive behaviours in ASD. With that said, there are a number of issues regarding the use of parent reports that should be noted. First, 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. Second, parent reports do not allow for the ability to discriminate between hypersensitivity and hyperreactivity. 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 SP2 also has limitations regarding the measurement of sensory processing, specifically. The SP2 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, 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 specifically sensory items, 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. In addition, it should be noted that the SP2 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 repetitive behaviours 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 repetitive behaviours to determine whether this relationship could also be important in explaining this phenomenon.

Finally, while these data demonstrate a relationship between sensory hypersensitivity and repetitive behaviours, this design is unable to assess whether sensory hypersensitivity is only related to repetitive behaviours or if sensory hypersensitivity is related to all autism symptomatology. It would be particularly fruitful in future work to explore further the relationship between sensory hypersensitivity and social and communication deficits, as such deficits have been linked to a number of sensory processing issues (Hellendoorn et al., 2014; Miguel et al., 2017; Stevenson et al., 2014a, 2017b; for review, see Stevenson et al., 2014b, 2015, 2017a; Thye et al., 2017; Wallace and Stevenson, 2014; Woynaroski et al., 2013).

**Conclusion**

These results demonstrate a clear relationship between sensory hypersensitivity and repetitive behaviours 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 repetitive behaviours 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 repetitive behaviours were more severe in ASD. Furthermore, previous findings, which were extended in the current data, show that this relationship holds across specific sensory modalities (audition, vision, tactile and oral) and specific categories of repetitive behaviours including repetitive motor movements, rigidity and adherence to routine, preoccupation with restricted patterns of interest, and unusual sensory interests. Importantly, the presence of repetitive behaviours, 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 repetitive behaviours equally in ASD and TD individuals.

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**References**

- Baranek G (1999) *Sensory processing assessment for young children (SPA)*. Unpublished Manuscript, University of North Carolina at Chapel Hill, Chapel Hill, NC, USA.


