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# The Perceived Causal Relations Between Sensory Reactivity Differences and Anxiety Symptoms in Autistic Adults

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## Abstract

**Background:** Rates of anxiety are inordinately high in autistic adults. Sensory reactivity differences, such as hyperreactivity (e.g., strong reactions to sound), hyporeactivity (e.g., no, or slower reactions to pain), and seeking (e.g., fascination with spinning objects), are a diagnostic criterion of autism and have been linked with anxiety. Understanding how individuals perceive these to be causally related can impact the assessment and treatment of anxiety. Therefore, we examined the perceived causal relations (PCR) between sensory reactivity differences and anxiety in autistic adults.

**Method:** Two hundred forty-six autistic adults aged 18–76 years took part in an online study. They completed self-report assessments of sensory reactivity differences, and anxiety, followed by the PCR scale, indicating whether they perceived their sensory reactivity differences to be more of a cause or an effect of their anxiety symptoms.

**Results:** We found sensory reactivity hyperreactivity, hyporeactivity, and seeking to be significantly correlated with anxiety. Further, we found total sensory hyperreactivity, and visual, auditory, and olfactory hyperreactivity, to be perceived as significantly more of a cause of anxiety than an effect, and total sensory seeking, and tactile and vestibular seeking, to be perceived as significantly more of an effect of anxiety than a cause.

**Conclusion:** Future individualized approaches to treating anxiety in autistic individuals may benefit from differentiating between potential sensory causes of anxiety (e.g. hypersensitivities) vs. potential sensory effects of anxiety (e.g. sensory seeking behaviors).

**Keywords:** autism, anxiety, sensory, perceived causal relations, adults

## Community Brief

*Why is this an important issue?*

Autistic people are more likely to experience anxiety compared with the general population. Sensory reactivity differences, such as hyperreactivity (e.g., strong reactivity to sounds), hyporeactivity (e.g., not noticing touch), or seeking (e.g., being fascinated by spinning objects), are common in autistic individuals, and may be a risk factor for anxiety. However, existing anxiety treatments are not always effective for autistic people. Understanding how autistic people feel their anxiety and sensory reactivity differences are causally linked could be important to help clinicians understand the challenges that should be prioritized in anxiety treatment for autistic people.

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*What was the purpose of this study?*

In this study, we aimed at examining sensory reactivity differences and anxiety symptoms in autistic adults, and asking them whether they perceive their anxiety symptoms to be more of a cause or an effect of their sensory reactivity differences.

*What did the researchers do?*

In our study, we measured sensory reactivity differences and anxiety symptoms using online surveys. For the sensory reactivity differences and anxiety symptoms that each individual reported to be present, they were then asked how much they felt each anxiety symptom was a cause of their sensory reactivity differences, and how much they felt each sensory reactivity difference was a cause of their anxiety symptoms. This study included 246 autistic adults aged 18–76 years.

*What were the results of the study?*

Our results showed that the autistic individuals felt that their sensory hyperreactivity, including hyperreactivity related to vision, hearing, and scent, is more of a cause than an effect of anxiety. However, they also felt that their sensory seeking, especially touch- and balance-related seeking, is more of an effect than a cause of anxiety.

*What do these findings add to what was already known?*

Although sensory hyperreactivity has been shown earlier to be a cause of anxiety for autistic individuals, our study was the first to suggest that anxiety may influence sensory seeking, which is something that can be tested in future research studies.

*What are potential weaknesses in the study?*

We did not ask participants about co-occurring conditions, such as if they have additional diagnoses related to intellectual disability or attention deficit hyperactivity disorder, which means there may be important differences between individuals that we did not examine. Also, we did not measure key symptoms associated with wider anxiety conditions and autism-related anxiety symptoms, such as social fears unrelated to negative self-assessment, which would be important for clinical understanding.

*How will these findings help autistic adults now or in the future?*

Understanding how people perceive their traits and symptoms to be causally related can impact how effective anxiety treatments are for individuals. So, our findings can importantly help inform clinical approaches to the treatment of anxiety for autistic individuals.

## Introduction

**A**UTISM SPECTRUM CONDITIONS are neurodevelopmental conditions with diagnostic criteria relating to social interaction and communication differences, and restricted and repetitive behaviors (RRBs) and interests.<sup>1</sup> Autistic\* adults are at a greater risk of experiencing clinical anxiety compared with the general population, with lifetime prevalence estimates suggesting that it affects 42% of autistic adults.<sup>4</sup> Prevalence rates for specific anxiety conditions vary across studies, but generalized anxiety disorder (GAD), separation anxiety, and social anxiety disorder are all commonly diagnosed in autistic children and adults.<sup>5–7</sup>

Anxiety has a significant impact on daily living and quality of life for autistic individuals,<sup>8,9</sup> which is believed to be greater than the impact of being autistic.<sup>8</sup> Accurate assess-

ment and identification of anxiety in autistic individuals is important for access to appropriate interventions.<sup>5</sup> However, there is currently a lack of understanding of anxiety presentations in autistic individuals.<sup>10–13</sup> Therefore, it is important to understand more about autism-specific risk factors, such as sensory reactivity differences.

Sensory reactivity differences, a criterion under the RRBs domain, have been suggested as a risk factor for anxiety in \*autistic individuals.<sup>14</sup> Sensory reactivity differences include sensory hyperreactivity (i.e., strong reactions to sensory input such as sounds), hyporeactivity (i.e., no, or slower reactions to sensory input such as pain), and seeking (i.e., fascination or fixation with sensory input such as watching spinning objects). Individuals often experience varying patterns of differences across a range of contexts and modalities, such as vision, hearing, and touch.<sup>15–17</sup>

Sensory reactivity differences are commonly experienced by ~94% of autistic adults,<sup>18</sup> but they are also often present more generally in neurodivergent individuals, such as with the condition clinically known as attention deficit hyperactivity

\*The language used in this article reflects the preferred terms of the autistic community<sup>2</sup> and importantly supports the reduction of stigma.<sup>3</sup>

disorder (ADHD).<sup>19</sup> Although some sensory input can be experienced as enjoyable, other input can be extremely distressing and sometimes painful for individuals.<sup>20,21</sup> This can cause individuals to feel overwhelmed in their daily lives and is believed to affect long-term physical and mental health outcomes, including anxiety.<sup>20</sup>

Subsequently, sensory reactivity differences and anxiety have been associated with wider impacts, such as reduced engagement with activities, public spaces (e.g., public transport), and workplaces for autistic individuals.<sup>9,22,23</sup>

Sensory hyperreactivity is commonly experienced across a range of modalities (e.g., visual, auditory), and it is associated with inordinate distress and feelings of overwhelm.<sup>20</sup> In research, it has frequently been linked to anxiety in autistic children and adults.<sup>21,24–28</sup> Although it has more recently been understood that autistic individuals can experience distinct autism-related anxiety symptomology, such as social fears unrelated to negative self-appraisal, sensory hyperreactivity has been found to predict traditional anxiety symptomology aligning with the Diagnostic and Statistical Manual of Mental Disorders (DSM),<sup>1</sup> rather than distinct anxiety symptomology.<sup>29</sup> For instance, previous research has found sensory hyperreactivity to be related to symptomology associated with GAD, separation anxiety, social anxiety, and specific phobia.<sup>24,27–30</sup>

Researchers have suggested three theoretical models conceptualizing the possible link between sensory hyperreactivity and anxiety.<sup>31</sup> The primary anxiety model proposes anxiety to be a cause of sensory hyperreactivity, as individuals may be more likely to be conditioned to attend and overreact to sensory input due to characteristics of anxiety (e.g., hypervigilance, hyperarousal, attentional bias, and avoidance). Second, the primary sensory over-responsivity (SOR) model proposes sensory hyperreactivity to be a cause for anxiety, as aversive sensory input can be conditioned, either toward a specific stimulus or across contexts due to the uncontrollability or unpredictability of stimuli. Third, it is proposed that there may be a non-causal link between sensory hyperreactivity and anxiety, but the association is due to an additional factor, for instance, similarities in amygdala activation or diagnostic overlap.

In support of the primary hyperreactivity model, longitudinal work in autistic toddlers has found sensory hyperreactivity to be an early unidirectional predictor of anxiety in autistic individuals.<sup>25</sup> In addition, there is some evidence to support that the link may be due to common overactivation in the amygdala and hippocampus.<sup>32</sup> However, more research is needed to unpick the causal association between sensory hyperreactivity and anxiety.

Relatively little research has examined whether sensory hyporeactivity and seeking relate to anxiety in autistic individuals. Research that has included sensory hyporeactivity has inconsistently found evidence of a significant relationship to anxiety. Some previous work has found greater sensory hyporeactivity to be related to greater anxiety in autistic adults and children.<sup>26,33</sup> However, our previous work in autistic children found sensory hyporeactivity to be related to lower anxiety, including symptomology relating to social anxiety when controlling for broader autistic traits.<sup>27</sup>

Alternatively, research in autistic children has suggested that sensory hyporeactivity may instead be indirectly related to anxiety through RRBs.<sup>34</sup> However, for sensory seeking,

quantitative research in autistic children and non-autistic adults has primarily not found a significant link with anxiety.<sup>16,27,28,35</sup> However, a study with neurodivergent young people, which included autistic children and teenagers, has shown a link between sensory seeking and anxiety, specifically GAD.<sup>36</sup>

Qualitative research in autistic adults has indicated that sensory seeking can be a soothing or calming strategy in times of stress.<sup>20,37,38</sup> Moreover, researchers have suggested that sensory seeking may be indirectly linked to anxiety as a strategy to regulate arousal, either seeking out sensory input in response to hyporeactivity, or interlinked with RRBs to soothe in response to sensory hyperreactivity.<sup>16</sup> Although sensory hyporeactivity and seeking are prominent in adulthood, research examining their association with anxiety is vastly lacking, with no known studies yet to examine the relationship between sensory seeking and anxiety in autistic adults.

Although it is important to elucidate the causal associations between sensory reactivity differences and anxiety, examining how autistic individuals perceive these to be causally related can also importantly improve the effectiveness of anxiety treatments. Although individuals often perceive their behaviors and clinical symptoms to be causally related, clinical assessments primarily assess co-occurring symptomology in isolation.<sup>39</sup> Assessing perceived causal relations (PCR) of co-occurring psychological behaviors/symptoms at an individual case level could be important for individualizing clinical assessments, providing information and context of the challenges that should be addressed and at what stage in treatment.<sup>40,41</sup>

The PCR is a rating scale used to understand the cognitive perception of causal \*relationships between two or more symptoms.<sup>39,40</sup> The PCR provides a more reflective account of the perceived causal relationship than, for example, inferring causal associations from statistically modeling questionnaire data. It can provide detailed insights at idiographic level, or aggregated to group level, and is therefore a beneficial approach to inform the development of targeted treatments.<sup>39</sup>

The PCR \*scale has previously been used in autism research to analyze relationships between obsessive compulsive disorder and autistic repetitive behaviors.<sup>42</sup> It is especially relevant for treatment approaches to anxiety and other mental health conditions in autistic individuals due to the heterogenous nature of this population.<sup>43</sup> Further, there has been a push to increase stakeholder involvement in autism research, which has previously not been common practice. Using a method such as PCR brings the perspectives of autistic individuals into research. Thus, findings are more likely to reflect and represent lived experiences and, consequently, improve outcomes for autistic people.<sup>44</sup>

Understanding how sensory reactivity differences are associated with anxiety, and perceptions of the causal relationship, has important implications for treatment approaches that are effective and suitable for autistic adults. Therefore, we conducted an online study that was the first known to examine the correlational and \*perceived causal relations between sensory reactivity differences (hyperreactivity, hyporeactivity, and seeking, across domains, including visual, auditory, tactile, interoception, vestibular, gustatory, and olfactory) and anxiety in autistic adults.

First, we aimed at investigating whether sensory reactivity differences are associated with anxiety in autistic adults, examining sensory seeking for the first time. Second, we aimed at understanding whether autistic adults perceive their sensory reactivity differences to be more of a cause or an effect of their anxiety symptoms, using the novel PCR scale approach.

## Methods

### Participants

We recruited 282 autistic adults for this online study. Inclusion followed a two-step process: First, participants were included who self-reported that they had an official autism diagnosis; and second, participants had to score above the cutoff ( $\geq 6$ ) on the Autism Spectrum Quotient—10 (AQ-10).<sup>45</sup> Therefore, 246 participants were included in the final analysis (aged 18–76 years, mean [ $M$ ]=41.9, standard deviation [ $SD$ ]=13.7, 143 female, 21 trans female, and 82 male). We did not record specific data on race and ethnicity, socioeconomic status, and educational attainment levels.

We recruited via the Centre for Autism Database at the University of Reading, the Autism Research Centre, and UK autistic adults' charities Facebook pages. Participants provided informed consent to take part. Ethical approval was granted before the commencement of this study by the University of Reading Ethics Committee.

### Measures

**Sensory Processing Scale Inventory.** The Sensory Processing Scale Inventory (SPSI)<sup>46</sup> is a self-reported questionnaire assessment of sensory reactivity differences for use in children and adults. The SPSI assesses sensory hyperreactivity, hyporeactivity, and seeking across a range of domains (auditory, visual, tactile, olfactory, gustatory, vestibular, and interoception). It is usually scored dichotomously (1=yes, 0=no); however, to capture a wider range scores and more sensitive differences between participants, Likert-scale scoring was used, in line with the Sensory Profile scoring (1–5; almost always, frequently, occasionally, seldom, almost never).<sup>47</sup>

The measure has good internal reliability (hyperreactivity=0.89; hyporeactivity=0.88; sensory seeking=0.93) and discriminant validity (medium to large effect sizes; 0.56–0.1.53).<sup>46,48</sup>

**Screen for Adult Anxiety Related Disorders.** The Screen for Adult Anxiety Related Disorders (SCAARED)<sup>49</sup> is a self-reported questionnaire screening the assessment of DSM anxiety disorders for use in adults. The SCAARED assesses total anxiety symptoms, as well as specific anxiety disorders including GAD, social anxiety, separation anxiety, and is scored 0–2 using a Likert-scale (not true or hardly ever true, somewhat true or sometimes true, very true or often true). It has good to excellent internal consistency (0.86–0.94) and discriminant validity.<sup>49</sup>

Although the SCAARED has not specifically been validated for use with autistic people, the scale is adapted from the child version (Screen for Child Anxiety Related Emotion Disorders<sup>50</sup>), which has been found to have comparable psychometric properties across autistic and non-autistic

samples.<sup>51</sup> Questionnaires of anxiety validated in the general population are commonly used in autism research due to the lack of population specific measures.

**PCR scaling.** We used the PCR scaling method<sup>39</sup> to examine the cognitive perception of the causal relationships between sensory reactivity differences and anxiety symptoms. In the PCR scale, we used the items of the SPSI and SCAARED questionnaires, asking participants to which extent they perceive their sensory reactivity differences (hyperreactivity, hyporeactivity, and seeking in each domain, for example, auditory hyperreactivity) to be a cause of anxiety (generalized anxiety, separation anxiety, and social anxiety), and to which extent they perceive their anxiety to be a cause of their sensory reactivity differences.

In the case that participants endorsed items relating to sensory reactivity differences as well as anxiety, they were asked to “Rate on a 0–10 scale (0= ‘not at all’, 5= ‘moderate cause’, 10= ‘strong cause’), to which extent you think your [X sensory reactivity difference] causes your [Y anxiety symptom]?” and “Rate on a 0–10 scale (0= ‘not at all’, 5= ‘moderate cause’, 10= ‘strong cause’) to which extent you think your [Y anxiety symptom] causes your [X sensory reactivity difference]?” The number of items in the PCR scale was unique for each participant depending on the amount of sensory reactivity differences and anxiety symptoms that were present.

A sensory reactivity difference on the SPSI was included if participants rated the item as “frequently” or “almost always,” and an anxiety symptom was included if participants rated the item as “very true or often true.” If participants endorsed all sensory reactivity differences and anxiety symptomologies, the maximum number of PCR items would be 60 (20 SPSI subscales  $\times$  3 SCAARED subscales). Missing PCR items (because of SPSI or SCAARED items not being endorsed) were treated as missing values at an individual case level.

From the PCR items, we calculated cause and effect composite scores for not only total sensory reactivity differences (hyperreactivity, hyporeactivity, and seeking) but also sensory reactivity differences by domain (visual, auditory, tactile, interoception, vestibular, gustatory, and olfactory).

### Procedure

We used Gorilla experiment builder to develop and host this study.<sup>52</sup> Participants accessed the study via a direct link to the study's Gorilla webpage. Participants were then able to read the study information and provided informed consent electronically, before completing the demographic information and the standardized questionnaires (AQ-10, SPSI, and SCAARED; the SPSI and SCAARED were presented in a counterbalanced order). Participants then completed the PCR scale, informed by their answers to the SPSI and SCAARED items.

### Analysis

We conducted statistical analysis using JASP,<sup>53</sup> a statistical program based on R, and SPSS.<sup>54</sup> Following normality checks, we first conducted a Spearman's bivariate correlation analysis to examine the associations between sensory reactivity (hyperreactivity, hyporeactivity, and seeking), and

TABLE 1. DESCRIPTIVE STATISTICS FOR SENSORY REACTIVITY DIFFERENCES (SPSI), ANXIETY (SCAARED), AUTISM TRAITS (AQ-10), AND AGE

	Range	M	SD	SE
Hyperreactivity	15–73	51.21	10.82	0.69
Hyporeactivity	12–46	25.76	6.37	0.41
Seeking	10–46	24.32	7.38	0.47
Total anxiety	0–54	33.15	11.27	0.72
Autistic traits	6–10	8.48	1.28	0.08
Age	18–76	41.86	13.70	0.87

AQ-10, autism spectrum quotient—10; M, mean; SCAARED, Screen for Adult Anxiety Related Disorders; SD, standard deviation; SE, standard error; SPSI, Sensory Processing Scale Inventory.

anxiety, as well as the covariates (autistic traits and age). Second, we examined whether anxiety was perceived to be more the cause or the effect of sensory reactivity differences (hyperreactivity, hyporeactivity, and seeking, overall and in each domain).

For the PCR analysis we conducted a series of paired-samples *t*-tests to test whether the mean cause was significantly different from the mean effect.<sup>39</sup> As items were variable at a case level, depending on whether an item was endorsed or not by a participant, each analysis varied in sample size. A significant correlation between constructs, but not a significant difference between cause and effect, may indicate the perception of a non-causal association.

Community involvement

We conducted this research study with an autistic researcher as part of the core research team. In addition, the research questions for this study align with the research priorities as identified by stakeholders in association with Autistica and the James Lind Alliance.<sup>55</sup> Ethical approval for this study was granted by the University of Reading Ethics Committee.

Results

Descriptive statistics

Shapiro–Wilk test of normality indicated that not all the variables were normally distributed ( $p < 0.05$ ) (see Table 1 for descriptive statistics). Based on scores from the SCAARED, 85% scored above the cut-off for GAD, 68% scored above the cut-off for separation anxiety disorder, and 85% scored above the cut-off for social anxiety disorder,

indicating clinically elevated symptoms indicative of these anxiety disorders.

Correlation analysis

We conducted a Spearman’s bivariate correlation analysis, with a Bonferroni corrected alpha level of  $p \leq 0.017$  (0.05/3), to examine the relationships between sensory reactivity and anxiety (see Table 2 for correlation results and Supplementary Figure S1 for scatterplot matrix). We found that sensory hyperreactivity was significantly correlated with total anxiety ( $r_s = 0.383, p < 0.001$ ), sensory hyporeactivity was significantly correlated with total anxiety ( $r_s = 0.157, p = 0.014$ ), and sensory seeking was significantly correlated with total anxiety ( $r_s = 0.295, p < 0.001$ ).

We did not find age or autistic traits to be significant covariates after Bonferroni correction (seven comparisons: adjusted  $p > 0.006$ ). However, pre-correction, we found age to be significantly correlated with sensory seeking ( $r_s = -0.171, p = 0.007$ ).

PCR between sensory reactivity differences and anxiety

We conducted a series of paired-samples *t*-tests (Wilcoxon signed-rank) to examine whether sensory reactivity differences were perceived to be significantly more of a cause or an effect of anxiety. We applied a Bonferroni corrected significance level of  $p = 0.017$  (0.05/3 tests) to control for multiple tests. See Table 3 for summary of these results.

We found that sensory hyperreactivity was perceived to be a significantly greater cause of anxiety ( $PCR_{hyper \rightarrow anx}; M = 4.62, SD = 2.20$ ), than an effect of anxiety ( $PCR_{anx \rightarrow hyper}; M = 4.29, SD = 2.41$ ),  $Z(238) = 15,864.5, p = 0.001, r_{rb} = 0.248$ . However, we found that sensory seeking was perceived to be a significantly greater effect of anxiety ( $PCR_{anx \rightarrow seek}; M = 3.60, SD = 2.60$ ), than a cause of anxiety ( $PCR_{seek \rightarrow anx}; M = 3.14, SD = 2.50$ ),  $Z(215) = 6142.5, p = 0.008, r_{rb} = -0.229$ .

We then conducted a series of paired-samples *t*-tests (Wilcoxon signed-rank) to examine whether sensory reactivity differences in specific domains were significantly perceived to be more of a cause or an effect of anxiety. We applied a Bonferroni corrected significance level of  $p = 0.0025$  (0.05/20 tests) to control for multiple tests. See Table 3 for a summary of these results.

We found that auditory hyperreactivity was perceived to be a significantly greater cause of anxiety ( $PCR_{audhyper \rightarrow anx}; M = 5.73, SD = 2.51$ ), than an effect of anxiety ( $PCR_{anx \rightarrow audhyper}; M = 5.07, SD = 2.83$ ),  $Z(229) = 11,229.5, p < 0.001$ ,

TABLE 2. SPEARMAN’S CORRELATIONS BETWEEN SENSORY REACTIVITY DIFFERENCES (SPSI), ANXIETY (SCAARED), AUTISM TRAITS (AQ-10), AND AGE

	Hyperreactivity	Hyporeactivity	Seeking	Autistic traits	Age
Total anxiety	<b>0.383*** (0.000)</b>	<b>0.157* (0.014)</b>	<b>0.295*** (0.000)</b>	0.027 (0.674)	-0.063 (0.325)
Autistic traits	0.122 (0.056)	0.121 (0.057)	0.038 (0.551)	—	—
Age	-0.054 (0.403)	-0.123 (0.054)	<b>-0.171** (0.007)</b>	0.095 (0.135)	—

Correlations significant before Bonferroni correction are indicated in bold without being flagged.

\*Correlation is significant at the Bonferroni corrected  $p \leq 0.016$  (0.05/3) level (two-tailed).

\*\*Correlation is significant at the Bonferroni corrected  $p \leq 0.008$  (0.05/6) level (two-tailed).

\*\*\*Correlation is significant at the  $p \leq 0.001$  level (two-tailed).

TABLE 3. PAIRED-SAMPLES *t*-TEST RESULTS SUMMARY FOR PERCEIVED CAUSAL RELATIONS BETWEEN SENSORY REACTIVITY DIFFERENCES AND ANXIETY

	<i>n</i>	$PCR_{sensory \rightarrow anxiety}$		$PCR_{anxiety \rightarrow sensory}$		<i>p</i>	<i>r<sub>rb</sub></i>	<i>l</i> - $\beta$	Significant PCR
		M	SD	M	SD				
<b>Hyperreactivity</b>	<b>238</b>	<b>4.62</b>	<b>2.20</b>	<b>4.29</b>	<b>2.41</b>	<b>0.001*</b>	<b>0.25</b>	<b>0.84</b>	PCR <sub>sensory</sub> → anxiety
<b>Visual</b>	<b>205</b>	<b>5.14</b>	<b>2.73</b>	<b>4.75</b>	<b>2.77</b>	<b>0.002**</b>	<b>0.29</b>	<b>0.65</b>	PCR <sub>sensory</sub> → anxiety
<b>Auditory</b>	<b>229</b>	<b>5.73</b>	<b>2.51</b>	<b>5.07</b>	<b>2.83</b>	<b>&lt;0.001**</b>	<b>0.29</b>	<b>0.97</b>	PCR <sub>sensory</sub> → anxiety
Tactile	206	4.19	2.58	4.39	2.76	0.164	-0.13	0.25	—
<b>Interoception</b>	<b>94</b>	<b>4.91</b>	<b>2.55</b>	<b>4.87</b>	<b>2.56</b>	<b>0.013</b>	<b>0.013</b>	<b>0.05</b>	—
Vestibular	167	4.44	2.69	4.22	2.75	0.092	0.18	0.38	—
<b>Gustatory</b>	<b>131</b>	<b>3.62</b>	<b>2.78</b>	<b>3.15</b>	<b>2.96</b>	<b>0.006</b>	<b>0.32</b>	<b>0.63</b>	—
<b>Olfactory</b>	<b>183</b>	<b>4.28</b>	<b>2.55</b>	<b>3.67</b>	<b>2.76</b>	<b>0.001**</b>	<b>0.31</b>	<b>0.93</b>	PCR <sub>sensory</sub> → anxiety
Hyporeactivity	217	3.41	2.48	3.71	2.46	0.099	-0.14	0.56	—
Visual	46	4.05	2.76	4.48	2.78	0.41	-0.17	0.20	—
Auditory	156	3.41	2.72	3.22	2.66	0.18	0.14	0.13	—
<b>Tactile</b>	<b>113</b>	<b>3.26</b>	<b>2.72</b>	<b>3.84</b>	<b>2.80</b>	<b>0.004</b>	<b>-0.37</b>	<b>0.76</b>	—
Interoception	94	4.05	3.03	4.67	3.21	0.057	-0.25	0.48	—
Vestibular	96	3.19	2.52	3.52	2.76	0.40	-0.12	0.27	—
Gustatory	41	3.73	2.70	3.73	2.81	0.90	0.03	0.05	—
Olfactory	25	3.07	2.62	2.71	2.65	0.53	0.19	0.11	—
<b>Seeking</b>	<b>215</b>	<b>3.14</b>	<b>2.50</b>	<b>3.60</b>	<b>2.60</b>	<b>0.008*</b>	<b>-0.23</b>	<b>0.87</b>	PCR <sub>anxiety</sub> → sensory
Visual	105	3.86	2.74	4.31	2.87	0.095	-0.21	0.35	—
Auditory	77	4.39	2.88	4.29	2.66	0.701	0.06	0.07	—
<b>Tactile</b>	<b>88</b>	<b>2.91</b>	<b>2.75</b>	<b>4.86</b>	<b>2.88</b>	<b>&lt;0.001**</b>	<b>-0.79</b>	<b>0.99</b>	PCR <sub>anxiety</sub> → sensory
<b>Vestibular</b>	<b>40</b>	<b>2.51</b>	<b>2.59</b>	<b>3.40</b>	<b>3.10</b>	<b>&lt;0.001**</b>	<b>-0.81</b>	<b>0.94</b>	PCR <sub>anxiety</sub> → sensory
Gustatory	168	2.96	2.71	2.91	2.81	0.633	0.05	0.06	—
Olfactory	72	3.51	2.85	4.15	2.86	0.073	-0.28	0.46	—

Significant *t*-tests indicate that sensory is perceived to be more a cause of anxiety (PCR<sub>sensory</sub> → anxiety) than anxiety is perceived to be a cause of sensory (PCR<sub>anxiety</sub> → sensory) or vice versa.

Correlations significant before Bonferroni correction are indicated in bold without being flagged.

\*Correlation is significant at the Bonferroni corrected  $p \leq 0.017$  (0.05/3) level (two-tailed).

\*\*Correlation is significant at the  $p \leq 0.0025$  (0.05/20) level (two-tailed).

PCR, perceived causal relations.

$r_{rb}=0.291$ , olfactory hyperreactivity was perceived to be a significantly greater cause of anxiety ( $PCR_{olfhyper \rightarrow anx}$ ;  $M=4.28$ ,  $SD=2.55$ ), than an effect of anxiety ( $PCR_{anx \rightarrow olfhyper}$ ;  $M=3.67$ ,  $SD=2.76$ ),  $Z(183)=7405.5$ ,  $p=0.001$ ,  $r_{rb}=0.308$ , and visual hyperreactivity was perceived to be a significantly greater cause of anxiety ( $PCR_{vishyper \rightarrow anx}$ ;  $M=4.14$ ,  $SD=2.14$ ), than an effect of anxiety ( $PCR_{anx \rightarrow vishyper}$ ;  $M=4.75$ ,  $SD=2.77$ ),  $Z(205)=8080.5$ ,  $p=0.002$ ,  $r_{rb}=0.287$ .

However, we found that tactile seeking was perceived to be a significantly greater effect of anxiety ( $PCR_{anx \rightarrow tactseek}$ ;  $M=4.86$ ,  $SD=2.88$ ), than a cause of anxiety ( $PCR_{tactseek \rightarrow anx}$ ;  $M=2.91$ ,  $SD=2.75$ ),  $Z(88)=31.5$ ,  $p<0.001$ ,  $r_{rb}=-0.789$ , and vestibular seeking was perceived to be a significantly greater effect of anxiety ( $PCR_{anx \rightarrow vestseek}$ ;  $M=3.40$ ,  $SD=3.10$ ), than a cause of anxiety ( $PCR_{vestseek \rightarrow anx}$ ;  $M=2.51$ ,  $SD=2.59$ ),  $Z(40)=31.5$ ,  $p<0.001$ ,  $r_{rb}=-0.806$ .

## Discussion

Our study is the first to advance our understanding of the perceived causal relationships between sensory reactivity differences and anxiety in autistic adults. First, we found a significant correlational relationship between sensory hyperreactivity and anxiety and sensory hyporeactivity and anxiety, in line with our previous work and that of others.<sup>25–28,34</sup> However, we also found sensory seeking to be significantly correlated with anxiety, the first known to examine this relationship in autistic adults.

Further, for the first time we found that autistic adults perceive sensory hyperreactivity, notably visual, auditory, and olfactory hyperreactivity, to be more of a cause of their anxiety symptoms than an effect, and that they perceive sensory seeking, notably tactile and vestibular seeking, to be more of an effect of their anxiety symptoms than a cause. However, it is important to note that due to the limited samples sizes in some of the domain-specific PCR analyses, it may be that significance was not achieved due to lack of power (e.g., gustatory hyporeactivity and seeking).

Research in autistic children and adults, including the present results, has consistently found a significant link between sensory hyperreactivity and anxiety.<sup>25–28,34</sup> Further, as we found autistic adults perceive sensory hyperreactivity to be more of a cause than an effect of their anxiety symptoms, this aligns with longitudinal work that has found sensory hyperreactivity to be a unidirectional predictor of anxiety.<sup>25</sup> Hence, our results provide further support for the Primary SOR Model.<sup>31</sup>

Sensory hyperreactivity may cause anxiety due to autism-related difficulties with the unpredictability of aversive sensory input, which may lead to anxiety developing through context conditioning from increased hypervigilance, negative bias, and avoidance of generalized contexts.<sup>31,56</sup> Interestingly, our results indicate that hyperreactivity in the visual, auditory, and olfactory domains is perceived to be more of a cause of anxiety symptoms than an effect.

Visual and auditory input is more commonly associated with sensory hyperreactivity in autistic individuals than with hyporeactivity and seeking.<sup>20,57</sup> Visual, auditory, and olfactory hyperreactivity, such as difficulties with bright or flickering lights, sudden loud sounds, and intense scents, has been commonly reported by autistic individuals and are associated with distress, overwhelm, and anxious responses.<sup>20</sup> There-

fore, sensory input associated with these domains may be more likely to condition anxious responses in individuals compared with other domain input.

Overall, our findings suggest that supporting challenges with sensory hyperreactivity could be an important first step in treatment approaches for anxiety in autistic adults. There is some evidence to suggest that adapted Cognitive Behavioral Therapy, supporting self-understanding of sensory reactivity differences and the development of coping strategies, could be used to target anxiety arising from sensory hyperreactivity.<sup>58</sup> Due to the complex and individualistic nature of sensory experiences,<sup>20</sup> it may be that clinical services could support individuals to identify and develop personal strategies to help them navigate and reduce the impact of hyperreactivity.

As for sensory seeking, our study was the first known to examine its associations with anxiety in autistic adults. Previous work in autistic children<sup>16,27,28</sup> has primarily not found a significant association between sensory seeking and anxiety. However, a study with neurodivergent young people, including autistic children and teenagers, found sensory seeking to be associated with anxiety, specifically GAD.<sup>36</sup> Our study builds on existing research to suggest that autistic adults perceive it to be an outcome of anxiety.

This may suggest sensory seeking is a regulatory strategy and reflect findings from existing qualitative work in this population, which has shown that sensory-seeking behaviors can be experienced as soothing or calming in times of stress.<sup>20,37,38</sup> The domain results indicate that autistic adults perceive tactile and vestibular seeking to be more of an effect of their anxiety symptoms than a cause. Autistic \*adults commonly seek out tactile experiences, such as certain soft or fluffy textures, and feeling warm or cold surfaces on their skin.<sup>20</sup>

As for vestibular seeking, autistic adults engage in stimulating behaviors, such as spinning or rocking, to self-regulate and feel calm when feeling overwhelmed or anxious.<sup>59,60</sup> Self-soothing behaviors have been linked to the release of oxytocin, important for well-being and stress reduction, and the anti-stress effects of oxytocin release have been suggested to be acutely strong in response to “low intensity” stimulation of the skin.<sup>61</sup> Thus, seeking out enjoyable tactile input and vestibular behaviors may be important self-soothing strategies that can be supported and developed at a later stage in therapeutic approaches for anxiety in autistic adults.

Regarding sensory hyporeactivity, although we found a significant correlation with anxiety, we did not find a significant causal association, suggesting that autistic individuals do not perceive it to be causally implicated in their anxiety symptoms. Research has commonly been inconsistent in regard to sensory hyporeactivity, with some finding it to be related to anxiety in autistic adults and children,<sup>26,27,33,62</sup> whereas others have not.<sup>28,34</sup> Sensory hyporeactivity has been suggested to be experienced after periods of hyperreactivity, where individuals may inversely “shutdown” from sensory input.<sup>63,64</sup> Therefore, sensory hyporeactivity may be implicated in anxiety indirectly due to its association with hyperreactivity.

## Limitations

Due to the heterogeneous nature of autism, individuals present with varying strengths and difficulties as well as co-

occurring conditions.<sup>43</sup> Therefore, it could have been informative if we collected additional demographic information, such as co-occurring diagnoses (e.g., intellectual disability or ADHD), to ascertain whether there were any key subgroup differences. Future research should examine the influence of other individual factors, as well as aiming \*to replicate these findings in more specific subgroups of autistic adults, as this may have an important impact on clinical approaches.

Although GAD, separation anxiety, and social anxiety can all co-occur in autistic individuals, our study did not examine additional common anxiety symptomology, such as specific phobia, or examine anxiety symptoms that are distinct to autistic individuals.<sup>5,6</sup> Although sensory reactivity differences have been found to predict traditional anxiety symptomology, there is growing evidence to suggest that anxiety presentations differ in autistic individuals compared with the general population, such as social fears that are not related to negative self-appraisal.<sup>29</sup>

Research has yet to examine associations between sensory reactivity differences and distinct autism-related anxiety symptomology in autistic adults. Since the conception of this study, there has been the development of an anxiety questionnaire for use with autistic adults,<sup>65</sup> which we could now use in future research to further elucidate the links between sensory reactivity differences and anxiety symptomology in autistic individuals.

## Conclusion

Our study found sensory hyperreactivity, hyporeactivity, and seeking to be correlated with anxiety in autistic adults. Further, we found that autistic adults perceive sensory hyperreactivity to be more of a cause than an effect of their anxiety symptoms, but sensory seeking to be more of an effect than a cause of their anxiety symptoms. Our results have implications for future research directions, informing hypotheses for objective longitudinal research designs. In addition, our findings have clinical implications for the progression of individualized treatment approaches for anxiety in autistic individuals.

## Authorship Confirmation Statement

I.V. conducted the research design, programming of the survey, recruitment, data collection, data analysis, and dissertation writing. K.M. conducted additional data analysis and wrote this article. A.H. provided statistical support to this project. T.T. conducted the research design and supervised the project.

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## Author Disclosure Statement

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## Supplementary Material

Supplementary Figure S1

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