Measuring Sensory Sensitivities in Children: The *Parent-completed Glasgow Sensory Questionnaire* (*GSQ-P*)

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Author contributions

RS, JS and LR designed the study. RS interpreted the results, ran the data analysis and wrote the paper. RS and LR carried out the data collection.

Abstract

Children can find sensory information more disruptive than adults (Ahn, Miller, Milberger, & McIntosh, 2004; Chin & Ward, 2018) but we have a relatively poor understanding of sensory sensitivities in children. We know that sensory sensitivities incorporate both *hyper-sensitivity* (sensory overload leading to avoidance-behaviours) and *hypo-sensitivity* (sensory dampening leading to seeking-behaviours), and here we present a novel, easy to administer child measure to assess both. Our 42-item *Parent-completed Glasgow Sensory Questionnaire* (*GSQ-P*) is adapted from an adult tool (Robertson & Simmons, 2013) to measure children's hyper- and hypo-sensitivity across seven senses (visual, auditory, gustatory, olfactory, tactile, vestibular, proprioception). We explore its psychometric properties when validated on 601 English children 6-11 years, both typically and non-typically developing, comparing age groups and genders. In response to our data, we also devised a reduced 24-item version (*rGSQ-P*). We offer both instruments (*GSQ-P* and r*GSQ-P*) as reliable measures in different circumstances, and we outline their characteristics. We also provide important insight into the structure of sensory sensitivities in children, and how *hyper-sensitivity* and *hypo-sensitivity* domains map onto other behavioural and well-being measures.

Keywords: Sensory sensitivity, hyper-sensitivity, hypo-sensitivity, children, autism

Introduction

Sensory sensitivity is characterised by over- (hyper) or under- (hypo) responding to sensory stimuli, and can occur within a number of different sense domains (e.g., *visual*, *auditory*, *olfactory*, *gustatory*, *tactile*, *vestibular*, *proprioceptive*). *Hyper-sensitivity* typically incorporates sensory overload and avoidance behaviours, while *hypo-sensitivity* incorporates sensory under-responsivity and seeking behaviours. For example, a person with hyper-sensitivity might find strong smells overwhelming (i.e., sensory overload) and avoid them (i.e., sensory avoidance), while a person with hypo-sensitivity might fail to notice strong smells at all (i.e., sensory under-responsivity or 'dampening') and actively seek them out (i.e., sensory seeking). Children can find sensory information more disruptive than adults, but their sensory sensitivities are poorly understood. Limited research has concentrated to a large extent on clinical groups (see below), but beyond clinical groups, our knowledge is vague. One barrier has been a lack of instruments that can measure childhood sensory sensitivities across both clinical and non-clinical populations, while also adequately capturing the complexity of sensory experiences and their multifaceted nature. Any useful measure would need to be able to test multiple sense domains (vision, audition, olfaction etc.), for both hyper and hypo sensitivity, with both sensory and behavioural components (i.e., overload/dampening vs. avoidance/seeking). The current paper presents an instrument which aims to fulfil all these requirements.

We noted above that research in sensory sensitivities has tended to focus on clinical populations, and in particular, one focus has been on children with an *Autism Spectrum Condition* (*ASC*) where sensitivities are particular high (Baranek, Boyd, Poe, David, & Watson, 2007; Billstedt, Gillberg, & Gillberg, 2007; McCormick, Hepburn, Young, & Rogers, 2016; Robertson & Simmons, 2013;

Watling, Deitz, & White, 2001). Indeed sensory sensitivities now form part of the diagnostic criteria for ASC within the *Diagnostic and Statistical Manual of Mental Disorders* (*DSM-V:* (American Psychiatric Association, 2013). Other conditions, too, show differences in sensory sensitivities, including Attention Deficit Hyperactivity Disorder (ADHD: Cheung & Siu, 2009; Ghanizadeh, 2011; Panagiotidi, Overton, & Stafford, 2018; Yochman, Parush, Occupational, & 2004, 2004), and childhood developmental delays (Baranek et al., 2007; McCormick et al., 2016). Nonetheless, sensory processing issues are not limited to atypical groups. As many as 14% of children who are typically developing can display sensory sensitivities, according to various estimates (Ahn et al., 2004) with a notable degree of within-group variation (Brockevelt, Nissen, Schweinle, Kurtz, & Larson, 2013; Cheung & Siu, 2009). And where sensitivities arise, they present early in development (Ben-Sasson, Carter, & Briggs-Gowan, 2010). For all these reasons, it is important to recognise sensory sensitivities in children who are both typically and non-typically developing, and to recognise it early.

It is also important to recognise sensory sensitivities bceause they can have a significant impact on children's lives. Dunn, and colleagues (Dunn, Little, Dean, Robertson, & Evans, 2016) found that children with higher levels of sensory processing issues were more likely to have difficulties in everyday routines such as eating, playing, family interactions, and other social/activity participation. Hyper-sensitivities in particular (described by Dunn et al. as 'Low threshold') were associated with higher levels of anxiety, shyness and more challenging behaviours. Conversely, hypo–sensitivities (described by Dunn et al. as 'high threshold') were associated with under-responsivity and potentially repetitive self-harming behaviours. In otherwise typically developing populations, sensory sensitivities have also been linked to reduced play behaviours (Bundy, Shia,

Qi, & Miller, 2007), compulsive-like behaviour (Dar, Kahn, & Carmeli, 2012), modulated movement (Buitendag & Aronstam, 2010; Gal, Dyck, & Passmore, 2010), and feeding problems (Davis et al., 2013). These findings suggest that understanding children's sensory sensitivities might be a key focus for developmental scientists.

Measuring sensory sensitivity in children

There are a number of existing instruments to identify sensory sensitivities in children (Jorquera-Cabrera, Romero-Ayuso, Rodriguez-Gil, & Triviño-Juárez, 2017), each with their own strengths and limitations. The *Sensory Profile 2* is one of the most commonly used questionnaires, available in a full 125 item version (Dunn, 1999, 2014) as well as a 38 item short form (*Short Sensory Profile*; SSP2) and is designed for parents or teachers of children from birth to 14 years (SSP2). The Sensory Profile (SSP2) provides scores for six sense domains (auditory, visual, touch, movement, body position, oral) and for four outcome domains (seeking, avoiding, sensitivity, registration). It has excellent psychometric properties (Dunn et al., 2016) but also certain limitations. As well as excluding olfactory sensitivities, the latest version (SSP2), as with the original, does not specifically split sensitivities by hyper versus hypo domains. Another measure of childhood sensory sensitivities is the *Sensory Experiences Questionnaire* (Ausderau & Baranek, 2013; Baranek, David, Poe, Stone, & Watson, 2006; Little et al., 2011). Its latest edition (version 3.0) currently comprises 105 items for 2-12 year olds (Baranek, 2009) across five sense domains (auditory, visual, tactile, gustatory, and vestibular) and four outcome domains (described by the authors as *Hyper*, *Hypo*, *Sensory seeking* and *Enhanced perception*; i.e., they use the terms hyper/hypo for over/under-*sensing* rather than related behaviours e.g., seeking). However, as well as being very long, this measure was developed specifically for sensory symptoms in children with

ASC or developmental disabilities so it is unclear whether it has suitability for normative populations. Finally, the *Sensory Processing Measure* is a questionnaire for caregivers of 5-12 year olds (Parham, Ecker, Miller-Kuhaneck, Henry, & Glennon, 2007), and comprises 62 items across five sense modalities (*visual*, *auditory*, *tactile*, *proprioception*, *vestibular*). The key focus of this questionnaire is tangential to sensory sensitivities per se, measuring sensory processing, praxis, and social participation in school. Other behavioural assessments are available, such as the *Sensory Integration and Praxis Tests* (Ayres, 1989), the *Sensory Processing Assessment* (Baranek, 1999) and the *Sensory Processing Scale Assessments* (Schoen, Miller, & Sullivan, 2017). But these assessments might be considered too labour-intensive for many research situations (where sensory sensitivity can be just one aspect of assessment among many). For example, a complete *Sensory Integration and Praxis Test* comprises a two-hour battery, incorporating a number of different elements beyond sensory sensitivities themselves, and the *Sensory Processing Scale Assessments* requires a 1 hour assessment led by a trained administrator.

Given the limitations of existing sensory processing measures (primarily in the breadth of sense domains covered, the populations they are limited to, or the time requirements) we sought to produce a single comprehensive instrument that would be relatively fast and easy to administer to the parents of children from a relatively young age, for both clinical and non-clinical populations. We chose a parent report in particular (as opposed to children's *self*-report) for several reasons. Firstly, although children below 8 years can reliably self-report in domains such health and well-being (Riley, 2004; Smees, Rinaldi, & Simner, 2019), more complex domains such as problem-behaviour or personality typically require more labour- intensive approaches for younger children (Measelle, Ablow, Cowan, & Cowan, 1998; Norwood, 2007; Rebok et al., 2001; Rinaldi, Smees,

Carmichael, & Simner, 2020a; Ringoot et al., 2017). Secondly, for our measure to be valuable to children who are both typically and non-typically developing, a parent-report would be required given that conditions where sensory sensitivities arise (e.g., ASC) can often present with poorer reading comprehension and/or introspection skills (Frith & Happe, 1999; Kinnaird, Stewart, & Tchanturia, 2019; Robinson, Howlin, & Russell, 2017).

We have named our novel child measure the *Parent-completed Glasgow Sensory Questionnaire* (*GSQ-P*) because it is based on an equivalent pre-existing adult measure *GSQ;* (Robertson & Simmons, 2013). Exactly like the adult measure, our test was designed to assess hyper and hypo-sensitivity (21 items each) split equally across seven sense domains (e.g., *visual*, *auditory*, *olfactory*, *gustatory*, *tactile*, *vestibular*, *proprioceptive*), incorporating both sensory and behavioural dimensions (i.e., sensory overload/ avoidance behaviour, as well as sensory under-responsivity/ seeking behaviour). Importantly, although items from the existing adult GSQ were originally chosen to reflect knowledge within the ASC literature on sensory sensitivities (Baranek et al., 2006; Robertson & Simmons, 2013) it has been successfully validated and utilised in normative adult populations. Furthermore, adult instruments have been successfully adapted to a parent-report perspective (Rinaldi, Smees, Carmichael, & Simner, 2020b). Our tool therefore took the form of an appropriate re-wording of the GSQ, to create a parent-report for describing children from both typically-developing and clinical populations.

We validated our new child measure, the *GSQ-P*, on the parents of 601 children of primary school age (6-11 years). We investigated its psychometric properties in terms of reliability and validity, looking at both the general population as well as how it serves to reflect children within our sample who have learning vulnerabilities - here, using the UK schooling classification of *Special Educational Needs and Disabilities* (*SEND*). The SEND system in England and Wales is designed

to provide educational support to children and young people (aged 0-25) who have additional needs, as laid out in the SEND Code of Practice 2014 (Department for Education and Department of Health, 2015) and the Children and Families Act 2014 (Department of Education, 2014). SEND status signifies that a child has a learning difficulty and/or a disability that requires additional support in school, and includes multiple conditions including Autism, sensory impairment and mental health problems. Needs cover four main areas: (i) communication and interaction, (ii) cognition and learning; (iii) social, emotional and mental health; and (iv) sensory and/or physical needs (e.g., vision impairment). Hence this population is a heterogenous group but is known to show meaningfully group-wise characteristics (Evangelou et al., 2008; Gaspar, Bilimória, Albergaria, & Matos, 2016; Schwab, 2019). This classification allows us to retrieve a usable sample size and, importantly, is considered to represent a unified group not only psychologically (Wigelsworth, Oldfield, & Humphrey, 2015) but also for educational purposes (e.g., overseen by a single co-ordinator in schools).

For our study, parents completed our novel *GSQ-P*, as well as four other measures: a demographic questionnaire, a wellbeing questionnaire, an anxiety questionnaire, and an empathy questionnaire. These instruments were chosen because they provide information known to be associated with sensory sensitivities (see *Methods*) in both adults and children (Ashburner, Bennett, Rodger, & Ziviani, 2013; Horder, Wilson, Mendez, & Murphy, 2014; Robertson & Simmons, 2013). We therefore investigated these measures within our own sample as an index of convergent validity for our novel test. In validating our test on children we will also take the opportunity to compare our children to adults (where data is taken from previous studies using the equivalent GSQ adult measure; see *Results*). This comparison will allow us to better understand how sensory sensitivities

might evolve over time. Below we describe our empirical investigation, including details of how we created the *GSQ-P* by adapting the corresponding adult measure to make it fitting for children.

Method

Participants

The data for this study were collected from the parents of children involved in the MULTISENSE project, a longitudinal study funded by the European Research Council intended to investigate multisensory learning in children aged 6-11 years (e.g., Rinaldi et al., 2020b) Eligibility for the MULTISENSE project was simply attending one of 22 target schools, and there was a 99% uptake of students into the cohort. These 22 schools were state-maintained infant, junior, or primary (infant + junior) schools in the southern counties of England. To describe the representativeness of our sample, we can consider the percentage of pupils entitled to the UK benefit of *Free School Meals*, an indicator of socio-economic disadvantage within the school district (Taylor, 2018). Across our schools, the percentage FSM averaged at 13.4% (range 0.7% to 38.1%), where the national average from the same year is 14.5%. This suggests our sample was representative of schools country-wide in terms of socio-economic status.

All parents of children involved in the MULTISENSE project (n = 3690) were invited to take part in the current study (no information were given about sensory sensitivities). Our final cohort comprised the parents of 601 children, nearly half were girls (47%) and aged 6-11 years (M = 8.74, SD= 1.22). This sample included 32 children with *SEND* status (5%), 510 children who are typically developing (84%), and 62 with status unknown (10%; i.e., where parent failed to give

SEND status of their child). In total, 65% of children came from households where the highest qualification was degree level or above. In addition to our n601 sample, an additional 64 parents took part but were subsequently excluded: 24 began but did not complete our questionnaire, and a further 43 were removed because they referred to a child not part of the MULTISENSE project (e.g., a sibling). In 38 cases, a parent had completed the questionnaire twice, and in these cases we took the first completed questionnaire. Our study had ethical approval from the University's Science and Technology Research Committee.

Materials and Procedure

Parents completed our questionnaires either via paper copy (delivered to their school) or online (via a link provided in email). The choice of paper versus online was dictated simply by how each school regularly communicated with its parents, and both versions were identical in all other ways. The task took approximately 20 minutes and parents completed the following measures in the order shown below.

The Parent-completed Glasgow Sensory Questionnaire (GSQ-P)

The *GSQ-P* is our 42 item parent-report questionnaire, assessing sensory sensitivities in the children of respondents. Our questionnaire was adapted from the adult version of the same name (Robertson & Simmons, 2013) and details of this adaptation are given below. Half of the items addressed hyper-sensitivity and half addressed hypo-sensitivity. As in the adult version, these items were equally distributed across seven sense domains (*visual*, *auditory*, *gustatory*, *olfactory*, *tactile*, *vestibular*, *proprioception*) giving three questions per cell (e.g., 3 questions for visual hyper-sensitivity, 3 questions for visual hypo-sensitivity, 3 questions for auditory hyper-

sensitivity, etc.). Each question had five possible responses: *Never, Rarely, Sometimes, Often, Always* (coded 0 to 4).

To date the GSQ has been validated in adults only, in both neuro-typical and ASC populations, and in the UK and cross-culturally (Kuiper, Verhoeven, & Geurts, 2018; Sapey-Triomphe, Moulin, Sonié, & Schmitz, 2018; Ujiie & Wakabayashi, 2015), showing excellent internal reliability for the global scale (Cronbach's Alpha ranging .93 - .95), as well as correlating strongly with both autistic and sub-autistic traits (Horder et al., 2014; Kuiper et al., 2018; Ujiie & Wakabayashi, 2015).

GSQ-P Instrument Development

The starting point for creating our new measure was the GSQ for adults. For our parent adaptation, response categories were left unchanged (*Never, Rarely, Sometimes, Often* and *Always*) and the original wording was retained wherever possible. However, some necessary changes were implemented. The prefix to the original items 'Do you…' was replaced with 'Does your child…', and any other instances of 'you' were replaced with 'he/she'. In total, 15 items required only these minimal changes and no others. Twenty-four additional items underwent minor text changes (e.g., the adult item "*Do bright lights ever hurt your eyes…?*" became "*Does your child ever complain that bright lights hurt his/her eyes…?*") and the remaining three items underwent more substantive changes (e.g., the adult item "*Are you ever told by others you wear too much perfume, after-shave?*" became "*Does your child 'borrow' your perfume, after-shave?*"). See Supplementary Information (SI) for full details of these changes, and see the Appendix for the complete *GSQ-P* questionnaire.

Goodman's strengths and Difficulties Questionnaire (SDQ)

The SDQ is a 25-item emotional and behavioural screening questionnaire, incorporating five subscales: Conduct problems, Emotional symptoms, Peer problems, Hyperactivity and Prosocial behaviours (Goodman, 1997). Each item is a statement about the child over the last six months, and responses are made on a 3-point Likert scale: *Not tru*e, *Somewhat true*, and *Certainly true* (coded 0-2). For example, Item 17 relates to Prosocial behaviours and states "Kind to younger children". A systematic review of the psychometric properties of the SDQ (Kersten et al., 2015) found good internal consistency ($\alpha = .73$, see also Muris, Meesters, & van den Berg, 2003). It has been recommended that re-combining into two scales only is more robust for measuring behaviour in general populations (Goodman, Lamping, & Ploubidis, 2010), these scales being *Externalising Behaviours* (combining Hyperactivity and Conduct problems) and *Internalising Behaviours* (combining Peer problems, Emotional symptoms), so we take this approach in our analyses below.

The Screen for Child Anxiety Related Disorders (SCARED)

The *SCARED* (Brent, Cully, Balach, Kaufman, & McKenzie Neer, 1997) is a 41-item childhood screening questionnaire for Anxiety Disorder, with anxiety symptoms related to Panic disorder, General anxiety disorder, School avoidance, Social anxiety or Separation anxiety. Questions are presented as statements, which parents rate based on their child over the past three months. For example, Item 36 relates to school avoidance and states "My child is scared to go to school". Parents respond on a 3-point Likert scale "*Not true or hardly ever true*/ *Somewhat true or sometimes true*/ *Very true or often true*". The 41 item scale (Birmaher et al., 1999) has shown excellent internal consistency ($\alpha = .90$), and parent-child correlations for the total scale are $\rho = .32$.

Empathy Quotient (EQ-C)

The empathy quotient for children EQ-C (Auyeung et al., 2009) is a 27-item questionnaire, measuring children's cognitive empathy (e.g., perspective taking) and emotional empathy (e.g., emotional response). For example, Item 11 states "My child is often rude or impolite without realising it". Each question has four possible responses: *Definitely agree, Slightly agree, Slightly Disagree, Definitely Disagree*. These are coded, respectively, 2 1 0 0 for positively worded items reflecting high empathy (e.g., *Definitely Agree* would be scored 2) and are coded as 0 0 1 2 for negatively items reflecting low empathy (e.g., *Definitely Agree* would be scored 0). The original study (Auyeung et al., 2009) showed excellent internal consistency ($\alpha = .93$).

Demographic Questionnaire

This in-house 20-item questionnaire elicited background information such as highest parental qualification, mother's age at child's birth, child's age, as well as whether the child had a *SEND* status. These latter two dimensions were relevant for our current interests (and results from other factors will be published elsewhere).

Results

Analytical Approach: In the analyses below we look first at the reliability and domain structure of the *GSQ-P* in isolation, then look at its convergent validity with other measures (e.g., Goodman's SDQ), and finally, we consider demographic differences (e.g., whether there are any differences in the sensory sensitivities of boys and girls). Throughout our analyses we consider children as a whole but also, where relevant, as sub-groups (Typically Developing vs. SEND, and here we

exclude the 62 children with status unknown). Missing responses from respondents who answered over 90% of questions were imputed with the item mean (respondents with fewer responses than this were removed). All statistical analyses were carried out using SPSS 24.0 statistical software and statistical significance was set at $p < 0.05$. Finally we point out that all data was elicited from parents; hence where our results describe children, this should be taken in the context of parental-reported characteristics.

GSQ-P Scale Validation, Reliability and Factor structure

In this section we analysed the structure of the *GSQ-P* overall, and its three sensitivity domains (*total Sensitivity*, *hyper-sensitivity*, *hypo-sensitivity*) and seven sense domains (*visual*, *auditory*, *gustatory*, *olfactory*, *tactile*, *vestibular*, *proprioception*; i.e., combining hyper and hypo-sensitivities for each sense)[1]. We also considered the internal consistency of the scale, and its factor structure.

For the sample as a whole, the relationship between total *GSQ-P* hyper- and hypo-sensitivity was large (i.e., they strongly correlated; $r(599) = .78$, $p < .001$). Within individual sense domains, this same relationship was less pronounced, but was generally moderate in size (see Table 1) with the weaker correlations found for *vestibular*, *tactile* and *olfactory* senses. These relationships suggest, as found previously (Sapey-Triomphe et al., 2018) that hyper and hypo-sensitivities can cluster within a single individual domain to some extent for some domains (i.e., for *vision*, *audition*, *gustation*, and *proprioception*) more than others (i.e., *tactile*). Considering now our participant

[1] Note that we are using the terminology of 'sense domains' to refer to sensory channels (e.g., *visual*, *auditory*, *gustatory*…) and 'sensitivity domains' to refer to the type of sensitivity (*total sensitivity*, *hypo-* *hyper-*). We point out that although fourteen individual sub-domains were possible at the finest level (hyper/hypo x seven senses), these were not investigated directly unless relevant for further data reduction analyses.

sub-groups, we found that associations between the hyper and hypo domains were larger for the *SEND* group than children who are typically developing, particularly within individual sense domains. See also SI, which provides comparable findings from adults in two recent studies using the related adult (GSQ) scale. In other words, the evidence suggests that the pattern of associations between *hyper- and hypo-* scales is found for both typical and non-typical populations.

We next considered the reliability of the scale in terms of its internal consistency (i.e., the extent to which the separate questions within our scale express a single concept of sensory sensitivity). Internal consistency, measured by Cronbach's alpha was excellent for the overall *GSQ-P* scale (All children $\alpha = 0.93$, Typically developing $\alpha = 0.93$; *SEND* $\alpha = 0.95$), as well as for separate hyper and hypo domains (*hyper-sensitivity*: All children $\alpha = 0.90$, Typically developing $\alpha = 0.88$; *SEND* $\alpha = 0.93$; *hypo-sensitivity*: All children $\alpha = 0.85$, Typically developing $\alpha = 0.83$; *SEND* $\alpha = 0.87$). In terms of the sense domains, internal reliability was somewhat lower, although was "moderate" or "good" (Hair, Black, Babin, & Anderson, 2010) in most instances (see Table 1 below; all but *Tactile* fell in the range of "moderate" or "good" [2] for our sample). Similarly, the reliability remained "good" for all sense domains except tactile for the SEND group. The reliability statistics from three other adult samples can be found in the SI for comparison. The adult studies found similarly high reliability for the broader scales (*overall GSQ-P, hyper-sensitivity, hypo-sensitivity*) and, in line with our own findings, somewhat poorer reliability for individual sense domains. Taken together, the results suggest that the broader scales (*Overall GSQ-P, hyper-sensitivity, hypo-sen*sitivity) form more reliable scales, but the lower reliability for sense domain

[2] Using Hair's rule of thumb for Cronbach's alpha: Poor < .6; Moderate .6-.7; Good .7-.8; Very good .8-.9; Excellent >.9.

scales (e.g., within the visual domain, or within the auditory domain) suggests scales scores for individual sense domains should be treated with some caution.

Table 1

Validation of the sense domain scales of the GSQ-P, within each sense domain and for each participant cluster (All; Typically Developping TD; SEND). Table shows in columns 1-3 the associations between the hyper and hypo sensivity scales for each sense domain (e.g., collapsing across visual hyper and visual hypo sensivity scales. Columns 4-6 show the internal consistency expressed as Cronbach's alpha for children in the current study for each sense domain

	Correlation between hyper- & hypo-Sensitivity (Rho)			Internal consistency expressed as Cronbach's alpha		
	All	TD	SEND	All	TD	SEND
Visual	*.48*	*.46*	*.61*	.66	.66	.80
Auditory	*.49*	*.47*	*.44*	.77	.77	.79
Gustatory	*.51*	*.51*	*.41*	.69	.69	.73
Olfactory	*.39*	*.37*	*.53*	.68	.68	.77
Tactile	*.34*	*.28*	*.44*	.53	.53	.65
Vestibular	*.33*	*.28*	*.60*	.65	.65	.74
Proprioception	*.49*	*.44*	*.64*	.67	.67	.76
N	601	509	31	601	509	31

Note. All Rho correlations from the current study shown in Table 1 were significant at $p < .001$

In summary, we have provided evidence for the robustness of the broader scales of the *GSQ-P*, but failed to find the same level of robustness for the individual sense domains.

Factor structure of the GSQ-P

We next considered the factor structure of the *GSQ-P*. The factor structure of the adult GSQ has been investigated previously, and shown to load successfully as both a unitary factor based on an un-rotated Principle Components Analysis (Robertson & Simmons, 2013) and a rotated two factor structure largely falling into hyper and hypo-sensitivities (Sapey-Triomphe et al., 2018). In other words, adults show an overall trait of sensory sensitivity as well as separate traits of hyper- and

hypo-sensitivity. We therefore repeated a similar analysis in our child data since the factor structure may differ in younger samples. Whilst we expected to find distinct hyper and hypo sensitivity domains (i.e., two factors), we did not know a priori whether individual questionnaire items would replicate in a developmental population, especially as they now were no longer first person report. We therefore took an exploratory approach with the expectation of one and two factor solutions, with flexibility to also explore individual questions within the instrument for robustness.

In the current study, the Kaiser–Meyers–Olkin measure of sampling adequacy was found to be "excellent" (*KMO* = 0.93), indicating a high degree of potential shared variance between the 42 questionnaire items. Our Bartlett's test of Sphericity was also excellent, χ^2 (1, DF = 861) = 8767.64, $p < .001$. These results indicate that the data is suitable for factor analysis (which requires a minimum degree of shared variance between items within an instrument).

Based on our own Scree plot inspection and previous literature we performed an exploratory Factor Analysis with oblique rotation on the full 42 items, constraining extraction to two factors. The two factor model explained 29% (26 and 3% respectively) of the variance, and the majority of items loaded on the correct hyper or hypo domain to which they were originally assigned by (Robertson & Simmons, 2013). Five items loaded on the incorrect hyper/hypo domain (Items 7, 11, 32, 37, 40) and five items did not load on either factor (<.30; Items 3, 5, 10, 29, 38). Six of these non-complying items were proprioception questions (the entire scale): all either loading on the incorrect factor or on neither factor (<.30, see SI for factor loadings).

In the light of these issues we created a shortened version of the *GSQ-P*, retaining the largest factor loadings on the correct hyper/hypo domain within each sense. The exception was proprioception, which was removed from the scale entirely. We named this new "reduced" scale the *rGSQ-P* and it contained 24 items (i.e., two questions for each sensitivity domain [*hyper*, *hypo*] within each sense domain [*visual*, *auditory*, *olfactory*, *gustatory*, *tactile*, *vestibular*]). We repeated the previous EFA on this reduced scale, explaining 29% (25 and 4% respectively) of the variance. All items loaded on the correct domain (see SI for full details of the factor loadings). The *rGSQ-P* overall hyper- and hypo- domains become more distinct, (*r(599)* = .58), and was greater for the sense domains (e.g., gustatory *hyper-sensitivities* now show only low correlation with gustatory *hypo-*sensitivities, see SI). This is to be expected given we have removed cross-loading items, and we return to this issue in the *Discussion*. Similar to the long *GSQ-P* scale the internal reliability of the *rGSQ-P* scale was very good/excellent for the full scale (All children α = 0.87; Typically developing α = 0.85; *SEND* α = 0.91), and favourable for separate hyper and hypo domains (*hyper-sensitivity* All children α = 0.77; Typically developing α = 0.83; *SEND* α = 0.90; *hypo-sensitivity* All children α = 0.77; Typically developing α = 075; *SEND* α = 0.79). Reliability for individual sense domains was lower than found for the *GSQ-P (* ranging from .51-.70, see SI), suggesting the *rGSQ-P* should not be used for sense domain information.

Group differences in sensory sensitivity

Above we found the long and short form scales possessed their own strengths and issues. Although the broader scales were robust, the long from *GSQ-P* possessed better reliability on sense domains scales, whilst the *rGSQ-P* displayed a stronger factor structure. Here we now explore differences in sensory sensitivity scores across age groups, gender and SEND classification. Our demographic

comparisons utilised one-way independent sample t tests and ANOVAs, bootstrapped where appropriate. We explored both *GSQ-P* and *rGSQ-P* (for *total sensitivity, hypo-Sensitivity, hyper-Sensitivity)* and full statistics are found in the SI but are summarised here. There were no significant gender or age differences were found for either the *GSQ-P* or *rGSQ-P*. In contrast, children with a *SEND* status scored significantly higher on all sensitivity domains than children who are typically developing, *GSQ-P*: *total sensitivity, t*(31.759) = -6.112, *p* <.001, *Bootstrapped p* <.001, as well as *hyper-sensitivity* t(31.802) = -6.174, *p* <.001, *Bootstrapped p* <.001, and *hypo-sensitivity t(*31.915) = -5.450, *p* <.001, *Bootstrapped p* <.001; *Total Hypo-Sensitivity, rGSQ-P*: *t*(31.759) = -5.598, *p* < .001, *Bootstrapped p* < *.001*, *Hypo-sensitivity* (*GSQ-P*: *t*(538) = -5.480, *p* < .001, *Bootstrapped p* < .001, and *Hyper-sensitivity* (*GSQ-P t*(31.788) = -5.578, *p* < .001, *Bootstrapped p* < .001.

Convergent validity

Convergent validity was assessed by comparing the *GSQ-P* and *rGSQ-P* scores with the Empathy Quotient (EQ-C), the Strengths and Difficulties Questionnaire (SDQ) and the SCARED anxiety questionnaire using correlation statistics for children with available data on these measures. As noted earlier, anxiety is known to be associated with sensory sensitivities, in both adults and children (Ashburner et al., 2013; Ben-Sasson et al., 2009; Horder et al., 2014). We therefore, investigated these co-morbidities using anxiety measures from both *SCARED* and from the appropriate scale of the *SDQ* (i.e., the *Internalising* scale, which combines *Emotional symptoms* and *Peer problems*). Both the SCARED and the *Internalising* scale were significantly correlated with total *GSQ-P* and *rGSQ-P* scores; higher levels of anxiety and internalising behaviours were associated with greater sensory sensitivities. The results are summarised in Table 2 (for full details

see SI). Sensory sensitivity is also known to be been linked with lower levels of empathy in children (Tavassoli et al., 2018) as well as with poorer *Externalising* scores (i.e., poorer outward behaviour) on the Goodman's SDQ measure (Fox et al., 2014). Here again this was mirrored in our data: both the EQ-C questionnaire and the SDQ *Externalising* sub-scale were significantly associated with overall *GSQ-P* and *rGSQ-P* scores in the expected direction. These findings suggest that sensory sensitivities, as measured by the *GSQ-P* or *rGSQ-P*, show the expected associations with anxiety, empathy, and Internalised/ Externalised wellbeing.

Next we looked within each of the two sensitivity (hyper/hypo) domains, and found associations with EQ-C, SDQ and SCARED scales, albeit weaker than for combined scores (see Table 2 below). For both scales, poorer *emotional* wellbeing (i.e., .SDQ-Internalising scores and anxiety (*SCARED*) was more closely related to hyper-sensitivity, while poorer *behaviour* (i.e., SDQ-*Externalising* scores) more closely related to hypo-sensitivity (this latter is likely to be because the child is constantly engaging in sensory-seeking behaviour).

Table 2

Correlations between well-being (EQ-C, SCARED, and SDQ) and sensory sensitivity (GSQ-P, rGSQ-P) This tables shows how closely sensory sensitivities (column 1) are related to Empathy (column 2), Anxiety (column 3), and behaviour (columns 4 and 6). The strongest associations were found between Anxiety (SCARED) and Hyper-sensitivity.

	EQ-C	SCARED	SDQ: Externalising	SDQ: Internalising
GSQ-P (long form)				
Total sensitivity	-.40***	.54***	.37***	.46***
Hyper-sensitivity	-.38***	.59***	.31***	.51***
Hypo-sensitivity	-.36***	.41***	.40***	.36***
rGSQ-P (short form)				
Total sensitivity	-.35***	.53***	.34***	.44***
Hyper-sensitivity	-.34***	.57***	.24***	.48***

Hypo-sensitivity	-.28***	.34***	.37***	.27***

Note. Correlations are Pearson's r. *** p < .001

Investigating sensitivity clusters within hyper-sensitivity and hypo-sensitivity domains

To explore how lower domains scores (e.g., visual hyper, visual hypo, etc.) clustered together within this developmental sample we replicated an earlier cluster analysis by Horder and colleagues which had been performed in adults (Horder et al., 2014). Employing hierarchical clustering of domain scores (Ward's minimum variance method, using squared Euclidean distance (Yim & Ramdeen, 2015) on each instrument in turn (*GSQ-P*, *rGSQ-P*) we found the two factor solution was largely supported by the data. In line with our exploratory factor analysis above -- the proprioception domain again was problematic in the long form, because hyper-items clustered within hypo- domains (specifically gustatory behaviours, see Figure 1 left panel). Cluster analysis of the short form scale (*rGSQ-P*) revealed two distinct clusters: hyper and hypo sensitivity (see Figure 1; right panel).

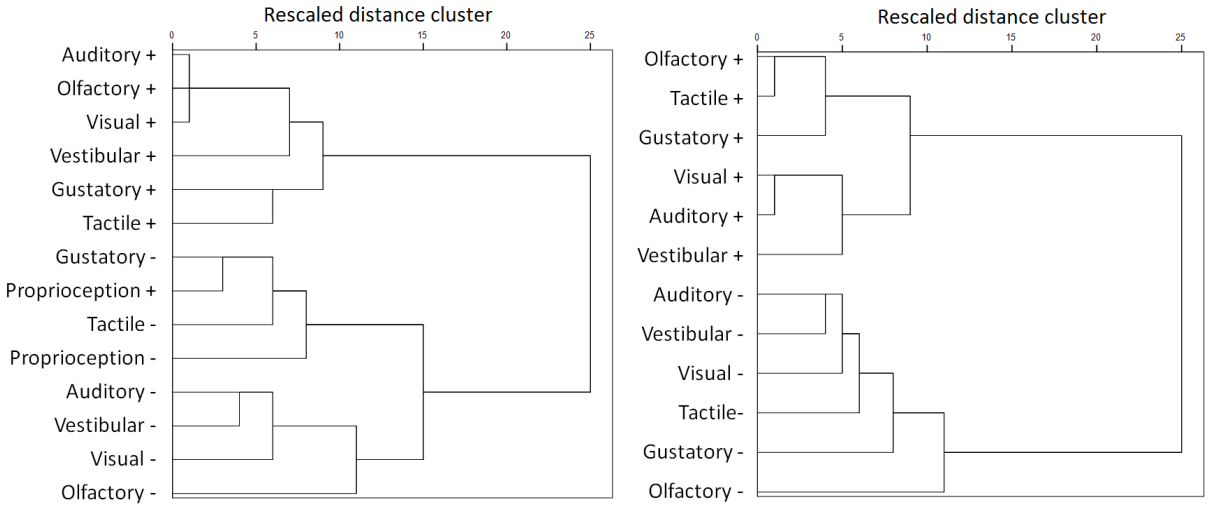

Figure 1. Cluster analysis of the 14 sub-domains within the *GSQ-P* (left panel), and 12 sub-domains within the *rGSQ-P* (right panel). Each sub-domain is labelled by its sense (e.g., "Auditory") and its sensitivity ("+" represents hyper-sensitivity; "-" represents hypo-sensitivity). For example, the sub-domain "Auditory +" is the domain of auditory hyper-sensitivity. Groupings

represent how closely the sub-domains are linked hierarchically in our analyses. Left hand panel shows that questions already loosely cluster into hyper- and hypo-domains in the long form of the scale, but with some exceptions (i.e., "+" elements are largely grouped together, except proprioception). The right hand panel shows a yet cleaner separation in the reduced form *rGSQ-P*.

Within Figure 1, our analysis *a priori* forces together items within the smallest cell units (e.g., we pair *a priori* the individual auditory hyper-sensitivity).

We also carried out a novel cluster analysis. Using the *rGSQ-P* to avoid the issues of cross-loading items described earlier, we entered all items from the questionnaire individually. We see in Figure 2 the expected clustering for hyper-sensitivity (i.e., the two auditory questions cluster together; the two visual questions cluster together etc.). In contrast, we do not find this for hypo-sensitivity (which initially seem to show more arbitrary clusterings, see Figure 1). This suggests that questions within each sense are more closely mirroring each other for hyper-sensitivity, but this is less true for hypo-sensitivity. We return to the interesting possible reasons for this in our *Discussion.*

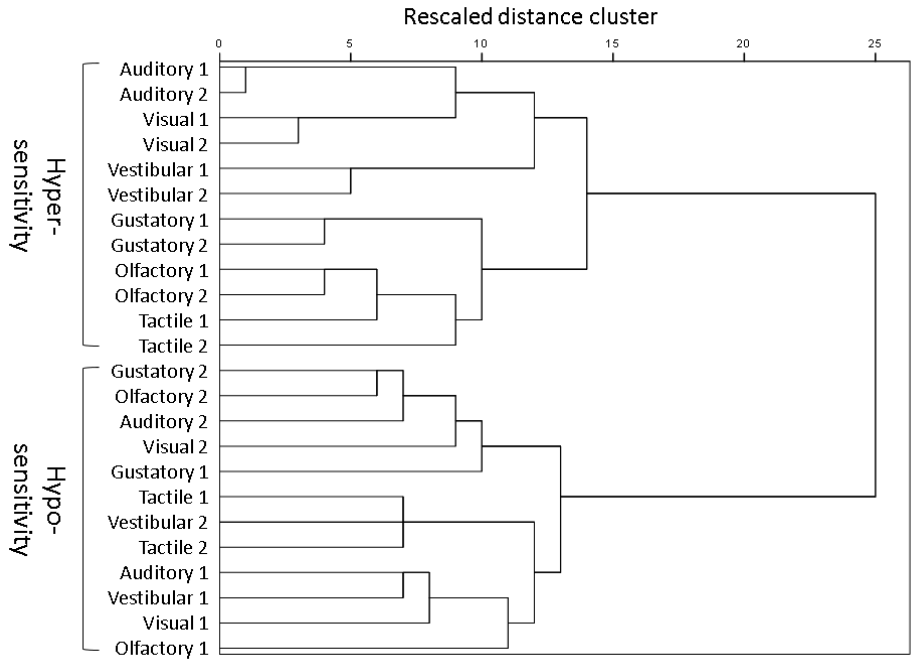

Figure 2. Cluster analysis of the *rGSQ-P*. Figure shows the clear division into hyper questions (top) and hypo questions (bottom). Within each sensitivity domain, questions for the same sense are labelled 1 and 2 (e.g., Gustatory 1 and Gustatory 2). Figure shows that hyper-sensitivity questions cluster by sense domain (e.g., Auditory 1 clusters with Auditory 2) but this is not true for hypo-sensitivity.

Discussion

This paper evaluated the psychometric properties of our novel adaptation of the adult version of the *GSQ* (Robertson & Simmons, 2013) into both full and reduced short–form scales (*GSQ-P*, *rGSQ-P*). Re-designed to measure sensory sensitivities in children via parent report, the long form *GSQ-P* had 42 items (mirroring the adult version; Robertson & Simmons, 2013), crossing hyper- and hypo-sensitivity within each of seven sense domains (*visual*, *auditory*, *gustatory*, *olfactory*, *tactile*, *vestibular*, *proprioception*) giving three questions per cell. The short form (*rGSQ-P*) had 24 items, again crossing hyper- and hypo-sensitivity but this time with two questions only in each

of six sense domains (*proprioception* was excluded given cross-loading in the long-form; see below). Both versions are freely available to use (presented in entirety in the Appendix), as comprehensive yet brief measures of sensory sensitivity suitable for parents reporting on younger children, and validated here on 6-11 year olds.

The adult version has been used extensively elsewhere for research (e.g., Horder et al., 2014; Ward, Brown, Sherwood, & Simner, 2018) and we here present a comparable version for children. The original adult version of the *GSQ* has been found elsewhere to have excellent psychometric properties and this was replicated here for the overall scale in both long and reduced forms. The suitability of both the *GSQ-P* and *rGSQ-P* for general sensory sensitivity is also evidenced by their relatively similar overall Cronbach's alphas as well as from their similarity in convergent validity with other measures. Both showed expected empathy and well-being associations known to be co-morbid with sensory sensitivities in children (Boterberg & Warreyn, 2016; Dean, Little, Tomchek, & Dunn, 2017; Green, Ben-Sasson, Soto, & Carter, 2012). Both the long and short form (*GSQ-P* and *rGSQ-P*) were unrelated to age and gender, making it a useful measure for all children across the 6-11 age group. In addition, both successfully distinguished between SEND and typically-developing populations. It may be useful in future studies where numbers of SEND children were available to investigate profiles of sensory sensitivity within specific SEND categories. The sensitivity sub-domains of both *GSQ-P* and *rGSQ-P* (*total Sensitivity, hypo-Sensitivity scale*, *hyper-Sensitivity scale*) also showed very good (*rGSQ-P*) or excellent (*GSQ-P*) internal consistency (i.e., collapsing across senses). Exploratory and cluster analyses of the full scale (*GSQ-P*) revealed two main factors, which largely reflected hyper and hypo-sensitivity. However, there were notable issues with individual questionnaire items due to cross-loading (and hence increasing

the correlation between hyper and hypo domains) or poor factor loadings, and these ultimately led to our generating the reduced scale (*rGSQ-P*). Items in the *proprioception* modality were found to be particularly problematic and it is possible that proprioceptive items are more difficult to assess accurately from a parental perspective than sensitivities in other modalities. It should be noted that the correlation between total proprioception score (combining hyper and hypo proprioceptive sensitivities) and *GSQ-P* total sensitivity score (excluding proprioception) was strong (*Rho* = .66) suggesting, parents are likely to notice proprioceptive sensitivities but may be mis-identifying hyper and hypo responses. The removal of poorer items made hyper and hypo domains in our reduced scale more distinct (r = .58 compared to r = .78 for the full scale). By removing problematic items all hyper and hypo-sensitivity items to now load correctly. Correlation with the full 42 item scale was still extremely high (r = .94-.97 = .97 for hyper-, and total sensitivity scales). It is hoped the *rGSQ-P* may therefore be a useful addition to the psychometrically evaluated instruments available, especially when time is at a premium, and for future research wishing to specifically tease apart hyper- and hypo- experiences. In contrast, the long form offers the opportunity to investigate sensitivity if comparison with adult populations is required (i.e., the adult *GSQ*).

Cronbach's Alphas *within* individual senses were somewhat poorer than for the broader domains. Specifically, when looking at gross sensitivities within any sense (e.g., collapsing across hyper- and hypo-sensitivities within vision) the long form had "acceptable" or "good" Cronbach's alphas for all but the *Tactile* sense, while the short form was generally "acceptable" at best. This suggests that if scores for individual sense domains are required (e.g., visual; i.e., when collapsed over hyper- and hypo- items) the long form *GSQ-P* would provide the most reliable diagnostic scores.

A similar pattern of lower reliability for sense domains has been found in an adult-*GSQ* sample (Sapey-Triomphe et al., 2018) and could be explained by a relatively small number of items per scale (Heo, Kim, & Faith, 2015) or, alternatively, reflect the reduced utility in measuring sensitivities in this way. A possibility that needs to be explored is that hyper and hypo-sensitivities may not necessarily be constrained to the same sense modality. A child who exhibits visual hyper-sensitivity (e.g., aversion to bright lights) may have hypo-sensitivities in other domains (e.g., gustatory dampening). Hence collapsing items *within* any given sense may be somewhat fallacious, and could explain our low correlations between hyper/hypo questions *within* senses.

We also found further evidence that hyper-sensitivity may stand apart conceptually and psychologically from hypo-sensitivity. Our cluster analysis showed a more cohesive structure within hyper-sensitivities versus hypo-sensitivities (in reduced form *rGSQ-P*). Specifically, hyper-sensitivity questions clustered by sense modality (e.g., tactile questions grouped together; visual questions grouped together), whereas hypo-sensitivity questions did not. Instead, hypo- responses grouped by behavioural outcomes, with clusters of seeking-behaviours (e.g., seeking either olfactory, tactile or auditory stimuli), clusters of sensory dampening (e.g., not feeling pain; not feeling cold), and an apparent cluster of repetitive behaviours (e.g., repetitively playing the same piece of music [auditory], spinning round and round [vestibular]). Hypo versus hyper-sensitivity may therefore spring from different mechanisms. Other differences are that hypo- outcomes are often enjoyable (Kapp et al., 2019) in contrast to hyper-sensitivities, and may help regulate sensory input and reduce stress (Liss, Timmel, Baxley, & Killingsworth, 2005; Steward, 2015). Yet more difference is our findings that poorer emotional wellbeing relates more to hyper-sensitivity [SDQ-Internalising/ Anxiety], while externalising behaviours relates more to hypo-sensitivity [SDQ-

Externalising: hyperactivity, Conduct problems]). In summary, we have found a number of ways in which hyper-sensitivity stands apart from hypo-sensitivity, despite falling within the single dimension of 'sensory sensitivities'.

In conducting our study we were aware of certain limitations. As with any parent report measure, the child is not describing his/her own experiences directly. Although parent and child reports of behaviour and traits are known to converge in many ways (Powers et al., 2003; Zhou et al., 2008), their perspectives also differ, for example in measures of wellbeing, behaviour and personality -- where somewhat lower associations between parent and child perspectives have been reported (Barbaranelli, Caprara, Rabasca, & Pastorelli, 2003; Brown, Mangelsdorf, Agathen, & Ho, 2008; Phares, Compas, & Howell, 1989). Future work is in progress to investigate an alternative self-report for children version of the *GSQ* (see Brown, Millington, Robertson, & Simmons, 2021) which could allow triangulation of the data and a greater understanding of underlying sensitivities as they emerge through modes of reporting. It would also be useful in future studies to investigate measurement invariance in respect to age and gender for the *GSQ-P* and *rGSQ-P*. We also acknowledge that this analysis is exploratory. Future validations using confirmatory techniques would be useful.

A strength of our paper is that we investigated sensory sensitivity in a population sample recruited from mainstream schools. It is the first study to date, as far as we are aware, to measure sensory sensitivities in children who are both typically-/non-typically developing (SEND) using six or more sense modalities and two domains of sensitivity (hyper-/ hypo-), rather than a single global measure (Ben-Sasson et al., 2008; Schoen, Miller, & Sullivan, 2014). This affords potentially

important novel insights. The size of our SEND sample meant we could not explore sensitivity profiles within specific sub-groups of SEND children. Future work on a targeted ASC sample would allow a validation of the questionnaire on children with autism specifically. Finally, future studies might also compare our measure alongside existing sensory sensitivity questionnaires such as the widely used *Sensory Profile 2*. Given our interests in Open Science, we presented a study that could be replicated by others without cost. However, other sensory sensitivity measures are available, such as the *Sensory Experiences Questionnaire* or indeed the *Sensory Integration and Praxis Tests* which we were unable to run on our large sample of >600 children given its labour-intensity (e.g., 2 hour complete test). This type of concurrent validity in future studies would be particularly important, although we point the reader to our recent work showing concurrent validity between the *rGSQ-P* and the *Sussex Misophonia Scale for Adolescents* (Simner, Rinaldi, Koursarou, & Ward, 2021). Misophonia is a type of sensory hyper-sensitivity to certain categories of sound (e.g., chewing; (Jastreboff & Jastreboff, 2001). High scores on the *Sussex Misoponia Scale for Adolescents* mapped onto high scores within the *rGSQ-P* domain of sensory hyper-sensitivity, but not hypo-sensitivities -- exactly as we might expect since misophonia is a type of hyper- (but not hypo-) sensitivity. Hence our measures also shows concurrent validity against another scale of hyper-sensitivity. For *convergent* validity, beyond that already shown here, our *rGSC-P* has now also been compared against measures of creativity (Smees, Rinaldi, & Simner, 2021) where our hypo-sensitivity subscale predicted higher scores on the creativity-linked trait of Openness to Experiences (Kaufman et al., 2016) and greater orientation towards creative activities involving movement and dance (exactly as we might expect from the sensory seeking aspect of the hypo-sensitivity trait). In summary, we have presented a range of ways in which our measure

of childhood sensory sensitivities shows convergent validity, as well as showing convergent and concurrent validity elsewhere.

To conclude, the measures we have presented here provide robust indicators of sensory sensitivity as an overall scale, and (in the short form especially) for the separate dimension of hyper-sensitivity as distinct from hypo-sensitivity. The *rGSQ-P* short form would be especially useful where time is limited and shows a particularly high correspondence to the full scale, although it no longer has functionality within the proprioceptive domain. The *GSQ-P* long form would be more useful where comparison with adult populations is required (i.e., the adult *GSQ*), and allow researchers to track sensory sensitivities longitudinally. We hope this validation might enable future researcher a better understanding of the sensory sensitivities of children, especially as viewed through the eyes of their caregivers.

Appendix

Table A.1 The GSQ-P and rGSQ-P questionnaires (short and long forms)

The Parent-completed Glasgow Sensory Questionnaires (short and long forms). The short form items are presented first and displayed shaded. The additional items to complete the long form are displayed afterwards and are unshaded (i.e., the full GSQ-P is the entire set of questions). Also shown are the item numbers used during our validation.

Item numbers during validation	**Does your child…**	**Never**	**Rarely**	**Sometimes**	**Often**	**Always**
2	gag when eating certain foods, perhaps feeling as if he/she is going to be sick?	☐	☐	☐	☐	☐
6	find certain noises/pitches of sound annoying?	☐	☐	☐	☐	☐
8	ever complain of bright lights hurting his/her eyes or causing a headache?	☐	☐	☐	☐	☐
9	like to listen to the same piece of music or part of a song over and over again?	☐	☐	☐	☐	☐
10	ever seem ill, dizzy or peculiar if he/she has to reach up high or bend down low for something?	☐	☐	☐	☐	☐
12	like to spin round and round?	☐	☐	☐	☐	☐
15	dislike having a haircut …?	☐	☐	☐	☐	☐
16	sometimes hurt him/herself but not appear to feel pain?	☐	☐	☐	☐	☐
17	'borrow' your perfume, after-shave etc.?	☐	☐	☐	☐	☐
18	ever seem bothered by fluorescent or flickering lights?	☐	☐	☐	☐	☐
19	like lining objects up?	☐	☐	☐	☐	☐
21	complain about going into a strong smelling shop …?	☐	☐	☐	☐	☐
22	complain about the labels in clothes and ask for them to be taken out?	☐	☐	☐	☐	☐
23	hate the feeling or texture of certain foods in his/her mouth?	☐	☐	☐	☐	☐
24	complain about going to restaurants because he/she can smell a certain odour?	☐	☐	☐	☐	☐
25	dislike loud noises?	☐	☐	☐	☐	☐
28	ever complain of having a weak sense of taste?...	☐	☐	☐	☐	☐
30	complain about feeling dizzy or ill when playing fast-paced sports..?	☐	☐	☐	☐	☐
33	really like listening to certain sounds…?	☐	☐	☐	☐	☐
34	like to run about more than the average child, perhaps up and down in straight lines or round in circles?	☐	☐	☐	☐	☐
35	chew and lick objects that aren't food …because he/she likes the feel of them in the mouth?	☐	☐	☐	☐	☐
36	seek out strong smells like perfumes, plastics, paints etc.?	☐	☐	☐	☐	☐
39	seem to be able to go outside without a coat or jacket when other people think that it is too cold?	☐	☐	☐	☐	☐
42	flick his/her fingers in front of his/her eyes?	☐	☐	☐	☐	☐
Q	***Additional long form items below***					
1	... dislike the physical sensation from when people hug him/her?	☐	☐	☐	☐	☐
3	... seem to find it difficult to manipulate his/her hands when completing a delicate task (for example, picking up small objects or transferring objects from one hand to the other)?	☐	☐	☐	☐	☐
4	... ever run his/her hand around the outside of an object before picking it up?	☐	☐	☐	☐	☐
5	... stand very close or very far when he/she is talking to someone?	☐	☐	☐	☐	☐
7	... ever smell food before eating it?	☐	☐	☐	☐	☐

Item numbers during validation	**Does your child…**	**Never**	**Rarely**	**Sometimes**	**Often**	**Always**
11	... seem to be fascinated by small particles (for example, little bits of dust in the air)?	☐	☐	☐	☐	☐
13	... complain about feeling ill from smelling a certain odour?	☐	☐	☐	☐	☐
14	... seem to find it difficult to hear what people are saying?	☐	☐	☐	☐	☐
20	... rock him/herself backwards and forwards?	☐	☐	☐	☐	☐
26	... use the tip of his/her tongue to taste food before eating it?	☐	☐	☐	☐	☐
27	... ever say his/her body feels ‘numb’ - or act like he/she can’t feel anything against the skin?	☐	☐	☐	☐	☐
29	... seem to be unaware of his/her body's signals (for example, doesn't complain about being hungry, tired or thirsty)?	☐	☐	☐	☐	☐
31	... react strongly when he/she hears an unexpected sound?	☐	☐	☐	☐	☐
32	... complain about walking on uneven surfaces?	☐	☐	☐	☐	☐
37	... seem to position his/her body in a way that is different to most people (for example, lying on his/her back on a sofa with legs straight up in the air at a 90° angle)?	☐	☐	☐	☐	☐
38	... find it more difficult than other children to tie up his/her shoelaces or button up clothes?	☐	☐	☐	☐	☐
40	... like to eat the same foods most of the time?	☐	☐	☐	☐	☐
41	... turn his/her whole body (rather than only the head) when looking at something or someone?	☐	☐	☐	☐	☐

Scoring: Never=0, Rarely = 1, Sometimes = 2, Often = 3, Always = 4

Table A.2 Coding sheet for the Parent-completed Glasgow Sensory Questionnaires

Coding sheet for the Parent-completed Glasgow Sensory Questionnaire. Shading denotes the appropriate sense domain (visual, auditory, gustatory, olfactory, tactile, vestibular, proprioceptive) and sensitivity domain (+ hyper-sensitivity; - hypo-sensitivity). Scoring: Never=0, Rarely = 1, Sometimes = 2, Often = 3, Always = 4.

Total Sensitivity score is the sum of items across the questionnaire (range in long-form = 0-168; range in short-form = 0-96). *Hyper-sensitivity* score is the sum of items across the hyper-items (n21 items in the long-form; range = 0-84; n12 items in the short-form; range = 0-48). *Hypo-sensitivity* score is the sum of items across the hypo-items (n21 items in the long-form; range = 0-84; n12 items in the short-form; range = 0-48).

Item: Short form only	**VIS**		**AUD**		**GUS**		**OLF**		**TAC**		**VES**		**PRO**	
Does your child…	+	-	+	-	+	-	+	-	+	-	+	-	+	-
gag when eating certain foods, perhaps feeling as if he/she is going to be sick?					■									
find certain noises/pitches of sound annoying?			■											
ever complain of bright lights hurting his/her eyes or causing a headache?	■													
like to listen to the same piece of music or part of a song over and over again?				■										
ever seem ill, dizzy or peculiar if he/she has to reach up high or bend down low for something?											■			
like to spin round and round?												■		
dislike having a haircut …?									■					
sometimes hurt him/herself but not appear to feel pain?										■				
'borrow' your perfume, after-shave etc.?								■						
ever seem bothered by fluorescent or flickering lights?	■													
like lining objects up?		■												
complain about going into a strong smelling shop …?							■							
complain about the labels in clothes and ask for them to be taken out?									■					
hate the feeling or texture of certain foods in his/her mouth?					■									
complain about going to restaurants because he/she can smell a certain odour?							■							
dislike loud noises?			■											
ever complain of having a weak sense of taste?...						■								
complain about feeling dizzy or ill when playing fast-paced sports..?											■			
really like listening to certain sounds…?				■										

like to run about more than the average child, perhaps up and down in straight lines or round in circles?														
chew and lick objects that aren't food …because he/she likes the feel of them in the mouth?														
seek out strong smells like perfumes, plastics, paints etc.?														
seem to be able to go outside without a coat or jacket when other people think that it is too cold?														
flick his/her fingers in front of his/her eyes?														
Additional items for long form	**VIS**		**AUD**		**GUS**		**OLF**		**TAC**		**VES**		**PRO**	
Does you're your child…	+	-	+	-	+	-	+	-	+	-	+	-	+	-
dislike the physical sensation from when people hug him/her?														
seem to find it difficult to manipulate his/her hands when completing a delicate task …?														
ever run his/her hand around the outside of an object before picking it up?														
stand very close or very far when he/she is talking to someone?														
ever smell food before eating it?														
seem to be fascinated by small particles …?														
complain about feeling ill from smelling a certain odour?														
seem to find it difficult to hear what people are saying?														
rock him/herself backwards and forwards?														
use the tip of his/her tongue to taste food before eating it?														
ever say his/her body feels 'numb' - or act like he/she can't feel anything against the skin?														
seem to be unaware of his/her body's signals (for example, doesn't complain about being hungry, tired or thirsty)?														
react strongly when he/she hears an unexpected sound?														
complain about walking on uneven surfaces?														
seem to position his/her body in a way that is different to most people…?														
find it more difficult than other children to tie up his/her shoelaces or button up clothes?														
like to eat the same foods most of the time?														
turn his/her whole body (rather than only the head) when looking at something or someone?														

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Supplementary Materials

Modifying the *GSQ* for parent report

First, the prefix to the original items; 'Do you…' was replaced with 'Does your child…', and any other cases of 'you' were replaced with male/female third person singular pronouns (i.e., 'he/she'). In total, 15 items required only these minimal changes and no others. In addition, 24 items underwent minor text revisions, with either the addition of wording or removal of excessive text. For example, the adult item "*Do bright lights ever hurt your eyes…?*" became "*Does your child ever complain that bright lights hurt his/her eyes…?*"; and the relatively long adult item "*Do you stand very close (for example, less than 1 metre/3 feet away) or very far (for example, more than 3 metres/9 feet away) when you are talking to someone?*" became "*Does your child stand very close or very far when he/she is talking to someone?*". The remaining three items underwent more substantive revisions. The adult item "*Are you ever told by others you wear too much perfume, after-shave?*" became "*Does your child 'borrow' your perfume, after-shave?*"; The adult item "*Do you enjoy wearing very strong perfumes/after-shaves?*" became "*Does your child seek out strong smells like perfumes, plastics, paints etc.?*". Lastly the proprioceptive adult item "*Do you like to wear something/hold something (for example, a hat or a pencil) so that you know where your body 'ends'?*' was replaced with one that caregivers could more easily assess: "*Does your child turn his/her whole body (rather than only the head) when looking at something or someone?*' (i.e., on the assumption that a parent cannot know the internal thought-motivation for a child holding something). This latter item was taken from a larger pool of 70 *GSQ* items, used in the development of the original *GSQ* adult scale (Robertson & Simmons, 2013) and was chosen as the item not

already included which had the highest factor loading in the original PCA analysis for hyper-sensitivity in proprioception (i.e., the relevant category which required replacement).

Factor structure of the *GSQ-P* and *rGSQ-P*

Table SI1

Factor loadings for the full scale (*GSQ-P*). Each item (column 1) is a question prefaced by "Does your child…". Column 2 (Q) indicates the question number as presented to participants in our validation study. Column 3 (Domain) indicates the sensitivity domain (+ Hyper-sensitivity item; – Hypo-sensitivity items) and sense domain (A-Auditory; V-Visual; G-Gustatory; O-Olfactory;- T-Tactile; VE-Vestibular; P-Proprioception). Column 4 (F1) indicates factor loadings Hyper items, and column 5 (F2), indicates factor loadings Hypo items. Factor loadings are order by size within factor.

Item	Q	Domain	F1	F2
find certain noises/pitches of sound annoying?	6	A +	0.83	
dislike loud noises?	25	A +	0.75	
complain about going into a strong smelling shop …?	21	O +	0.72	
complain about going to restaurants because he/she can smell a certain odour?	24	O +	0.64	
complain about feeling ill from smelling a certain odour?	13	O +	0.63	
react strongly when he/she hears an unexpected sound?	31	A +	0.62	
ever complain of bright lights hurting his/her eyes or causing a headache?	8	V +	0.59	
dislike having a haircut ?	15	T +	0.55	
ever seem bothered by fluorescent or flickering lights?	18	V +	0.54	
hate the feeling or texture of certain foods in his/her mouth?	23	G +	0.53	
gag when eating certain foods, perhaps feeling as if he/she is going to be sick?	2	G +	0.51	
use the tip of his/her tongue to taste food before eating it?	26	G +	0.40	
ever smell food before eating it?	7	O -	0.39	
complain about feeling dizzy or ill when playing fast-paced sports..?	30	VE +	0.38	
complain about the labels in clothes and ask for them to be taken out?	22	T +	0.37	
dislike the physical sensation from when people hug him/her?	1	T +	0.34	
like to eat the same foods most of the time?	40	G -	0.34	
find it more difficult than other children to tie up his/her shoelaces or button up clothes?	38	P +	0.27	0.25
ever seem ill, dizzy or peculiar if he/she has to reach up high or bend down low for something?	10	VE +	0.26	0.24
seem to find it difficult to manipulate his/her hands when completing a delicate task …?	3	P -	0.25	0.21
turn his/her whole body (rather than only the head) when looking at something or someone?	41	P +		0.62
like to run about more than the average child, perhaps up and down in straight lines or round in circles?	34	VE -		0.58
like to spin round and round?	12	VE -		0.54
seek out strong smells like perfumes, plastics, paints etc.?	36	O -		0.53
rock him/herself backwards and forwards?	20	VE -		0.50
sometimes hurt him/herself but not appear to feel pain?	16	T -		0.50

chew and lick objects that aren't food …because he/she likes the feel of them in the mouth?	35	G -		0.50
really like listening to certain sounds…?	33	A -		0.46
seem to position his/her body in a way that is different to most people…?	37	P +		0.45
seem to be able to go outside without a coat or jacket when other people think that it is too cold?	39	T -		0.45
flick his/her fingers in front of his/her eyes?	42	V -		0.45
seem to be fascinated by small particles …?	11	V +		0.43
ever complain of having a weak sense of taste?...	28	G -		0.40
ever say his/her body feels 'numb' - or act like he/she can't feel anything against the skin?	27	T -		0.40
like lining objects up?	19	V -		0.39
like to listen to the same piece of music or part of a song over and over again?	9	A -		0.33
ever run his/her hand around the outside of an object before picking it up?	4	V -		0.33
seem to find it difficult to hear what people are saying?	14	A -		0.33
complain about walking on uneven surfaces?	32	VE +		0.33
'borrow' your perfume, after-shave etc.?	17	O -		0.29
stand very close or very far when he/she is talking to someone?	5	P -	0.26	0.28
seem to be unaware of his/her body's signals (for example, doesn't complain about being hungry, tired or thirsty)?	29	P -	0.23	0.26

Table SI2.

Factor loadings for the short form ("reduced") scale (*rGSQ-P*). See Table SI3. for column descriptors.

Item	Q	Domain	F1	F2
find certain noises/pitches of sound annoying?	6	A +	0.75	
dislike loud noises?	25	A +	0.69	
complain about going into a strong smelling shop …?	21	O +	0.69	
complain about going to restaurants because he/she can smell a certain odour?	24	O +	0.64	
ever complain of bright lights hurting his/her eyes or causing a headache?	8	V +	0.63	
ever seem bothered by fluorescent or flickering lights?	18	V +	0.58	
dislike having a haircut …?	15	T +	0.57	
hate the feeling or texture of certain foods in his/her mouth?	23	G +	0.50	
gag when eating certain foods, perhaps feeling as if he/she is going to be sick?	2	G +	0.49	
complain about feeling dizzy or ill when playing fast-paced sports..?	30	VE +	0.42	
complain about the labels in clothes and ask for them to be taken out?	22	T +	0.35	
ever seem ill, dizzy or peculiar if he/she has to reach up high or bend down low for something?	10	VE +	0.34	
seek out strong smells like perfumes, plastics, paints etc.?	36	O -		0.58
like to run about more than the average child, perhaps up and down in straight lines or round in circles?	34	VE -		0.54
like to spin round and round?	12	VE -		0.51
seem to be able to go outside without a coat or jacket when other people think that it is too cold?	39	T -		0.49
really like listening to certain sounds…?	33	A -		0.47
chew and lick objects that aren't food …because he/she likes the feel of them in the mouth?	35	G -		0.45
sometimes hurt him/herself but not appear to feel pain?	16	T -		0.41
like to listen to the same piece of music or part of a song over and over again?	9	A -		0.39
like lining objects up?	19	V -		0.37
'borrow' your perfume, after-shave etc.?	17	O -		0.35
ever complain of having a weak sense of taste?...	28	G -		0.34
flick his/her fingers in front of his/her eyes?	42	V -		0.30

Table SI3.

Correlation between hyper and hypo-sensitivity scales of the GSQ-P, within each sense domain and for each participant cluster (All; Typically Developping TD; SEND). Related adult findings are shown from two other studies using the GSQ adult scale (Kuiper et al., 2018; Sapey-Triomphe et al., 2018a) *where typical adults are compared to adults with confirmed or suspected ASD respectively*

	Children			**Adults**				
	Current Study			**Kuiper et al.**		**Sapey-Triomphe et al.**		
Correlation between hyper- & hypo-Sensitivity	**All**	**TD**	**SEND**	**TD**	**ASD**	**All**	**Low AQ**	**High AQ**
Collapsed across senses	.78	.74	.83	.73	.60	.82	.60	.73
Within sense domains								
Visual	*.48*	*.46*	*.61*	*.48*	*.57*	.60	.31	.54
Auditory	*.49*	*.47*	*.44*	*.35*	*.15*	.57	.23	.30
Gustatory	*.51*	*.51*	*.41*	*.41*	*.24*	.36	.23	.45
Olfactory	*.39*	*.37*	*.53*	*.19*	*.27*	.25	.09	.21
Tactile	*.34*	*.28*	*.44*	*.21*	*.02*	.57	.15	.33
Vestibular	*.33*	*.28*	*.60*	*.22*	*.39*	.54	.18	.46
Proprioception	*.49*	*.44*	*.64*	.37	*.57*	.63	.38	.45
N	601	509	31	68	79	245	143	102

Note. Spearmans Rho shown in italics. All other associations are Pearson r All correlations from the current study shown in Tbale 1 were significant at the $p < .001$ level

Table SI4.

Internal consistency expressed as Cronbach's alpha for children in the current study (using *GSQ-P*) in comparison to two other adults studies using the GSQ adult scale (Kuiper et al., 2018; Sapey-Triomphe et al., 2018a) where typical adults are compared to adults with confirmed or suspected ASD respectively (this latter from scores ≥26 on the AQ) and a third study testing typical adults (Ujiie & Wakabayashi, 2015)

Internal consistency expressed as Cronbach's alpha	Children			Adults				
	Current Study			**Kuiper et al.**		**Ujie & Wakabayashi**	**Sapey-Triomphe et al.**	
	All	TD	SEND	TD	ASD	TD	Low AQ	High AQ
Collapsed across senses								
Hyper-sensitivity	.88	.88	.93	.85	.87	--		
Hypo-sensitivity	.83	.83	.87	.81	.85	--		
Total sensitivity	.93	.93	.95	.90	.91	.84	.84	.91
Within sense domains								
Visual	.66	.66	.80	.67	.75	.51		
Auditory	.77	.77	.79	.71	.61	.56		
Gustatory	.69	.69	.73	.64	.57	.43		
Olfactory	.68	.68	.77	.44	.59	.42		
Tactile	.53	.53	.65	.44	.42	.32		
Vestibular	.65	.65	.74	.50	.73	.53		
Proprioception	.67	.67	.76	.53	.67	.49		

Domain validations and scale validations for the rGSQ-P

Scale validation

Table SI5.

Scale reliability (Cronbach's alpha) for *rGSQ-P*.

	Cronbachs All	*Cronbachs TD*	*Cronbachs SEND*
Visual	.60	.54	.73
Auditory	.70	.67	.78
Gustatory	.51	.51	.46
Olfactory	.51	.50	.56
Tactile	.54	.49	.48
Vestibular	.53	.42	.63
Hypo	.77	.75	.79
Hyper	.85	.83	.90
Total	.87	.85	.91

Note: Spearmans Rho shown in itaics. All other associations are Pearson r

Group differences (gender, age) for the rGSQ-P

There were no significant gender differences in *Total Sensitivity (rGSQ-P)*, $t(599) = -0.730$, $p = .466$, *Bootstrapped* $p = .470$, nor *Hyper-Sensitivity*, $t(599) = 0.256$, $p = .798$; *Bootstrapped* $p = .801$, nor *Hypo-Sensitivity*, $t(599) = -1.704$, $p = .0.089$, *Bootstrapped* $p = 0.073$. We also found that there were no age effects in sensitivity scores across the range of children tested here (6-11 years). This was the true for *Total Sensitivity (rGSQ-P)* score, $F(6, 594), = 0.242$, $p = .962$), and *Hypo-Sensitivity*, $F(6, 594) = 1.263$ $p = .272$) and *Hyper-*$F(6,594) = 1.239$, $p = .284$.

Group differences (gender, age) for the GSQ-P

There were no significant gender differences for *total sensitivity*, $t(599) = -0.662$, $p = .508$, *Bootstrapped* $p = .493$. Similarly there were no significant age differences in the *GSQ-P* for *total sensitivity*, $F(6, 594) = .141$ $p = .991$. This pattern held for *hyper-Sensitivity*, gender $t(599) = -0.604$, $p = .508$, *Bootstrapped* $p = .551$, age $F(6, 594) = .607$, $p = .725$ and *hypo-Sensitivity*, gender $t(599) = -0.648$, $p = .517$, *Bootstrapped* $p = .514$, age $F(6, 594) = .414$ $p = .870$.

We also found that there were no age effects in sensitivity scores across the range of children tested here (6-11 years). This was the true for *total sensitivity, GSQ-P* score, $F(6, 594) = .141$ $p = .991$, *hypo-sensitivity, GSQ-P*, $F(6, 594) = .414$, $p = .870$, and *hyper-sensitivity GSQ-P*, $F(6, 594) = .607$ $p = .725$.