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Prevalence and Severity of Auditory Sensory Over-Responsivity in Autism as Reported by Parents and Caregivers

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Abstract

Auditory sensory over-responsivity (aSOR) is a frequently reported sensory feature of autism spectrum disorders (ASD); however, there is little consensus regarding its prevalence and severity. This cross-sectional study uses secondary data from the Autism Diagnostic Interview-Revised (ADI-R; Item 71: *undue sensitivity to noise*) housed in the US National Institute of Mental Health Data Archives to identify prevalence and severity of aSOR. Of the 4,104 subjects with ASD ages 2 to 54 (M = 9, SD = 5.8) who responded to item 71, 60.1% (n = 1,876) had aSOR currently (i.e., point prevalence) and 71.1% (n = 2,221) reported having aSOR ever (i.e., lifetime prevalence). aSOR prevalence and severity were affected by age, but there were no associations with sex.

Key words: autism, auditory, sensory, prevalence, severity

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Declarations

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Conflicts of interest/Competing Interests

The authors have no relevant financial or non-financial interests to disclose.

Ethics Approval

This is a secondary data analysis study and determined non-human subjects' research. The FIU Institutional Review Board has confirmed that no ethical approval is necessary.

Data

Data and/or research tools used in the preparation of this manuscript were obtained from the National Institute of Mental Health (NIMH) Data Archive (NDA). NDA is a collaborative informatics system created by the National Institutes of Health to provide a national resource to support and accelerate research in mental health. Dataset identifier: *NIMH Data Archive Digital Object Identifier (DOI)* 10.15154/1520441. This manuscript reflects the views of the authors and may not reflect the opinions or views of the NIH or of the Submitters submitting original data to NDA.

Authors' contribution statement

All authors contributed to the study conception and design. Data collection and analysis were performed by Dr. Tana Carson and Dr. Matthew J. Valente. The first draft of the manuscript was written by Dr. Tana Carson and all authors commented on previous versions of the manuscript. All authors read and approved the final manuscript.

Abstract

Auditory sensory over-responsivity (aSOR) is a frequently reported sensory feature of autism spectrum disorders (ASD); however, there is little consensus regarding its prevalence and severity. This cross-sectional study uses secondary data from the Autism Diagnostic Interview-Revised (ADI-R; Item 71: *undue sensitivity to noise*) housed in the US National Institute of Mental Health Data Archives to identify prevalence and severity of aSOR. Of the 4,104 subjects with ASD ages 2 to 54 (M = 9, SD = 5.8) who responded to item 71, 60.1% (n = 1,876) had aSOR currently (i.e., point prevalence) and 71.1% (n = 2,221) reported having aSOR ever (i.e., lifetime prevalence). aSOR prevalence and severity were affected by age, but there were no associations with sex.

Although individuals with autism spectrum disorders (ASD) have been shown to have normal hearing (Gravel et al., 2006; Tharpe et al., 2006), auditory sensory over-responsivity (aSOR) is a commonly reported sensory feature of ASD (Gomes et al., 2008; Tomchek & Dunn, 2007). However, there is no consensus on the prevalence and severity of this problem within the ASD population. aSOR in ASD ranges widely across studies from 15 to 100% (Green, Shulamite A. et al., 2015; Khalfa et al., 2004; Schoen, 2009; Stefanelli, Ana Cecília Grilli Fernandes et al., 2020; Tomchek & Dunn, 2007) whereas the point prevalence in pediatric population ranges from 3.2 to 17.1% (Coelho et al., 2007; Pienkowski et al., 2014; Rosing et al., 2016).

aSOR (hyper-reactivity, hyper-responsivity, sensory over-responsivity, and hyperacusis) is characterized by discomfort and irritability in response to auditory stimuli (Rosenhall et al., 1999; Stefanelli, Ana Cecília Grilli Fernandes et al., 2020) and involves aversive responses to everyday sounds that do not bother others. aSOR differs from hyper-sensitivity which involves having a decreased threshold for detecting auditory stimuli. Although aSOR has been shown to differ in children with ASD compared to typically developing controls, hyper-sensitivity does not (Gravel et al., 2006; Rosenhall et al., 1999).

Across the lifespan for those with ASD, anxiety and over-responsivity to different types of sensory stimuli have been closely linked (Gillott & Standen, 2007; Green, Shulamite & Ben-Sasson, 2010; Mazurek et al., 2012; Syu & Lin, 2018). In fact, sensory over-responsivity has been shown to be a positive predictor of anxiety later in development for those with ASD (Green, Shulamite A. et al., 2012). For children with ASD, sensory over-responsivity has been linked to both child stress (Rance et al., 2017) and increased family stress (Kirby et al., 2015; Reynolds & Lane, 2008; Schaaf et al., 2011). There are currently no standardized assessments focused solely on evaluating aSOR in children, nor are there evidence-based treatments available for aSOR in ASD.

The purpose of this brief report is to utilize a large dataset to identify the prevalence of aSOR in ASD including both: (a) point prevalence, the proportion of individuals with ASD who have aSOR at the time of assessment, and (b) lifetime prevalence, the proportion of individuals who have ever had aSOR, even if they no longer have it at the time of assessment. Additionally, this study aims to evaluate age and sex effects on point prevalence and severity of aSOR among people with any form of ASD. Based on previous studies of age-related differences in anxiety (Llanes et al., 2018) and aSOR (Kern et al., 2006) among children with ASD, we hypothesize that the point prevalence and severity ratings of aSOR (e.g., mild to severe) would be greater in younger age groups compared to older age groups. Sex differences in ASD have been reported in core diagnostic criteria (Van Wijngaarden-Cremers, Patricia J M. et al., 2014), as well as in physiological domains such as brain morphology and function (Irimia et al., 2017; Irimia et al., 2018; Zhang et al., 2018). Importantly, sex differences in ASD have also been identified in sensory hyper-reactivity behaviors (Tavassoli et al., 2014) and in underlying neural networks related to sensory processing (Cummings et al., 2020). Therefore, this study also aims to identify whether aSOR differentially occurs in males and females with ASD. Based on previous studies, it is anticipated that if sex-differences exist, females would have higher rates of aSOR than males. This information can be useful for developing targeted assessments and interventions.

Methods

Secondary Data Analysis

Secondary data (i.e., data previously collected by other studies) were extracted from the US National Institute of Mental Health Data Archives (NDA) by entering “autism diagnostic interview-revised" (ADI-R) search terms in the Data Structure (i.e., questionnaire) search feature of the Data Dictionary. Subjects were included if they had the following data elements (i.e., questionnaire items) as follows: (1) ADI-R item number 72; (2) all four ADI-R items required for calculating cut-off scores for ASD vs. non-ASD [(i) Total for Section A (dbaes_atotal), (ii) Total for Section B - Non-Verbal (dbaes_bnvtotal), (iii) Total for Section B - Verbal (dbaes_bvtotal) and (iv) Total for Section C (dbaes_ctotal)], and (3) "interview_age" of two years and up. All other subjects were excluded. See Figure 1 for a flowchart detailing inclusion and exclusion decisions and resulting sub-samples.

Study Sample

The original data package included n = 7,001 subjects from 98 studies. After applying exclusion criteria, the remaining n = 4,104 subjects with ASD and n = 1,492 without ASD ages two and up were included in the study (Figure 1). Data Elements "interview_age" and "sex" were used to generate descriptive statistics on demographics for the study sample. Race and ethnicity data were only available for a small subset of subjects (~10) therefore no information is included on these variables. Four age-groups were created following guidelines of the US NICHD guidelines previously reported for pediatric research (Williams et al., 2012) as follows: early childhood (2 to <6 years), middle childhood (6 to < 12 years), early adolescent (12 to < 19 years), and adulthood (19 to 54.3 years).

Instrument

Autism Diagnostic Interviewer – Revised (ADI-R). The Autism Diagnostic Interviewer –R (ADI-R) (Lord et al., 1994) was utilized to confirm/deny ASD diagnoses and to identify aSOR prevalence and severity via instrument item 72: *undue sensitivity to noise*. This item of the ADI-R was selected over items from other sensory processing measures available in the NDA because it is a standardized clinical assessment of autism that includes a detailed question regarding aSOR and is widely used in ASD research. At the time of this study, the ADI-R provided the largest sample available that included both gold standard ASD diagnostic data as well as a detailed instrument item regarding aSOR. See supplemental material (Appendix A) for a summary table of all aSOR items housed in the NDA from sensory questionnaires.

Auditory Sensory Over-Responsivity (aSOR)

One item of the ADI-R (No. 72) asks about atypical, hyper-reactive responses to everyday sounds. Although the item is referred to as “undue general sensitivity to noise”, the description and coding is focused on aSOR behaviors rather than decreased thresholds for hearing sounds (i.e., sensitivity). Responses to this item are coded on a 4-point Likert scale from 0-3 (0 representing no evidence of aSOR and 1-3 representing evidence of aSOR ranging from mild to severe; Table 1). In order to receive a code of 1-3 on this item, parents/caregivers must report more than one instance of increased reactivity to “everyday sounds, such as household appliances or traffic, rather than a reaction to sudden, hard, or unexpected noise such as thunder or a loudspeaker”. Additionally, to qualify for a rating of 1-3, this type of increased reactivity must occur for 3 months or more. Information was gathered regarding the individual’s response to sounds currently as well as ever. For the purpose of this study, the current ratings were used to identify point prevalence, whereas the ever ratings were used to estimate lifetime prevalence in subjects 19 years and older.

Logistic Regression Analyses

To identify the prevalence in our sample, *undue sensitivity to noise (current)* was treated as a binary variable (0 = no evidence of hyper-reactivity and 1 = evidence of hyper-reactivity). To investigate point prevalence and severity across age groups, logistic and multinomial logistic regression analyses were conducted using only the *undue sensitivity to noise (current)* item (Long, 1997). To investigate questions of severity between age groups, ordinal response categories: 0 = normal, 1 = mild, 2 = moderate, and 3 = severe were used. The reference category was zero for all logistic regression analyses. All analyses were completed using PROC LOGISTIC in SAS 9.4.

Results

Demographics

Of the 7,001 shared subjects available with ADI-R data, 5,596 had complete data on ADI-R sections A – C which were used to diagnosis ASD and, of those, 73.3% (*n* = 4,104) met the cut-off for an ASD diagnosis (Figure 1). Of the 98 collections, 85 collections contained data on individuals that were diagnosed with ASD and that were in age groups >2. Of these 85 collections, the average completion rate for #72 was 73.89% and the median completion rate was 100%. The ASD sample was relatively young with an average interview age of 9.03, years (*SD* = 5.80). Most of the sample fell within two youngest age categories: early (2 to <6 years; 37.6%) and middle childhood (6 to < 12 years; 38.6%; Table 2).

Point Prevalence of aSOR in ASD

Of the 4,104 subjects with ASD, 76% (*n* = 3,118) had data on the *undue general sensitivity to noise (current)* item. In the ASD sample, 39.8% (*n* = 1,242) received a “normal” caregiver-reported rating (i.e., 0), while 60.2% (*n* = 1,876) were rated as having aSOR (ranging from mild to severe (i.e., ratings of 1-3; Table 3; Figure 2). As expected, higher point prevalence rates were observed in those with ASD compared to those without ASD.

Lifetime Prevalence of aSOR in ASD

Of the 4,104 subjects with ASD, 76% (*n* = 3,125) had data on the *undue general sensitivity to noise (ever)* item. In the ASD sample, 28.9% (*n* = 904) received a “normal” caregiver-reported rating (i.e., 0), while 71.1% (*n* = 2,221) were rated as having aSOR (ranging from mild to severe (i.e., ratings of 1-3; Table 3; Figure 2). As expected, higher lifetime prevalence rates were also observed in those with ASD compared to those without ASD.

Prevalence and Severity of aSOR Between Age Groups

The predictors of interest were age, sex, and the interaction between sex and age group. Three dummy-codes were created to compare the odds of aSOR prevalence and aSOR severity across the four age groups. Only the subjects that were diagnosed with ASD were included in these analyses. After listwise deletion there were 3,118 observations. There were no significant interactions of sex with age groups on the point prevalence or severity of aSOR, therefore these interaction terms were dropped from the model. Effects that were significant at alpha = 0.05 were reported below but odds ratios (OR), 95% confidence intervals, and *p*-values were reported for all predictors for prevalence and severity of aSOR in Table 4.

Predictors of aSOR Prevalence. There was no difference in the prevalence of aSOR across males and females. Subjects in middle childhood had higher odds of caregivers reporting aSOR (OR = 1.676, 95% C.I. [1.426, 1.970]) than those in early childhood. Subjects in early adolescence had higher odds of caregivers reporting aSOR (OR = 1.323, 95% C.I. [1.060, 1.650]) than those in early childhood. Subjects in early adolescence had lower odds of caregivers reporting aSOR than those in middle childhood (OR = 0.789, 95% C.I. [0.626, 0.994]). Adult subjects had higher odds of caregivers reporting aSOR (OR = 1.013, 95% C.I. [0.683, 1.504]) than those in early adolescence (See Table 4 for all age groups, 95% confidence intervals, and *p*-values)

Predictors of aSOR Severity. There was no difference in the severity of aSOR across males and females. Subjects in the middle childhood group had higher odds of caregivers reporting mild aSOR (OR = 1.487, 95% C. I. [1.185, 1.867]), moderate aSOR (OR = 1.815, 95% C.I. [1.515, 2.175]), and severe aSOR (OR = 1.468, 95% C.I. [1.056, 2.041]), compared to subjects in early childhood. Subjects in early adolescence and in adulthood had significantly higher odds of caregivers reporting mild aSOR (OR = 1.955, 95% C.I. [1.476, 2.589]; OR = 1.885, 95% C.I. [1.203, 2.953], respectively) compared to subjects in early childhood. Subjects in early adolescence and in adulthood had lower odds of caregivers reporting moderate aSOR (OR = 0.570, 95% C.I. [0.434, 0.748]; OR = 0.641, 95% C.I. [0.420, 0.980], respectively) compared to subjects in middle childhood (see Table 4 for all age groups, 95% confidence intervals, and *p*-values).

Discussion

In this cross-sectional study, for individuals with ASD whose caregivers answered item 72 of the ADI-R, 60.2% (n = 1,876) of individuals with ASD had some level of aSOR (mild to severe) at the time of assessment (i.e., point prevalence) and 71.1% (n = 2,221) were reported to have had aSOR at some point in life (i.e., lifetime prevalence). For both point prevalence and lifetime prevalence, higher frequencies were observed in moderate cases than mild or severe cases. According to these data, the frequency of caregiver-reported aSOR peaks in middle childhood. These findings narrow the wide range of occurrence rates (15% to 100%) previously reported in the literature (Green et al., 2015; Khalfa et al., 2004; Schoen, 2009; Stefanelli, Ana Cecília Grilli Fernandes et al., 2020; Tomchek & Dunn, 2007).

There were no effects of sex on either prevalence or severity of aSOR in ASD. This finding differs from neurophysiology indicating sex-differences in salience networks associated with SOR (Cummings et al., 2020) and other prominent behavioral features of ASD such as restricted repetitive behaviors that have been shown to differ in quality and quantity for females with ASD (McFayden et al., 2019). Both prevalence and severity of aSOR (*current* item ratings) did vary significantly as a function of age, however. Most notably an increase was observed in both prevalence and severity during middle childhood when compared to early childhood. In fact, greater severity of aSOR was reported at every level (mild, moderate, and severe) in middle childhood. This shift in prevalence at middle childhood is not surprising considering similar shifts noted in anxiety and ADHD symptoms in ASD also observed during this developmental time period (Llanes et al., 2018). Lower aSOR severity in older age groups supports previous cross-sectional findings using the Sensory Profile (Dunn, 1999a) with individuals with ASD ages 3 to 56 years (Kern et al., 2006). Although differences between age groups were observed, these data are not measured on the same individuals over the lifespan. Therefore, additional longitudinal observations are warranted to confirm whether a development process contributes to these differences in aSOR across development. The current study provides a cross-sectional observation of differences in the severity of aSOR across age groups.

Clinical Implications and Future Directions

Further research is needed to identify a critical time period for developing aSOR. Although specific aSOR assessments are lacking, the present study provides preliminary support for using the “undue sensitivity to noise” and “age of onset” items of the ADI-R toddler instrument to screen for aSOR in early childhood. It is evident from our results that aSOR may begin early in development, but that atypical hyper-reactivity behaviors are more apparent at the transition from early childhood to school-age. The data presented in the current study at a minimum, support the importance of early screening and identification of aSOR at the start of school age in Kindergarten (age 6).

At present, there are no standardized, valid clinical measures of aSOR specifically. The findings of the present study reflect that aSOR is a significant problem affecting over half of those with ASD in the NDA whose caregivers answered item 72 of ADI-R. It should be noted that 24% of available subjects were missing data on this item and it is unclear how those subjects' data would have impacted prevalence rates. For example, in the ASD group, if we assume all missing data on item 72 (current) were normal, then the point prevalence of aSOR would be lower (45.7% aSOR; 54.2% normal); whereas, if all missing data had aSOR, then point prevalence would be higher (69.7% aSOR; 30.3% normal). Similarly, if we assume all missing data on item 72 (ever) were normal, then the lifetime prevalence of aSOR would be lower (54.1% aSOR; 45.9% normal); whereas, if we assume all missing data indicated aSOR, then lifetime prevalence would be higher (76.1% aSOR; 23.9% normal). Although these findings cannot be generalized beyond the NDA data available, they do support the need for developing a specific assessment of aSOR. Further research should be conducted to evaluate the presentation of aSOR across development, paying special attention to the transition between early and middle childhood.

Table 1

ADI-R code, description, and study code for undue general sensitivity to noise

ADI-R Code and Description	Study Code
0 = no general sensitivity to noise	Normal
1 = slight sensitivity to noise: somewhat sensitive to loud sounds such as the vacuum cleaner, motorbikes or other appliances	Mild
2 = definite sensitivity to noises that are not distressing to most other people, the sensitivity being accompanied by a clear behavioral change (such as avoidance, hands over ears, or crying)	Moderate
3 = definite sensitivity to noises to the extent that subject’s distress/disturbance in relation to certain noises interferes with family or household routines	Severe
9 = N/K (not known) or not asked	Missing

Table 2
Demographics

	n	%	M (SD)	Min - Max	"Current" responses	"Ever" responses
ASD						
Sex						
Female	754	18.4%			605	606
Male	3350	81.6%			2513	2519
Interview Age	4104		9 (5.8)	2 - 54.3		
Age Groups with interview data						
Early childhood: 2 to <6 years	1544	37.6%	4.1 (1.0)	2 – 5.9	1421	1419
Middle childhood: 6 to <12 years	1584	38.6%	8.8 (1.7)	6 – 11.9	1133	1136
Early adolescent: 12 to <19 years	743	18.1%	14.5 (1.8)	12 – 18.9	426	431
Adult: 19 and up	233	5.7%	25.3 (6.0)	19 – 54.3	138	139
Non-verbal subjects	1069	26%			958	958
Verbal subjects	3035	74%			2160	2167
Non-ASD						
Sex						
Female	413	27.7%			348	339
Male	1033	69.24%			806	782
Interview Age	1492		8.1 (6.4)	2 – 53.5		
Age Groups with interview data	1492					
Early childhood: 2 to <6 years	751	50.3%	3.9 (0.9)	2 – 5.9	680	678
Middle childhood: 6 to <12 years	470	31.5%	8.7 (1.8)	6 – 11.9	352	319
Early adolescent: 12 to <19 years	180	12.1%	14.4 (1.9)	12 – 18.9	106	108
Adult: 19 and up	91	6.1%	26.9 (7.3)	19.2 – 53.5	54	54
Non-verbal subjects	181	12.1%			141	135
Verbal subjects	1174	78.7%			929	902

Note. *n* is the number of subjects with data on the respective demographic variable. Percentages of demographic variables are computed using the total number of subjects in the ASD group (4,104) and the non-ASD group

(1,492), respectively. In the case the percentages do not add up to 100%, the remaining percentage is due to missing data on the demographic variable.

Table 3

Number and percent of subjects that endorsed each severity category of undue general sensitivity to noise – current (point prevalence) and – ever (lifetime prevalence) in both groups (ASD and non-ASD)

	ASD	Non-ASD
Undue General Sensitivity to Noise – Current		
Normal	1242 (39.8)	679 (57.0)
aSOR (at any level)	1876 (60.2)	513 (43.0)
Mild	587 (18.8)	197 (16.5)
Moderate	1090 (35.0)	271 (22.7)
Severe	199 (6.4)	45 (3.8)
Total	3118 (100.0)	1192 (100.0)
Undue General Sensitivity to Noise – Ever		
Normal	904 (28.9)	592 (39.7)
aSOR (at any level)	2221 (71.1)	567 (48.9)
Mild	397 (12.7)	156 (13.5)
Moderate	1374 (44.0)	329 (28.3)
Severe	450 (14.4)	82 (7.1)
Total	3125 (100.0)	1159 (100.0)

Note. There were 986 observations missing for the ASD group on Undue General Sensitivity to Noise – Current, and 889 observations for the ASD group on Undue General Sensitivity to Noise – Ever. There were 300 observations missing for the Non-ASD group on Undue General Sensitivity to Noise – Current, and 333 observations for the ASD group on Undue General Sensitivity to Noise – Ever. The prevalence of any level of aSOR - current was almost twice as prevalent in the ASD group compared to the Non-ASD group in an analysis conditioned on sex and age group (OR = 1.99, 95% C.I. = [1.73, 2.29]. The prevalence of any level of aSOR - ever was over twice as prevalent in the ASD group compared to the Non-ASD group in an analysis conditioned on sex and age group (OR = 2.48, 95% C.I. = [2.15, 2.86].

Table 4
Age Grouping as a Predictors of aSOR Prevalence and Severity

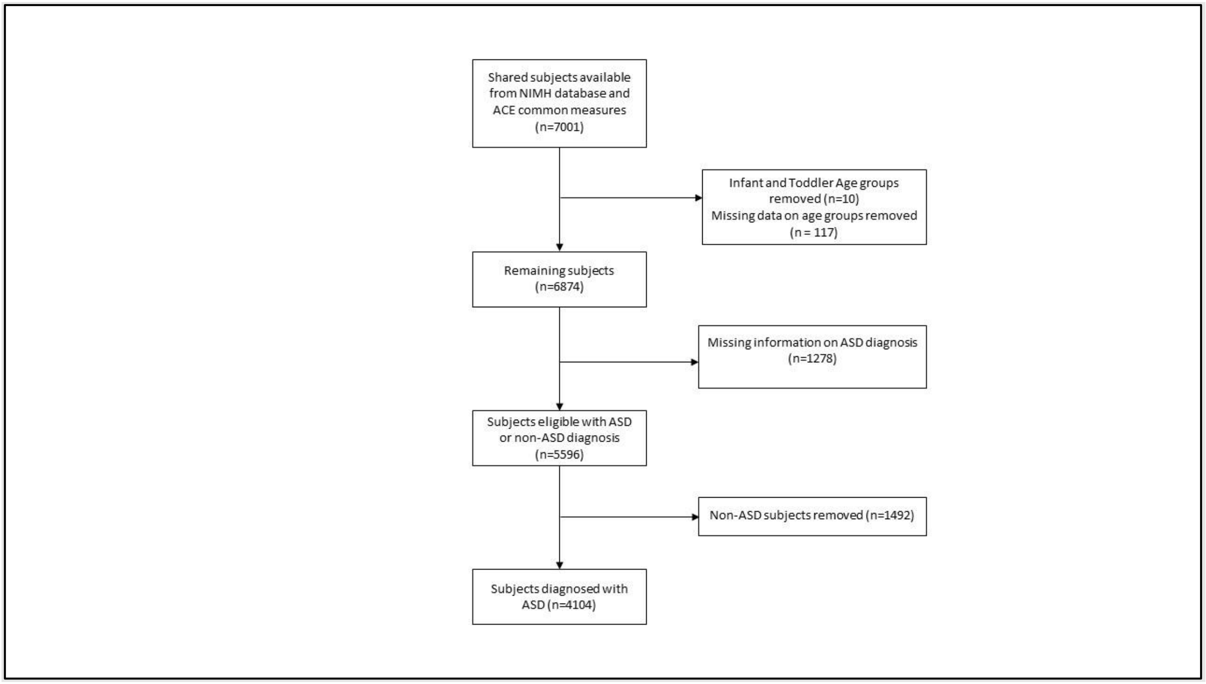
	Odds endorsing aSORVs. Normal	Odds endorsing Mild Vs. Normal	Odds endorsing Moderate vs Normal	Odds endorsing Severe vs Normal
Sex (Male = 0; Female = 1)	OR = 1.016, 95% C.I. = [0.846, 1.219], $p < .8668$	OR = 1.063 95% C.I. = [0.827, 1.367], $p < .6341$	OR = 0.989 95% C.I. = [0.804, 1.216], $p < .9255$	OR = 1.029 95% C.I. = [0.703, 1.506], $p < .8831$
Comparison group = Early childhood				
Middle childhood	OR = 1.676*, 95% C.I. = [1.426, 1.970], $p < .001$	OR = 1.487*, 95% C.I. = [1.185, 1.867], $p = .0006$	OR = 1.815*, 95% C.I. = [1.515, 2.175], $p < .0001$	OR = 1.468*, 95% C.I. = [1.056, 2.041], $p = .0224$
Early adolescent	OR = 1.323*, 95% C.I. = [1.060, 1.650], $p = .0132$	OR = 1.955*, 95% C.I. = [1.476, 2.589], $p < .0001$	OR = 1.034, 95% C.I. = [0.794, 1.348], $p = .8024$	OR = 1.134, 95% C.I. = [0.709, 1.811], $p = .6001$
Adulthood	OR = 1.340, 95% C.I. = [0.936, 1.918], $p = .1093$	OR = 1.885*, 95% C.I. = [1.203, 2.953], $p = .0057$	OR = 1.164, 95% C.I. = [0.765, 1.771], $p = .4782$	OR = 0.814, 95% C.I. = [0.340, 1.947], $p = .6431$
Comparison group = Middle childhood				
Early adolescent	OR = 0.789*, 95% C.I. = [0.626, 0.994], $p = .0444$	OR = 1.314, 95% C.I. = [0.981, 1.761], $p = .0672$	OR = 0.570*, 95% C.I. = [0.434, 0.748], $p < .0001$	OR = 0.772, 95% C.I. = [0.477, 1.249], $p = .2919$
Adulthood	OR = 0.800, 95% C.I. = [0.555, 1.152],	OR = 1.267, 95% C.I. = [0.803, 2.000], $p = .3093$	OR = 0.641*, 95% C.I. = [0.420, 0.980], $p = .0040$	OR = 0.554, 95% C.I. = [0.230, 1.335], $p = .1882$

	p = .2295			
Comparison group = Early adolescent				
Adulthood	OR = 1.013, 95% C.I. = [0.683, 1.504], p = .9476	OR = 0.964, 95% C.I. = [0.593, 1.567], p = .8827	OR = 1.125, 95% C.I. = [0.706, 1.794], p = .6195	OR = 0.718, 95% C.I. = [0.280, 1.838], p = .4893

* Indicates statistically significant effect with $p < .05$

Figure 1

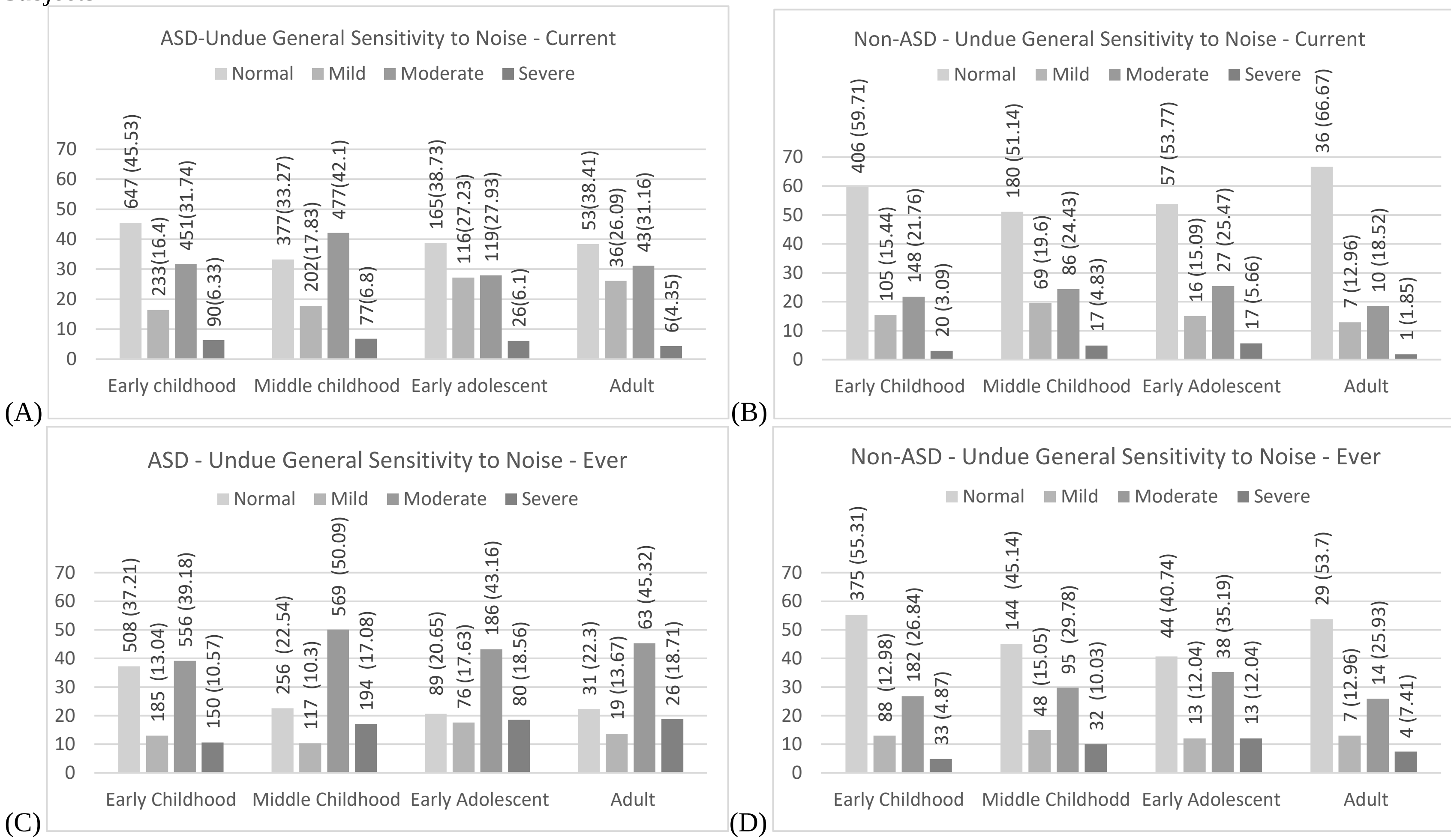
Flowchart of subject inclusion and exclusion from the study sample



Note. This table represents the decisions that were made to establish the ASD (n = 4,104) and non-ASD (n = 1,492) sub-samples.

Figure 2

Undue General Sensitivity to Noise- Current and Ever Frequencey and Percentages Within Each Age Group for ASD and Non-ASD Subjects



(A) Frequency and percentage of undue general sensitivity to noise – current for ASD. (B) Frequency and percentage of undue general sensitivity to noise – current for Non-ASD. (C) Frequency and percentage of undue general sensitivity to noise – ever for ASD. (D) Frequency and percentage of undue general sensitivity to noise – ever for Non-ASD.

Note. Percentages in parentheses represent percentage of the corresponding aSOR category within age group for those with complete data on the undue general sensitivity to noise – current item (ASD; *n* = 3118, Non-ASD; 1192) and undue general sensitivty to noise – ever item (ASD; *n* = 3125, Non-ASD; 1159).

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Data were obtained from the NIMH Data Archive by searching the Data structures for "ADI-R" resulting in diagnostic clinical assessment data from the ACE common measures and the NDA structure sources. The search yielded a dataset comprised of 98 collections and 7,001 unique cases. Collection IDs, study titles and investigator names are displayed in Table 1 along with the number and percent of cases that included ADI-R data in each collection.

Table 1

NIMH Data Archives Collection

Collection ID	Title	Investigator	Frequency	Percent	Cumulative Frequency	Cumulative Percent
1	UIC ACE: Translational Studies of Insistence of Sameness in Autism	Ed Cook	230	3.29	230	3.29
6	Biological and Information Processing Mechanisms Underlying Autism	Nany Minshew, M.D., Mark Strauss, Ph.D., Kevin Pelphrey, Ph.D., Marcel Just, Ph.D., Thomas Mitchell, Ph.D., and Diane Williams, Ph. D.	236	3.37	466	6.66
8	Yale Autism Center of Excellence: Mechanisms of Social Engagement in the Autism Spectrum Disorders	Fred Volkmar	121	1.73	587	8.38
9	Biomarkers of Autism at 12 Months: From Brain Overgrowth to Genes	Eric Courchesne, Karen	73	1.04	660	9.43

Table 1

NIMH Data Archives Collection

Collection ID	Title	Investigator	Frequency	Percent	Cumulative Frequency	Cumulative Percent
		Pierce and others.				
10	UCLA Sigman/Bookheimer ACE and ARRA	Sigman M, Geschwind D, Bookheimer S	267	3.81	927	13.24
14	Early Pharmacotherapy Guided by	Diane C Chugani	158	2.26	1085	15.50
19	Longitudinal MRI Study of Infants at Risk for Autism	Joe Piven	36	0.51	1121	16.01
20	CBT for Anxiety in Adolescents with Autism	Eric A. Storch, Ph.D.	21	0.30	1142	16.31
1201	Induced pluripotent cells in ASD with macrocephaly	Flora Vaccarino	4	0.06	1146	16.37
1300	Behavioral Treatment for Autism in Community Settings Using a Telehealth Network	Scott Lindgren	39	0.56	1185	16.93
1356	Identifying Brain-Based Biomarkers for ASD and their Biological Subtypes	Bradley S. Peterson	59	0.84	1244	17.77
1358	Biological Signatures of Autism	David G. Amaral	84	1.20	1328	18.97
1501	Neural and Behavioral Outcomes of Social Skills Groups in Children with ASD	A. Ting Wang, Latha V. Soorya	35	0.50	1363	19.47

Table 1

NIMH Data Archives Collection

Collection ID	Title	Investigator	Frequency	Percent	Cumulative Frequency	Cumulative Percent
1551	Neural Dissection of Hyperactivity/Inattention in Autism	Francisco Xavier Castellanos	89	1.27	1452	20.74
1601	Imaging Brain and Movement in ASD	Jeanne Townsend	15	0.21	1467	20.95
1654	UW ACE Extended Family Study	Bryan King	36	0.51	1503	21.47
1850	CBT for anxiety in adolescents with autism	Jeffrey Wood	25	0.36	1528	21.83
1854	Studies to Advance Autism Research and Treatment (STAART).	Aylward, Elizabeth; Buxbaum, Joseph; Dawson, Geraldine; Hollander, Eric; Landa, Rebecca; Rodier, Patricia; Sigman, Marian; Tager-Flusberg, Helen	24	0.34	1552	22.17
1866	1/2 Development of a Screening Interview for Research Studies of ASD	Christoper Monk, Somer Bishop and Cathy Lord	1	0.01	1553	22.18
1868	The Effects of Oxytocin on Complex Social Cognition in Autism Spectrum Disorders	Jennifer Bartz, PhD	20	0.29	1573	22.47

Table 1

NIMH Data Archives Collection

Collection ID	Title	Investigator	Frequency	Percent	Cumulative Frequency	Cumulative Percent
1886	PDN Screening Data	Audrey Thurm	79	1.13	1652	23.60
1888	Emergence and Stability of Autism in Fragile X Syndrome	Jane Roberts	7	0.10	1659	23.70
1889	ASD Mathematical Cognition: A Cognitive and Systems Neuroscience Approach	Vinod Menon, Stanford University	40	0.57	1699	24.27
1904	Functional Neuroimaging of Attention in Autism	Benjamin Yerys	50	0.71	1749	24.98
1920	Visual attention and fine motor coordination in infants at risk for autism	Anjana Narayan Bhat	8	0.11	1757	25.10
1932	Behavioral and Genetic Biomarker Development for Autism and Related Disorders	Linda Brzustowicz, M.D.	38	0.54	1795	25.64
1939	Cultural Equivalence of Autism Assessment for Latino Children	Sandra Magana	50	0.71	1845	26.35
1943	Decoding what and who in the auditory system of children with autism spectrum	Vinod Menon	10	0.14	1855	26.50
1955	Characterizing mechanistic heterogeneity across ADHD and Autism	Fair, Damien A	137	1.96	1992	28.45

Table 1

NIMH Data Archives Collection

Collection ID	Title	Investigator	Frequency	Percent	Cumulative Frequency	Cumulative Percent
1958	A Family-Genetic Study of Autism and Fragile X Syndrome	Molly C. Losh	33	0.47	2025	28.92
1965	Longitudinal Studies of Autism Spectrum Disorders: From 2 to 23	Cathy Lord, Ph. D	59	0.84	2084	29.77
1986	Testing the hyperspecificity hypothesis: a neural theory of autism	Robert Schultz	29	0.41	2113	30.18
2001	Influence of Attention and Arousal on Sensory Abnormalities in ASD	Jeanne Townsend	12	0.17	2125	30.35
2003	Autism: Social and Communication Predictors in Siblings (Landa) AND Effects of Active Motor and Social Training on Developmental Trajectories in Infants at High-risk for Autism Spectrum Disorders (Libertus)	Rebecca Landa, Klaus Libertus	1	0.01	2126	30.37
2007	Treatment of Autism Symptoms in Children (TASC): Initial RCT with Active Control	Jeffrey Wood	134	1.91	2260	32.28
2009	Study of Oxytocin in Autism to Improve Reciprocal Social Behaviors (SOARS-B)	Linmarie Sikich	105	1.50	2365	33.78
2017	Wireless EEG System for Training Attention	Jeanne Townsend	5	0.07	2370	33.85

Table 1

NIMH Data Archives Collection

Collection ID	Title	Investigator	Frequency	Percent	Cumulative Frequency	Cumulative Percent
	and Eye Movement in ASD					
2020	Adaptive Interventions for Minimally Verbal Children with ASD in the Community	Connie Kasari	111	1.59	2481	35.44
2021	Multimodal Developmental Neurogenetics of Females with ASD	Kevin Pelphrey	184	2.63	2665	38.07
2022	The Social Brain in Schizophrenia and Autism Spectrum Disorders	Michal Assaf	17	0.24	2682	38.31
2025	Minimally Verbal ASD: From Basic Mechanisms to Innovative Interventions	Helen Tager-Flusberg	121	1.73	2803	40.04
2026	Biomarkers of Developmental Trajectories and Treatment in ASD	Susan Bookheimer	87	1.24	2890	41.28
2027	A Longitudinal MRI Study of Infants at Risk for Autism (ACE 2)	Joseph Piven	348	4.97	3238	46.25
2029	Autism genetics: homozygosity mapping and functional validation (Years 1-5)	Christopher A. Walsh	38	0.54	3276	46.79
2030	Electrophysiological Response to Executive Control Training in Autism	Susan Faja	83	1.19	3359	47.98

Table 1

NIMH Data Archives Collection

Collection ID	Title	Investigator	Frequency	Percent	Cumulative Frequency	Cumulative Percent
2038	Gender and Cognitive Profile as Predictors of Functional Outcomes in School-Aged Children	Jennifer Moriuchi	17	0.24	3376	48.22
2039	Autism Brain Imaging Data Exchange	Michael Milham, MD, Ph.D.	379	5.41	3755	53.64
2055	Silvio O. Conte Center for Oxytocin and Social Cognition	Larry Young	20	0.29	3775	53.92
2060	Dysfunction of Sensory Inhibition in Autism	Richard Edden	24	0.34	3799	54.26
2063	Epidemiological Research on Autism in Jamaica - Phase II	Mohammad Rahbar	252	3.60	4051	57.86
2066	The CHARGE Study: Childhood Autism Risks From Genetics and the Environment	Irva Hertz-Picciotto	302	4.31	4353	62.18
2072	Intrinsic Brain Architecture of Young Children with Autism While Awake and Asleep	Adriana DiMartino	49	0.70	4402	62.88
2075	Mapping Thalamocortical Networks Across Development in ASD	Carissa Cascio	16	0.23	4418	63.11
2095	The neurophysiology of sensory processing and multisensory integration in ASD	Natalie Russo	38	0.54	4456	63.65

Table 1

NIMH Data Archives Collection

Collection ID	Title	Investigator	Frequency	Percent	Cumulative Frequency	Cumulative Percent
2108	Neural Phenotypes of Females with Autism Spectrum Disorder	Christine Wu Nordahl	60	0.86	4516	64.51
2129	Biological Determinants of Brain Variation in Autism	Janet Lainhart	20	0.29	4536	64.79
2149	Methylphenidate for Hyperactivity and Impulsiveness in Children and Adolescents With Pervasive Developmental Disorders (RUPP MPH PDD)	Larry Scahill	114	1.63	4650	66.42
2169	Human Clinical Trial of IGF-1 in Children with Idiopathic ASD	Alexander Kolevzon	2	0.03	4652	66.45
2179	Neural markers of shared gaze during simulated social interactions in ASD \- Modal Automated Assessment of Behavior during Social Interactions in Children with ASD	James McPartland and Adam Naples	103	1.47	4755	67.92
2181	Sex Differences in the Neural Mechanisms of Treatment Response	Pamela Ventola	11	0.16	4766	68.08
2197	The role of vasopressin in the social deficits of autism	Karen J. Parker and Antonio Hardan	37	0.53	4803	68.60

Table 1

NIMH Data Archives Collection

Collection ID	Title	Investigator	Frequency	Percent	Cumulative Frequency	Cumulative Percent
2198	Pivotal Response Treatment Package for Young Children with Autism	Antonio Hardan	12	0.17	4815	68.78
2254	The neurobiological basis of heterogeneous social and motor deficits in ASD	Lisa Aziz-Zadeh	14	0.20	4829	68.98
2255	Serotonin Receptor Subtypes as Pharmacotherapeutic Targets in Autism	Gene Blatt	12	0.17	4841	69.15
2262	Comparing Behavioral Assessments Using Telehealth for Children with Autism	Scott David Lindgren	109	1.56	4950	70.70
2266	Inhibitory dysfunction in autism	Scott Murray	21	0.30	4971	71.00
2282	Cognitive Enhancement Therapy for Adulthood Autism Spectrum Disorder	Shaun Eack	15	0.21	4986	71.22
2285	Integrity and Dynamic Processing Efficiency of Networks in ASD	Ralph-Axel Mueller	34	0.49	5020	71.70
2288	The Autism Biomarkers Consortium for Clinical Trials	James McPartland	287	4.10	5307	75.80
2292	Molecular Mechanisms of Atypical Habituation in Autism Spectrum Disorders	Natalia Kleinhans	133	1.90	5440	77.70

Table 1

NIMH Data Archives Collection

Collection ID	Title	Investigator	Frequency	Percent	Cumulative Frequency	Cumulative Percent
2293	Components of Emotional Processing in Toddlers with ASD	Katarzyna Chawarska	128	1.83	5568	79.53
2316	Quantitative Measurements of Cortical Excitability in Neurodevelopmental Disorder	Antonio Hardan	28	0.40	5596	79.93
2349	RUPP PI PDD: Drug and Behavioral Therapy for Children With Pervasive Developmental Disorders	Michael Aman	123	1.76	5719	81.69
2358	Neural networks for attention to internal and external sensory cues in ASD	Carissa Cascio	5	0.07	5724	81.76
2368	Clinical and Immunological Investigations of Subtypes of Autism	Susan Swedo	159	2.27	5883	84.03
2382	Phenotype and Genetic Factors in Autism Spectrum Disorders: Autism Consortium	Jordan Smoller	232	3.31	6115	87.34
2424	Neurobiology of Autism With Macrocephaly	Flora Vaccarino	3	0.04	6118	87.39
2440	Development of Behavioral and Neural Biomarkers for Autism Spectrum Disorder Using a Genetically Defined Subtype	Joseph Buxbaum	48	0.69	6166	88.07

Table 1

NIMH Data Archives Collection

Collection ID	Title	Investigator	Frequency	Percent	Cumulative Frequency	Cumulative Percent
2442	Emergence and Stability of Autism in Fragile X Syndrome	Jane Roberts	150	2.14	6316	90.22
2460	Emergence, Stability and Predictors of Anxiety in Fragile X Syndrome	Jane Roberts	45	0.64	6361	90.86
2557	Environmental Influence on Infant Microbiome Development and ASD Symptoms	Irva Hertz-Picciotto	54	0.77	6415	91.63
2559	Neural Mechanisms of CBT for Anxiety in Children with Autism Spectrum Disorder	Denis Sukhodolsky	53	0.76	6468	92.39
2561	Somatosensory Inhibitory Dysfunction in Autism Spectrum Disorder	Richard Edden	8	0.11	6476	92.50
2566	Direct Examination of Imitation-Based Learning in Autism	Joshua Ewen	5	0.07	6481	92.57
2605	Integrative Molecular and Phenotype Analysis of 22q11.2 Deletion Syndrome	Joachim F. Hallmayer	37	0.53	6542	93.10
2711	Motor abnormalities and functional brain mechanisms in autism spectrum disorder	Matthew Mosconi	24	0.34	6542	93.44
2761	Charting the trajectory of executive control in autism in order to	Susan Faja	32	0.46	6574	93.90

Table 1

NIMH Data Archives Collection

Collection ID	Title	Investigator	Frequency	Percent	Cumulative Frequency	Cumulative Percent
	optimize delivery of intervention					
2777	Center for the Development of Phenotype-Based Treatments of Autism Spectrum Disorder	David Amaral	26	0.37	6600	94.27
2778	Heterogeneity in Autism Spectrum Disorders: Biological Mechanisms, Trajectories, and Treatment Response	Susan Bookheimer	3	0.04	6603	94.32
2799	A Novel Framework for Impaired Imitation in ASD	Joshua Ewen	2	0.03	6605	94.34
2821	Cellular, molecular, and functional imaging approaches to understanding early neurodevelopment in autism	Katarzyna Chawarska	38	0.54	6643	94.89
2828	Sensory consequences of action in children with autism spectrum disorders	Jennifer Foss-Feig	30	0.43	6673	95.31
2845	Attentional, temperamental, and physiological process underlying anxiety in preschoolers with ASD	Katarzyna Chawarska	77	1.10	6750	96.41
2976	Autism Genetics Phase II: Increasing representation of human diversity	Daniel Geschwind	28	0.40	6778	96.81

Table 1

NIMH Data Archives Collection

Collection ID	Title	Investigator	Frequency	Percent	Cumulative Frequency	Cumulative Percent
3022	Electrophysiological Markers for Interventions in Phelan-McDermid Syndrome and Idiopathic Autism	Alexander Kolevzon	32	0.46	6810	97.27
3023	Neuroimaging Predictors of Pivotal Response Treatment in Young Children with Autism	Antonio Hardan	3	0.04	6813	97.31
3058	Behavioral Inflexibility in IDD Outcome Measurement	Brian Boyd	166	2.37	6979	99.69
3088	Brainstem Contributions to Sensorimotor and Core Symptoms in Children with Autism Spectrum Disorder	Brittany Travers	22	0.31	7001	100.00

Table 2

Summary of Auditory Sensory Over-Responsivity Questions from Sensory Processing Assessment Tools housed in the United States National Institute of Mental Health (NIMH) Data Archives

Data Structure	Data Element	Number of Subjects	Rating Scale	Reference
Child Sensory Questionnaire	My child is sensitive or bothered by sounds that don't seem to bother other people.	84	0 = False 1 = True	(Black et al., 2020)
Sensory Experiences Questionnaire	Does your child startle easily to sounds? Does your child notice sounds in the environment before other people? Have you ever wondered if your child experiences sounds differently from others?	966	1 = Almost never 2 = Once in a while 3 = Sometimes 4 = Frequently 5 = Almost always -9 = Missing value	(Baranek et al., 2006)
Glasgow Sensory Questionnaire	Do you find certain noises/pitches of sound annoying? Do you react very strongly when you hear an unexpected sound? Do you dislike loud noises?	142	0 = Never 1 = Rarely 2 = Sometimes 3 = Often 4 = Always 999=missing/NA/NK	(Robertson & Simmons, 2013)
Sensory Profile - Adult/Adolescent	I use strategies to drown out sound (for example, close the door cover my ears wear ear plugs). I stay away from noisy settings. I startle easily at unexpected or loud noises (for example vacuum cleaner dog barking telephone ringing).	1,322	1 = Almost never 2 = Seldom 3 = Occasionally 4 = Frequently 5 = Almost always	(Brown & Dunn, 2002)
Sensory Profile - Infant	My child startles easily at sound compared to other children the same age.	0	1 = Almost always 2 = Frequently 3 = Occasionally 4 = Seldom 5 = Almost never	(Dunn, 2002)

Sensory Profile - Toddler	My child startles easily at sound compared to other children the same age. My child tries to escape from noisy environments.	178	1 = Almost always 2 = Frequently 3 = Occasionally 4 = Seldom 5 = Almost never	(Dunn, 2002)
Sensory Profile - Caregiver	Responds negatively to unexpected or loud noises (for example cries or hides at noise from vacuum cleaner dog barking hair dryer) Holds hands over ears to protect ears from sound	698	1 = Always 2 = Frequently 3 = Occasionally 4 = Seldom 5 = Never	(Dunn, 1999)
Sensory Profile - Short	Responds negatively to unexpected or loud noises (for example cries or hides at noise from vacuum cleaner dog barking hair dryer) Holds hands over ears to protect ears from sound	660	1 = Always 2 = Frequently 3 = Occasionally 4 = Seldom 5 = Never	(Dunn, 1999)
Sensory Profile - Short 2	Reacts strongly to unexpected or loud noises Holds hands over ears to protect them from sound	478	0=Does not apply 1=Almost never 2=Occasionally 3=Half the time 4=Frequently 5=Almost always	(Dunn, 2014)
Sensory Over-Responsivity Scales (SensOR Scales)	Do these SOUNDS bother you: clothing that makes noise (swishing cloth, accessories), toilet flushing, doorbell ringing, dog barking, sirens, alarms, appliances e.g. blender, vacuum, hairdryer, electric shaver, sound of utensils against each other (spoon in bowl, knife on plate).[1] Are SOUNDS IN THESE PLACES too loud for you: concerts, large gatherings, crowded supermarket, restaurants, malls, cafeterias, gymnasium.[1] Are there any other ways that you are sensitive to sound?	465	0 = No 1 = Yes 9998 = subject skipped 9999 = NA/missing	(Schoen et al., 2008)

	Do these BACKGROUND NOISES bother you: radio, florescent lights, people talking, clock ticking, lawn mower, construction or landscaping equipment, water running or dripping.[1]	

Note. This table summarizes all aSOR items available in sensory questionnaires within the US NIMH Data Archives. To develop this table the word "sensory" was searched in the data structures. A key word search was conducted within each assessment for elements containing the words "noise", "sound", "ear", "hear", and "sensitive". This search was completed on February 14, 2021.

[1]The SensOR Scales include one question per auditory stimulus listed (i.e., Do these SOUNDS bother you: toilet flushing?; Do these SOUNDS bother you: doorbell ringing? Etc. They were collapsed into one item here for simplification).

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