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Development of Sensory Sensitivity Scales (SeSS): Reliability and validity analyses

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ABSTRACT

Background: Although adults are known to have sensory sensitivity differences, existing sensitivity scales have been mostly developed for children. The limited number of adult scales measure social/emotional features and modalities together.
Aims: To develop scales for adults that evaluate visual, auditory and somatosensory sensitivities as separate domains and independent of social/emotional features.
Methods and procedures: Two consecutive studies (visual-auditory part and somatosensory part) were conducted using the same methods. Both studies included a pilot (n_1 = 405 and n_2 = 294) and a main group (n_1 = 425 and n_2 = 603). An exploratory factor analysis produced a single-factor solution for the visual and auditory domains and a three-factor solution for the somatosensory domain (touch, pain, and itch) of Sensory Sensitivity Scales.
Outcomes and results: A confirmatory factor analysis revealed good construct validity in the the visual (CFI = .973, TLI = .965, and RMSEA = .075) auditory (CFI = .943, TLI = .927, and RMSEA = .074) and somatosensory (CFI = .955, TLI = .946, and RMSEA = .048) scales. The categories were internally consistent (α_v = .86, α_a = .79, α_s = .69). As an indicator of convergent validity, higher autistic traits were related to higher sensitivity ($r_{s\text{-}v}$ = .17, $r_{s\text{-}a}$ = .25, $r_{s\text{-}s}$ = .14).
Conclusions and implications: Sensory Sensitivity Scales (SeSS) can be used to screen sensory sensitivity variability or identify and follow up the outcome of sensory interventions in adults.

What this paper adds?

Sensory sensitivity differences are common in neurodevelopmental disorders and show great variations in healthy populations. In the current literature, there are not a sufficient number of tests that measure sensory sensitivity in adults independent of social and emotional features. However, to explore the neurobiological basis of sensory sensitivity, it is important to assess this construct as separate domains and independent of confounders. In addition, the investigation of sensory sensitivity differences in healthy populations provides useful insights into its mechanisms that are not confounded by the presence of comorbid conditions of a disease. Sensory Sensitivity Scales (SeSS) measure sensory sensitivity in visual, auditory and somatosensory domains without interference from social and emotional features in a typically developed adult population. The developed scales can be used to detect sensory

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sensitivity differences or identify and follow up the outcome of sensory interventions in adults.

1. Introduction

Senses are the means by which organisms experience the world. A sense can be described as a physiological capacity of organisms that provide data related to perception. The perception and interpretation of sensory environment by sensory systems shapes an individual's behavior and engagement in everyday life. Sensory processing encompasses registration, transmission and organization of sensory information, as well as the execution of appropriate responses to it (Brown, Tollefson, Dunn, Cromwell, & Filion, 2001).

The Ayres Sensory Integration (ASI) model explains how the processing and integration of sensory information from the body and the environment contribute to emotional regulation, learning, behavior, and participation in daily life (Roley, Mailloux, Miller-Kuhaneck, & Glennon, 2007). According to the ASI model, sensory integration consists of the steps of perception, modulation and integration of sensory information (Ayres, 1972). Perception refers to noticing sensory experiences, sensory modulation encompasses both a neurophysiological process (e.g., sensory over-responsivity or under-responsivity) and behavior (e.g., sensory seeking or avoiding tendencies; Brown, Tse, & Fortune, 2019), and Sensory integration allows the integration of sensory-motor processes for the generation of responses to both physical and social aspects of an environment (Lane et al., 2019).

One of the aspects of sensory modulation is sensory sensitivity, which has been shown to vary between individuals (Dixon et al., 2016; Horder, Wilson, Mendez, & Murphy, 2014; Robertson & Simmons, 2013; Tavassoli, Hoekstra, & Baron-cohen, 2014). In a recent study conducted with 906 participants without clinical diagnosis, it was reported that sensory sensitivity ranged from hyposensitivity to hypersensitivity for environmental stimuli (Lionetti et al., 2018). Hypersensitivity refers to an exaggerated behavioral response to stimuli (e.g., dislike of bright lights and covering ears in noisy environments), while hyposensitivity refers to the insufficiency or absence of a response to any kind of stimuli (e.g., being attracted by colorful objects or not responding to novel sounds) (Baranek, 2002; Baranek, David, Poe, Stone, & Watson, 2006). These differences can be related to neurophysiological process or behavior or both (Brown et al., 2019).

Since senses are the means through which organisms experience the world, if the capacity to receive or reliably process and organize sensory information is disrupted, the ability to interact with the world will also be impaired (Brown & Dunn, 2002). In support of this view, sensory processing abnormalities are found in many neurodevelopmental disorders, such as autism spectrum disorders (ASD), attention deficit hyperactivity disorders (ADHD), Williams syndrome, schizophrenia, and sensory processing disorder (Ghanizadeh, 2011; Glod, Riby, & Rodgers, 2019; Hornix, Havekes, & Kas, 2018; Reynolds & Lane, 2008; Robertson & Baron-Cohen, 2017). Although sensory sensitivity is mostly considered as a negative threat, it should be kept in mind that there are views where sensory sensitivity differences are considered as an ability (Bogdashina, 2014).

Among the neurodevelopmental disorders, ASD is characterized with the clear presence of unusual sensory responses, with the mostly altered modalities being visual, auditory and tactile senses (Fernández-Andrés, Pastor-Cerezuela, Sanz-Cervera, & Tárraga-Mínguez, 2015; Tavassoli et al., 2014, 2016). The reported prevalence of sensory sensitivity for this disorder ranges from 69 % to 96 % (Baranek et al., 2006; Geschwind, 2009; Klintwall et al., 2011; Marco, Hinkley, Hill, & Nagarajan, 2011). Similar to ASD, sub-threshold social interaction and communication deficits are present in individuals without clinical diagnosis (Baron-Cohen, 1995; Lundström et al., 2012; Ruzich et al., 2015), and they are called autistic traits (Constantino & Todd, 2003). ASD and autistic traits can be considered as a continuum, and it is consistently reported that autistic traits and sensory sensitivity differences coexist in the general population (Horder et al., 2014; Mayer, 2017; Robertson & Simmons, 2013).

Although sensory sensitivity differences are present in the non-clinical population, most available scales have been designed for clinical use since the differences in sensory sensitivity have high comorbidity with neurodevelopmental disorders. However, such scales are not purely sensory, and they also include items related to social and emotional features (Aron & Aron, 1997; Brown et al., 2001; Tavassoli et al., 2014). As mentioned in the ASI theory, sensory modulation has neurophysiological and behavioral components; therefore, it is important to evaluate sensitivity independent of the social and emotional load to understand the neurophysiological component. Another important point is that although it is very important to assess modalities separately both in neuroscience research and in planning treatment or therapies for the affected individuals, most of the existing scales evaluate sensory modalities together (Aron & Aron, 1997; Brown et al., 2001; Tavassoli et al., 2014).

To our knowledge, the literature contains only two scales that measure sensory modalities separately and independent of the social and emotional load. The first is the Sensory Hypersensitivity Scale (SHS) developed by Dixon et al. (2016), but this scale has the limitation of having only two or three items per domain, which does not allow a sufficient number of features to be measured. The second scale is the sensory perception quotient (SPQ) (Tavassoli et al., 2014), which was designed for individuals with ASD, and thus contains items that are specific to this group, limiting its area of use. In addition, most items included in SPQ aim to determine perception thresholds.

The last shortcoming in the sensory sensitivity scale literature is that although sensory abnormalities have been shown to be present in adulthood (Brown et al., 2001; Dixon et al., 2016; Tavassoli et al., 2014), the vast majority of the scales have been designed for children (for an excellent review, see Jorquera-Cabrera, Romero-Ayuso, Rodriguez-Gil, & Triviño-Juárez, 2017). For example, the Sensory Processing Measure (SPM) assesses sensory modalities separately without social emotional loads, but was developed for children (Parham, Ecker, Miller Kuhaneck, Henry, & Glennon, 2007) therefore not suitable for use in adults.

Considering the problems detailed above, in this study, we intended to develop scales to measure i. sensory sensitivity differences in adults; ii. visual, auditory and somatosensory sensitivities as separate domains; and iii. sensory sensitivity independent of social and emotional features. In order to achieve reliable and valid measurements using these scales, we decided to assess the following indicators: i. internal consistency; ii. CFI, TLI and RMSEA as indices of exploratory and confirmatory factor analyses; iii. criterion validity referring to the consistency between the factorial dissociation of submodalities and physiological fundamentals, as well as the consistency of the obtained gender differences with the literature; iv. discriminant validity examined by the relationship of the visual and auditory domains with age and education level and the relationship of the somatosensory domain with handedness; and v. convergent validity determined by the correlation of the sensory sensitivity scores with a known phenotype (autistic traits).

2. Methods

2.1. Study design

For the development of the scales, two consecutive studies were carried out with different populations using the same methods. The first study was planned as part of electroencephalography (EEG) research, in which auditory and visual stimuli were used. To measure the sensitivity-related differences between the subjects, we aimed to develop a sensory sensitivity scale. Considering that somatosensation is an important part of sensory sensitivity, we decided to address this domain in a separate study.

In both studies, a pilot application was initially undertaken with candidate items, and the exploratory factor analysis (EFA) was performed. The items were modified according to the preliminary results and expert opinions. The revised scales were then applied to different participants constituting the main study group. The scales received their final form after necessary modification according to the results of the confirmatory factor analysis (CFA). The autism spectrum quotient (AQ; (Baron-Cohen, Wheelwright, Skinner, Martin, & Clubley, 2001) was utilized as a convergent validity measure for both sensitivity scales. To determine discriminant validity, the handedness questionnaire (Chapman & Chapman, 1987) was used for the somatosensory sensitivity scale, age and education level for the visual and auditory sensitivity scales. Criterion validity was evaluated based on the consistency of the factorial structure of submodalities with physiological fundamentals and the consistency of the results on gender differences in modalities with the literature.

2.2. Participants

In pilot and main studies, a total of 896 people for the visual/auditory sensitivity scales (404 female, 492 male; mean age = 21.27 ± 2.90 years), and 930 people for somatosensory scale (523 female, 407 male; mean age = 23.68 ± 5.14 years) took part. Individuals who reported a history of epilepsy, migraine or any other neurological/psychiatric disorder were excluded from both studies. Additionally, people with visual impairments other than refractive errors or with auditory impairments were excluded from the first part, and those with contact dermatitis were excluded from the second part. The research was approved by the local ethical committee. All participants signed informed consent prior to the study.

2.3. Measurement tools

Demographic Form: All participants completed a form containing questions concerning age, sex and education. This form also questioned exclusion criteria.

The Autism-Spectrum Quotient (AQ): The Turkish version of AQ was used to assess autistic features. AQ is a self- report questionnaire originally developed by Baron-Cohen and colleagues (Baron-Cohen et al., 2001) and adapted to Turkish by Köse and colleagues (Kose, Bora, Erermıs, & Aydın, 2010). The score range of the questionnaire is between 0 and 50, with higher values indicating stronger autistic traits.

The Handedness Questionnaire: A 13-item questionnaire adapted to Turkish from the original version developed by Chapman and Chapman (1987) was used. The questionnaire requires the participants to indicate which hand they prefer for actions performed with a single hand, such as writing, drawing, and throwing (Nalçaci, Kalaycioğlu, Güneş, & Ciçek, 2002). A higher score represents a greater level of left-handedness. As the handedness questionnaire is completely related to motor function, it was used as a discriminative validity measure for somatosensory sensitivity.

2.4. Scale development

2.4.1. Visual/Auditory sensitivity scales

For the construction of the scale items, a group of 20 people (academicians from physiology and neuroscience departments and students from the medical faculty) were asked about visual and auditory stimuli with which they were uncomfortable. Depending on the collected responses, 16 visual and 20 auditory items were generated to measure only the sensory aspect of stimuli, with social and emotional aspects being excluded. The items were rated on a five-point Likert scale as *never, rarely, occasionally, usually,* and *always*. In the pilot study, the preliminary scale was applied to 467 participants. Fifty-two subjects were excluded based on the criteria, and the factor analysis was performed on the data of 405 participants (233 female and 172 male, mean age = 20.34 ± 2.09 years).

Bartlett's Sphericity Test and Keiser-Meyer-Olkin (KMO) were calculated as measures of the suitability of data for structure detection. For data to be considered suitable, the Bartlett's test should be significant and the KMO value should be over .80 (Bartlett, 1954; Kaiser & Rice, 1974). The data were suitable for factoring as the Bartlett's test was significant ($p < .001$) and the KMO value was .90 for visual and .85 for auditory domain, showing excellent values for factorial analyses. EFA was conducted for the categorical data using a robust weighted least squares approach. This analysis produced a single-factor solution for each domain with a root mean square error of approximation (RMSEA) of .08, comparative fit index (CFI) of .877, and Tucker-Lewis index (TLI) of .858 for the visual modality and RMSEA = .074, CFI = .866, and TLI = .850 for the auditory modality. Although the RMSEA values were slightly high and CFI and TLI were slightly low, it was concluded that the remaining set of items from EFA for both visual and auditory sets represented good starting points to create a unidimensional item set for each construct for further analysis.

According to the results of the factor analysis, four visual and eight auditory items with a factor loading below the cut-off point of .40 were removed from the scale. The factor loadings ranged from .42 to .73 for the visual modality and .41 to .62 for the auditory modality. The remaining 24 items were presented to seven experts (one ophthalmologist, one otorhinolaryngologist, two physiologists, two neurologists, and one psychiatrist). After the items were modified according to the expert opinions, the scale was finalized for the main study with 24 items (12 items belonging to each modality).

Data were then collected from 429 participants by taking the exclusion criteria into consideration, and 270 of these participants also completed AQ. CFA was performed on the data of 425 participants for the visual modality (212 female, 213 male; mean age = 22.18 ± 3.34 years) and 429 participants for the auditory modality (214 female, 215 male; mean age = 22.20 ± 3.36 years).

2.4.2. Somatosensory sensitivity scale

The somatosensory sensitivity scale was developed following the same procedure in the visual/auditory part. The researchers asked 20 individuals (special education teachers, academicians from physiology and neuroscience departments, and students from the medical faculty) about somatosensory stimuli with which they were uncomfortable. Based on their responses, 34 items focusing solely on the sensory aspect of stimuli were generated. Proprioception and visceral senses were not included in the scale. The items were rated on a five-point Likert scale as *never, rarely, occasionally, usually,* and *always*. The pilot data were collected online from 470 participants. After applying the exclusion criteria, the data from 294 participants (204 female and 90 male, mean age = 25.26 ± 5.53 years) were evaluated.

Bartlett's test was statistically significant ($p < .001$) and the KMO was .83, showing meritorious value for factorial analyses. For the categorical data, EFA was conducted with a robust weighted least squares approach. This analysis produced a three-factor solution with an RMSEA of .035, CFI of .941, and TLI of .923. Although TLI values is below .95, it is considered acceptable when TLI ≥ 0.90 (An et al., 2017). The model for somatosensory scale can be considered as acceptable. The items in the first factor were related to ‘touch’, those in the second factor ‘pain’, and the third factor ‘itch’. Fourteen items with factor loadings below .40 were removed from the scale. The factor loadings ranged from .41 to .87 for touch, .42 to .60 for pain and .60 to .87 for itch factors.

The remaining 20 items were presented to eight experts (three neurophysiologists, one dermatologist, two psychiatrists, and two physical therapists). In accordance with their feedback, one item was eliminated and some items were modified. The final version of the scale to be administered to the second group of participants in the main study consisted of 19 items (13 items for touch-pressure, four items for pain, two items for itch).

For the main study, the data were collected from 603 participants (318 female and 313 male, mean age = 20.7 ± 2.05 years) by taking the exclusion criteria into consideration. All participants completed the demographic form, AQ, the handedness questionnaire, and the somatosensory scale.

2.5. Statistical analysis of the main studies

The continuous data were summarized as mean ± standard deviation and median (minimum-maximum) values, and the categorical data were expressed as frequencies and percentages. The normality of the data distribution was tested by the Shapiro-Wilk method. The psychometric properties of the visual and auditory sensitivity scales and the somatosensory sensitivity scale were evaluated through both reliability and validity analyses. The reliability of the scales was tested by Cronbach’s alpha coefficient in terms of internal consistency (Cronbach, 1951), in which the minimum acceptable level is .70 (Streiner & Norman, 1995).

CFA was used to examine the validity of the scales. In order to evaluate whether the data fit the proposed unidimensional model for each of the visual and auditory sensitivity scales in the first part and the somatosensory sensitivity scale along with its subscales in the second part, first-order and second-order CFAs were applied to the categorical data using a weighted least (WLSM) χ^2 estimation with robust standard errors and mean- and variance-adjusted statistics. The items with factor loadings below .40 were eliminated. In order to assess the degree of fit between the model and the sample, the following goodness-of-fit indices were used: CFI > .90: acceptable, > .95: excellent; TLI > .90: acceptable, > .95: excellent; and RMSEA < .08: acceptable, < .05: excellent (Pai et al., 2006).

The external construct validity of all the scales was evaluated through convergent validity with AQ. The effect of age and educational level on sensitivity scales were examined for discriminant validity. In addition, for the somatosensory scale, discriminant validity was also evaluated with the handedness questionnaire. The degree of association was analyzed by Spearman’s correlation coefficient. The scores of the participants were compared according to sex.

Statistical significance was set to 0.05. All analyses were conducted using R 3.3.3, and the “lavaan” package was utilized to perform CFA (R Core Team, 2018; Rosseel, 2012).

3. Results

3.1. Construct validity

3.1.1. Confirmatory factor analysis

3.1.1.1. Visual/Auditory sensitivity scale. Twelve items for each modality of the visual and auditory sensitivity scales were subjected

Table 1
The factor loadings of the items in the visual and auditory sensitivity scales.

Modality	Items	Factor Loadings
Visual	I avoid places with bright lights	.65
	I feel uncomfortable in places with rapidly changing lights, such as a disco or a concert hall	.71
	I sit at home in dim light	.45
	I feel uncomfortable with car headlights when I sit in the passenger seat travelling at night	.66
	Fast moving images/scenes on TV or cinema make me feel uncomfortable	.73
	It makes me feel uncomfortable being in a room full of furniture of very different colors	.68
	Looking at signs with flashing lights makes me feel uncomfortable	.75
	I avoid looking at luminous colors	.77
	I cannot look at bright screens (computer, television, cell phone…)	.74
	I feel the need to squint my eyes in bright sunlight	.46
Auditory	I cannot sleep when there is noise	.53
	I am easily startled by unexpected sounds	.45
	Traffic noise makes me feel uncomfortable	.67
	I feel uncomfortable when the sound level is high in places, such as a wedding hall or a disco	.58
	I do not want to hear the sound from TV or radio at home	.66
	The noise of electrical household appliances (e.g., vacuum cleaner, washing machine, hair dryer) makes me feel uncomfortable	.58
	I watch TV with the sound at a lower level than many people	.48
	I do not like hearing rhythmic sounds (hammering, machine noise etc.) from far away	.59
	I cannot stand the sound of children playing in a park.	.53
	I cannot read a book/newspaper in crowded places like a café/dining hall	.55

to first-order CFA to confirm their unidimensional structures. According to the factor loadings and goodness-of-fit statistics, this unidimensional structure was confirmed for each of the two scales. The data showed a reasonable fit to the first-order CFA model, in which CFI = .973, TLI = .965 and RMSEA = .075 for the visual sensitivity scale, and CFI = .943, TLI = .927 and RMSEA = .074 for the auditory sensitivity scale. The items and factor loadings are given in Table 1. Two items were removed from each scale due to the factor loading being below .40: “Flashlight causes me to close my eyes involuntarily when my photo is being taken” and “I cannot sleep with the light on.” for the visual scale, and “Clock ticking makes me uncomfortable” and “I like very quiet places” for the auditory scale. The final versions of the visual and auditory sensitivity scales consisted of 10 items each. Turkish version of the scales can be found in supplemental Table S1.

3.1.1.2. Somatosensory sensitivity scale. Thirteen items for the touch subdomain, four items for the pain subdomain, and two items for the itch subdomain were subjected to the second-order CFA, and the factor loadings and goodness-of-fit statistics confirmed their unidimensional structures. The data showed a reasonable fit to the second-order CFA model, in which CFI = .955, TLI = .946, and RMSEA = .048. The items and factor loadings are given in Table 2. The items, “I do not like touching velvet or silk fabrics”, “I do not like people, even the hairdresser, touching my hair”, “I do not like touching ice”, and “I do not like wind blowing on my face” in the touch subdomain had factor loadings below .40; thus, they were removed from the scale. The final version of the somatosensory scale consisted of 15 items in total. Turkish version of the scale can be found in supplemental Table S1. The latent factor correlations between the touch, pain and itch subdomains were all positive (touch and pain: 0.74; touch and itch: 0.56; pain and itch: 0.28; for all correlations $p < 0.001$), indicating that individuals with a high score in one dimension were also likely to have a high score in the

Table 2
The factor loadings of the items in the somatosensory scale.

Modality	Items	Factor Loadings
Touch	I do not like walking barefoot on a carpet	.55
	I am uncomfortable touching packing foam (styrofoam)	.50
	I do not like sand touching my body on the beach	.55
	Touching rough surfaces like sandpaper/nail file makes me feel uncomfortable	.55
	Touching fuzzy fruits like peach/kiwi makes me feel uncomfortable	.54
	Walking barefoot on grass makes me feel uncomfortable	.57
	I do not like touching cotton	.65
	I am uncomfortable touching plush toys.	.63
	I do not like touching tracing paper	.58
Pain	I cannot hold a hot tea cup	.50
	I feel so much pain even after slight bumps	.83
	I think I am less resistant to pain compared to other people around me	.64
	Jokes like pinching and hair pulling hurts me a lot	.63
Itch	Wool sweaters make me itchy	.75
	Sleeping in a wool blanket makes me uncomfortable	.76
Somatosensory	**Touch**	.80
	Pain	.75
	Itch	.68

Table 3
Spearman's rho correlations for the Somatosensory Sensitivity Part.

	Touch		Pain		Itch		Total	
	r	p-value	r	p-value	r	p-value	r	p-value
AQ	.16	< .001	.07	.069	.07	.065	.14	< .001
Handedness	.02	.643	−.03	.518	.03	.478	.01	.719

Note: AQ = Autism-Spectrum Quotient; n = 603.

other two dimensions.

3.1.2. External validity

3.1.2.1. Visual/auditory sensitivity scale. The visual and auditory total scores were found to have positive correlations with AQ scores confirming the convergent validity. Correlation values are $r_s = 0.17$, $p = 0.006$, $r_s = 0.25$, $p < 0.001$ for visual and auditory domains, respectively.

3.1.2.2. Somatosensory sensitivity scale. Each of the somatosensory subdomains and total scores showed positive correlations with AQ scores, but had no correlation with handedness scores (Table 3).

Descriptive statistics for the final version of the three scales are presented in Table 4. The correlation between visual and auditory modalities was $r_s = 0.521$, $p < 0.001$. Although there was a significant correlation between age and the visual domain ($r_s = 0.112$, $p = 0.02$), we found no significant correlation between age and the auditory domain ($r_s = 0.075$, $p = 0.119$). Visual sensitivity scale scores were compared between the university graduates (*Mdn* = 24) and others (*Mdn* = 23), and there was no difference between the groups, $U = 10968.0$, $p = .380$. For auditory sensitivity, there were also no difference between the university graduates (*Mdn* = 27) and other participants (*Mdn* = 28 U = 11555.0, p = .811.

3.2. Reliability

The internal consistency of the visual and auditory sensitivity scales was adequate with a Cronbach's alpha of 0.86 (95 % CI: 0.84-0.88) and 0.79 (95 % CI: 0.76-0.82), respectively. Similarly, the internal consistency of the somatosensory subdomains and the total scale was adequate, with the Cronbach's alpha being 0.69 (95 % CI: 0.65-0.73), 0.65 (95 % CI: 0.61-0.70) and 0.67 (95 % CI: 0.62-0.72) for the touch, pain and itch subdomains, respectively, and 0.78 (95 % CI: 0.75-0.80) for the total scale.

The scores in all scales were compared between the female and male participants, and the former were found to score significantly higher than the latter in the total somatosensory scale and the pain subdomain (Table 5).

4. Discussion

Within the scope of this study, we developed and validated SeSS to measure sensitivity in the auditory, visual and somatosensory domains. SeSS consist of 35 five-point Likert-type items. The visual and auditory scales have 10 items each, and the somatosensory scale has 15 items (nine, four and two items for the touch, pain and itch subdomains, respectively). The sensitivity scores of each scale were calculated separately.

The structures of the scales were analyzed by CFA, and the results showed an acceptable model fit, indicating good construct validity. The somatosensory scale items formed three subdomains (touch, pain, and itch), while the visual and auditory sensitivity scales had a single-factor structure.

The external validity of the scales were assessed by convergent and discriminant validity analyses. Significant positive correlations were found between autistic traits and all sensory domains as an indicator of convergent validity. A handedness scale was used to evaluate the discriminant validity of somatosensitivity. There was no correlation between handedness and the somatosensory domain. Since there is no equivalent questionnaire similar to the handedness scale, age and education level were used to test discriminant validity for the visual and auditory domains. The sensitivity scores were found to be independent of these two

Table 4
Descriptive statistics for the subscales of the Visual/Auditory and Somatosensory Sensitivity Scales.

Scale	Min	Max	*M*	*SD*
Visual[a]	11	50	28.37	7.07
Auditory[b]	10	46	25.24	7.46
Somatosensory	15	60	28.45	8.11
Touch	9	36	14.70	4.95
Pain	4	20	8.66	3.26
Itch	2	10	5.09	2.19

Note: n = 603 except a = (n = 429) and b = (n = 425).

Table 5
Comparison of the subscale scores between the female and male participants.

Scale	Female	Male	p
Visual	25 (11–46)	24 (10–44)	.220[a]
Auditory	28.4 ± 7.1	28.3 ± 7.1	.151[b] MD: 0.1 [-1.2; 1.5]
Somatosensory	28 (15–58)	26 (15–60)	.003[a]
Touch	14 (8–32)	14 (8–36)	.382[a]
Pain	9 (3–20)	8 (4–18)	< .001[a]
Itch	5 (2–10)	5 (2–10)	.163[a]

Notes: a = The Mann-Whitney *U* test Descriptive statistics are presented as median (minimum - maximum) values; b = Student's t-test. Descriptive statistics are presented as mean ± standard deviations; MD = mean difference [95 % Confidence interval]; For the somatosensory domain, f:m = 318:313; visual domain f:m = 212:213; auditory domain, f:m = 214:215.

parameters. The only exception was the presence of a significant correlation between age and visual sensitivity.

Internal consistency was evaluated to confirm the reliability of SeSS. Cronbach's alpha values were within the acceptable range all for the visual, auditory and somatosensory scales. The subdomains of somatosensation (pain and itch) were slightly below the reliability threshold, which can be attributed to the relatively smaller number of items.

All scales have good validity measures. The factorial dissociation in somatosensation can be explained by functional-anatomical properties. Anatomically, two different pathways have been defined for the somatosensory system: pain and itch signals that are carried through one tract and discriminative touch signals transmitted through another (Carpenter & Reddi, 2012; Lang & Rubinson, 2017), which is compatible with the factorial structure of the somatosensory scale. Another indicator of validity is compatibility of the results on gender differences with the literature. It has been reported that men have a lower tolerance and sensory threshold for heat, cold and pressure than women (Fillingim, King, Ribeiro-Dasilva, Rahim-Williams, & Riley, 2009; Racine et al., 2012). Discriminative validity analyses also confirmed that the scales specifically measured sensory sensitivity (e.g., motor preferences were not related to somatosensory sensitivity). The single correlation between the visual domain and age was considered not to affect discriminant validity since it was low and restricted to one domain. The significant correlations between the AQ and SeSS scores indicate that the proposed scales have sufficient external validity. For external validity, we selected AQ, considering that sensory sensitivity differences are most common in ASD. In 2013, the Diagnostic and Statistical Manual of Mental Disorders (DSM-5) included abnormal sensory responses as a diagnostic criterion for ASD (American Psychiatric Association, 2013).

In addition to the validity measures, it would have been ideal to compare the developed scales with SPQ and SHS. Unfortunately, they do not have validated Turkish versions. The only scale with validated Turkish adaptation is the adolescent/adult sensory profile (Üçgül, Karahan, & Öksüz, 2017), consisting of four dimensions (low registration, sensory seeking, sensory sensitivity, and sensory avoiding). However, these dimensions do not solely focus on sensory features and do not overlap with the domains of SeSS.

Another limitation of the current study is that the sample group was limited to university students and a certain age group. In the current literature, there are studies showing a decline in sensory processing with age (e.g., Humes, 2015). Therefore, future studies should be conducted with different age groups to investigate the effect of age on sensory sensitivity and to confirm the generalizability of the current results and conclusions to a broader population.

A second limitation might be that we did not validate our sample in a patient population. This would have further strengthened the validity of scale, but we did show that the scale was related to autistic traits, which is a continuation of ASD. However, to determine the applicability of SeSS to patient populations, new studies are necessary. Another limitation concerns the use of two different populations for the scales, which did not allow for the comparison of the somatosensory scale with the visual or auditory scales. Again, combining these two groups within the same population would provide useful data. In addition, considering their content, one item from the visual scale and three items from the auditory scale can be considered to be affected by social interaction problems. Nevertheless, these items were not differentiated in factorial analyses. Finally, the pain and itch subdomains had lower coefficient values, which can be explained by Cronbach's alpha being affected by the number of items.

We believe that the developed scales may find a wide range of applications for the adult population. They can be used to screen sensory sensitivity differences in related diseases or broader phenotypes (e.g., broader autism phenotype, adult ADHD, and schizotypal personality). Currently, the related literature primarily focuses on children. However, considering that pediatric cases that are not treated in childhood grow into adults with sensory issues that lead to adaptive dysfunction, it is important to assess the different aspects of this dysfunction in adults to determine the right therapy or treatment according to the presence of a cognitive or sensorial basis. In this respect, SeSS may be useful for occupational therapists, neurologists and psychiatrists to identify and follow up the sensory sensitivity differences in interventions undertaken for adults. In addition, sensory sensitivity might be a topic of interest for researchers focusing on sense perception and sensory sensitivity without any disease comorbidity. SeSS can help determine perception differences in three senses and can serve as a marker for studies on the neuronal mechanisms of sensory sensitivity.

5. Conclusion

In this study, we aimed to develop scales to measure the visual, auditory and somatosensory sensitivities of adults. SeSS demonstrated good construct and external validity, with each domain containing enough items to collect detailed information about various aspects of modalities (e.g., color, fast-changing visions, and effect of noise on daily activities, as well as discriminative touch and pain). SeSS can help individually assess the sensitivity of these three senses independent of the effects of social interactions. The developed scales can be used to determine sensory sensitivity differences in neurophysiological studies. In addition, they can help in the diagnosis and follow-up of diseases accompanied by sensory disorders.

CRediT authorship contribution statement

Simge Aykan: Conceptualization, Methodology, Investigation, Writing - original draft. **Gözde Vatansever:** Conceptualization, Methodology, Investigation, Writing - original draft. **Beyza Doğanay-Erdoğan:** Conceptualization, Methodology, Formal analysis, Writing - review & editing. **Canan Kalaycıoğlu:** Conceptualization, Supervision, Methodology, Writing - review & editing.

Appendix A. Supplementary data

Supplementary material related to this article can be found, in the online version, at doi:https://doi.org/10.1016/j.ridd.2020.103612.

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