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Abnormal Linguistic Lateralization and Sensory Processing in High Functioning Children with Autism Spectrum Conditions

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Abstract

Brain lateralization for language in high-functioning children with autism spectrum conditions (ASC) and sensory processing were explored as a part of a neuropsychological profile. A dichotic listening test and the Luria laterality subtest were administered to all participants (including controls) and the sensory profile test only to the ASC group. The usual right ear advantage was not exhibited by children with ASC and anomalies in auditory filtering were found. The sensory profile of 60% of the sample was characterized by hypersensitivity to auditory stimuli, hyposensitivity to vestibular information, high emotional reactions to sensory experiences, poor psychosocial coping strategies, high distractibility and inability to interpret body and facial language. Hyper-responsiveness to environmental auditory stimuli was significantly associated with impaired attention. Similarly, non-adaptive responses to sensory quotidian experiences were strongly connected to poor coping strategies. Our results, although preliminary, contribute to emphasizing the importance of including additional assessment methods such as the dichotic listening and the sensory profile questionnaire in the evaluation of cognitive profile in high-functioning children with ASC to plan an individualized psycho-educative intervention.

Keywords

Children, High-Functioning Autism, Linguistic Lateralization, Neuropsychology, Sensory Profile

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1. Introduction

People with autism spectrum conditions (ASC) exhibit a neuropsychological pattern which includes some of the behavioral diagnostic markers such as communication impairments and poor social cognition. However, on the whole, the neuropsychological profile is much wider and is characterized by enhanced bottom-up information processing, lack of accurate global integration of data from different sources (top-down processing) and an aberrant sensory profile (hypo-, hyper-responsiveness and seeking behavior). Several authors consider these neuropsychological features to be powerful influencing factors which contribute to communication problems and strong adherence to routines [1]-[4].

Between 60% and 95% of people with ASC characteristically exhibit an unusual sensory profile [5]-[8]. In fact, the presence and limiting effect of sensory perception abnormalities have been considered sufficiently important to include them as one of the behavioral markers in the domain of the restricted and repetitive behaviors in the DSM-V [9]. Some authors argue that, because of their high incidence, specificity and their presence along the life span, these sensory symptoms have become good candidates to be added to the nuclear characteristics that define this type of disorder [7] [10]. Hypersensitivity to several sounds, tactile defensiveness or texture food rejections (hypersensitivity to tactile stimuli) are among the first noticeable red flag signs, even prior to those which refer to social interaction deficits. Furthermore, first concerns in parents of children with ASC previous to the diagnosis are also hearing impairment, severe attention deficits or behavioral problems, which could be related to sensory issues. In early childhood, many of these children do not usually respond to their name or follow verbal instructions which could reflect auditory processing alterations such as discrimination, modulation or integration difficulties. Moreover, there are many studies that indicate the existence of anomalies in auditory processing of language and reduced language left lateralization in the majority of individuals with autism (see for a review [11] [12]). Russo, Zecker, Trommer, Chen, and Kraus [13], using evoked potentials, showed how the auditory processing of children with high-functioning ASC in a quiet ambience is identical to that of children with neurotypical development in a noisy environment. Thus, there is evidence of problems in auditory processing of language at the central nervous level. Additionally, they do not benefit from visual cues such as lip reading, which would be a disadvantage in an excessively noisy ambience [14] [15]. Although several works have studied the laterality pattern for speech and language in ASC using EEG, MEG and fMRI, only a few aimed to relate this issue with the sensory processing problems. Orekhova *et al*. [16] and Stroganova *et al*. [17] found a strong correlation between the degree of sensory abnormalities, the presence of abnormal arousal, and an atypical hemispheric lateralization of the P100m component of auditory magnetic field response.

Dichotic listening (DL) is the leading behavioral technique for studying laterality and hemispheric asymmetry in healthy controls and clinical conditions. Two paired verbal stimuli, which could be syllables, words or digits, are presented simultaneously, one to the left and one to the right ear. In the non-forced paradigm, subjects are asked to report the syllable best heard. In this condition, an attentional bias to the right auditory space favors a right ear advantage (REA) (superior reports of right ear inputs) which reflects left hemisphere dominance for the control of speech and language and is sustained by a bottom-up processing strategy. Studies in clinical and healthy population showed that DL performance is closely related to the functional integrity of the corpus callosum. Thus, a greater dendritic density in the corpus callosum allows better interhemispheric communication and favors greater verbal capability [18]. In contrast, in some people with ASC there is evidence of a lower volume of the corpus callosum (total and some sub-regions) that correlates with social deficits, repetitive behaviors, sensory abnormalities and an altered pattern of the standard brain lateralization (right-handedness and left-hemisphere dominance for the control of speech and language) [19]-[21]. There is scarce and often contradictory information on DL results in the ASC population. In fact, when compared with controls (who exhibit REA), no differences, no ear preferences or even left ear advantage were found in people with high-functioning ASC [22]-[26]. This disparity in results correlated with the existence of a great heterogeneity in this population, which is evidenced by the use of the term spectrum or “autisms” when referring to autism conditions [27]. Thus, it would be interesting to delimit neuropsychological profiles in order to fit the psycho-educative interventions more efficiently to the individual (the most suitable treatment strategy nowadays). Consequently, the main goal of the present study was to evaluate the brain lateralization for language in a sample of children with ASC (using the DL task) and the sensory profile (especially the auditory perceptions).

2. Methods

2.1. Participants

The total sample consisted of thirty-five 6-year-old male children without intellectual disability (cognitive development previously evaluated by the psychologists in each center), hearing loss (assessed through threshold tonal audiometry), or visual impairment.

The ASC group included 17 individuals with diagnoses established by a psychologist and a pediatric neurologist with ASC expertise (according to DSM-IV: Autistic Disorder, Asperger's Syndrome or Pervasive Developmental Disorder, Not Otherwise Specified). Diagnoses were corroborated by the ADOS [28]. These children were recruited from "Psicotrade", a specialized autism center in Valencia (Spain).

An age-matched control group was formed by 18 boys with no evidence of sensory processing impairment, speech/language disorder or learning disabilities. These participants were recruited randomly from "Esclavas de María" school in Valencia (Spain).

2.2. Procedure

After collecting written informed parental consent and data about socio-demographic characteristics, an audiometry of each of the subjects was carried out in the speech frequency (2000 Hz) in order to check that they showed no hearing loss. If they met the audiometric inclusion criteria (<10 dB difference between ears at 500, 1000, 2000, 3000 and 6000 Hz), the DL test and the Luria laterality subtest were administered. The sessions lasted around 40 minutes and took place in the morning in a quiet room. Only parents of the ASC children filled in the sensory profile (SP) questionnaire regarding sensory responsiveness exhibited by their sons in quotidian situations. It was administered and interpreted by an occupational therapist specialized in sensory modulation and integration disorders and this professional also gave assistance during the administration of the test. The study was approved by the ethics committee of clinical investigation at the University of Valencia (Spain) and was in accordance with the ethical standards in human research, contained in the Helsinki Declaration of 1975, as revised in 2000 (http://www.wma.net/en/30publications/10policies/b3/index.html).

2.3. Dichotic Listening

This standard Consonant-Vowel DL test assesses hemispheric processing and ear preference using variables such as attention, concentration or type of information to be processed [29]. It has been widely validated through different studies [30]-[32] and reaches a test-retest reliability of 0.86 [29]. The children were asked to report only the syllables which were perceived the most clearly after being informed that they would be presented simultaneously to each ear (monosyllables at the standard frequency of the human voice of 2000 Hz). The syllables reproduced are TA, KA, GA, PA, BA and DA. Firstly, they are each paired with themselves in order to ensure that the participants are able to recognize them without any problem. All syllables are then paired between themselves, forming 60 pairs (30 initial and homonyms, for example KA-GA, GA-KA). These combinations are made so that each syllable of the pair is heard by each ear, subjects being instructed to verbalize aloud what they hear. Scoring is carried out by taking into account which of the two syllables, presented at the same time, is identified and correctly pronounced.

2.4. Luria Manual Laterality Test (Standardized for Spanish Children by [33])

This is a complementary test of the Luria Initial Battery which evaluates motor ability in young children (4 to 6 years old), testing differences in the use of both hands by observing their performance while carrying out activities. This task is based on the neuropsychological Luria-Nebraska Battery (for children aged 12 and older) [34]. It consists of five tasks: writing, drawing, throwing a ball, using scissors, and brushing teeth. The laterality preference quotient is obtained in order to classify subjects according to the preferred hand: (right hand score – left hand score) × 10.

2.5. Sensory Profile (SP; [35])

This questionnaire has been proposed by specialists who work with ASC children and provides information about sensory processing difficulties and associated behaviors, detecting which sensory systems could be involved in functional or dysfunctional performance. It is composed of 125 items rated with a five-point Likert scale (from never to always) and evaluates responses to tactile, olfactory, gustatory, vestibular, auditory and visual stimuli. All items are classified into 14 sections which are grouped into three categories (sensory processing, modulation, and behavioral/emotional responses). Additionally, 9 factors can be identified (see **Table 1**). The possible scores are organized into three groups (typical performance, probable difference or definite difference) in accordance with the performance of a population sample of children without disabilities (n = 1307); lower scores indicate greater symptoms. Probable difference corresponds to scores greater than 1 SD and less than 2 SD from the mean, and definite differences to scores greater than 2 SD from the normative mean. Internal consistency based upon Cronbach's alpha ranges from 0.47 to 0.91 and the internal validity correlations ranges from 0.25 to 0.76 [40].

2.6. Statistical Analysis

Normality (Kolmogorov-Smirnov) and homogeneity of variances (Levene) were checked for all variables.

Table 1. Sensory profile item categories.

	A. Sensory Processing	
1	*Auditory Processing*	Responses to things heard (e.g., "is distracted or has trouble functioning if there is a lot of noise around")
2	*Visual Processing*	Responses to things seen (e.g., "is bothered by bright lights after others have adapted to the light")
3	*Vestibular Processing*	Responses to movement (e.g., "becomes anxious or distressed when feet leave the ground")
4	*Touch Processing*	Responses to stimuli that touch the skin (e.g., "becomes irritated by shoes or socks")
5	*Multisensory Processing*	Responses to activities that contain a combined sensory experience (e.g., "seems oblivious within an active environment")
6	*Oral Sensory Processing*	Responses to touch and taste stimuli to the mouth (e.g., "limits self to particular food textures/temperatures")
	B. Modulation	
7	*Sensory Processing Related to Endurance/Tone*	Ability to sustain performance
8	*Modulation Related to Body Position and Movement*	Ability to move effectively
9	*Modulation of Movement Affecting Activity Level*	Demonstration of activeness
10	*Modulation of Sensory Input Affecting Emotional Responses*	Ability to use body senses to generate emotional responses
11	*Modulation of Visual Input Affecting Emotional Responses and Activity*	Ability to use visual cues to establish contact with others
	C. Behavioural and Emotional Responses	
12	*Emotional/Social Responses*	Psychosocial coping strategies
13	*Behavioural Outcomes of Sensory Processing*	Ability to meet performance demands
14	*Items Indicating Thresholds for Response*	Level of modulation
	Factor Scores	
1	*Sensation Seeking*	Interest in and pleasure with sensory experiences in everyday life
2	*Emotionally Reactive*	Affective responses to sensory experiences in everyday life
3	*Low Endurance/Tone*	Ability to use muscle tone to support self while engaging in activity
4	*Oral Sensory Sensitivity*	Responses to textures, tastes and smells, particularly related to foods
5	*Inattention/Distractibility*	Tendency to be pulled away from activities due to external stimuli, particularly sounds
6	*Poor Registration*	Tendency to miss cues from sensory experiences in everyday life
7	*Sensory Sensitivity*	Level of detection of movement stimuli during everyday life experiences
8	*Sedentary*	Tendency to be passive during everyday life
9	*Fine Motor/Perceptual*	Ability to use hands

Means of test scores and standard deviations for the different groups (ASD and control) were calculated. For DL, ANOVA with repeated measures was performed on the correctly reported items according to the design: 2 (Ear input: right *vs.* left) × 2 (Group: ASD *vs.* control). *Post-hoc* DHS Tukey tests were applied when corresponding. Afterwards, the means of the differences and their 95% confidence intervals were obtained to compare performance between both groups in the tests. Due to the size of the sample, Cohen's d index was calculated to establish the magnitude of the effects of t tests [36]. Finally, the correlation between raw scores of each ear was explored with the Pearson test in each group. Concerning the sensory data, percentages of definite and probable differences regarding typical performance were calculated and Pearson's Correlations between each of the SP components were obtained. SPSS for Windows version 19 was used for data analysis.

3. Results

According to the Luria Laterality Test, all subjects included in the sample were totally or preferably right-handed.

3.1. DL

Three ASC children were excluded from the DL data due to reluctance to put on the headphones in two of them and the presence of perseverations during the test in one child (e.g. more than 25 "Ka" responses). Thus, the sample for DL data consisted of 14 ASC and 18 control children.

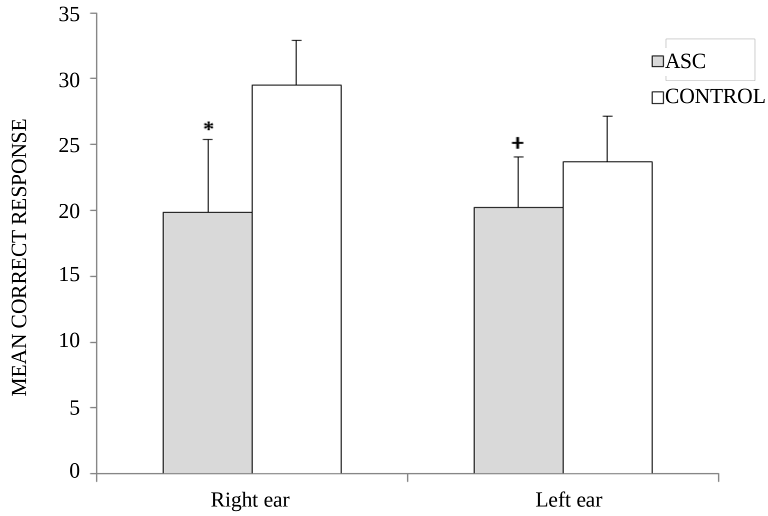
All variables were normally distributed (Kolmogorov-Smirnov test: $p > 0.05$) and variance was homogeneous (Levene test: $p > 0.05$). The ANOVA based on the children's data showed a significant main effect for the factor Group ($F(1, 30) = 62.383$, $MSE = 675.22$, $p < 0.001$) due to overall better accuracy for the control group (Mean of correctly reported items = 26.58, range 25.46 - 27.7) than for the ASC group (Mean of correctly reported items = 20.04, range 18.77 - 21.30). The main effect for the factor ear was significant ($F(1, 30) = 5.273$, $MSE = 118.08$, $p < 0.05$), the performance for the right ear was superior (Mean = 24.68, range 23.06 - 26.30) than for the left ear (Mean = 21.94, range 20.61 - 23.27). Finally, the Ear × Group interaction was also significant ($F(1, 30) = 6.738$, $MSE = 150.89$, $p < 0.05$). *Post-hoc* comparisons revealed that the group of controls showed a REA ($t(17) = 3.947$, $p < 0.001$), while the group of ASC did not show this otherwise typical REA ($t(13) = -0.185$, $p = 0.856$). Moreover, controls showed a significantly higher number of correct right ear items than ASC ($t(30) = -6.070$, $p < 0.001$), as well as a significantly higher number of left ear items than ASC, although to a lesser degree ($t(30) = -2.652$, $p < 0.05$). **Figure 1** depicts performance for both ears in each group. Finally, the Pearson correlations showed that the right and left ear scores were inversely correlated for controls ($r = -0.629$, $p < 0.01$), but not for the group of ASC ($r = -0.162$, $p = 0.579$).

3.2. SP

Taking into account the SP data, more than 50% of the ASC sample showed differences (probable and definite) with respect to typical performance in inattention/distractibility, auditory and vestibular processing, modulation of sensory input affecting emotional responses, emotional and social responses and, in the emotionally reactive factor (see **Figure 2** and **Table 2**). The sensory profile of the sample was characterized by hypersensitivity to auditory stimuli, hyposensitivity to vestibular information, high emotional reactions to sensory experiences, poor psychosocial coping strategies, high distractibility and inability to interpret body and facial language. **Table 3** shows the analysis of total scores from SP categories, which revealed a significant correlation. Inattention/distractibility correlated significantly with auditory ($p < 0.01$) and vestibular ($p < 0.05$) processing modalities. Additionally, a significant correlation was found between the last two ($p < 0.01$). Similarly, modulation of sensory input affecting emotional responses, emotional/social responses, and emotionally reactive variables correlated significantly between one another ($p < 0.01$ and $p < 0.05$). All these correlations indicate that if a lower score was found in one of these modalities, a lower score was more likely to be found in the other.

4. Discussion

The main goal of the present study was to evaluate the sensory profile and language lateralization using DL in a sample of high functioning boys with ASC in comparison to typically developing age-matched children. Although neuroimaging techniques have revealed an abnormal linguistic lateralization pattern in the majority of



	Right ear	Left ear
Cohen's (d)	2.23	0.98
Effect size	Huge effect	Large effect

Figure 1. Differences between high-functioning children with ASC and controls in the mean correct response of right and left ear (Means and Standard Errors provided). $^{*}p < 0.001$, $^{+}p < 0.05$.

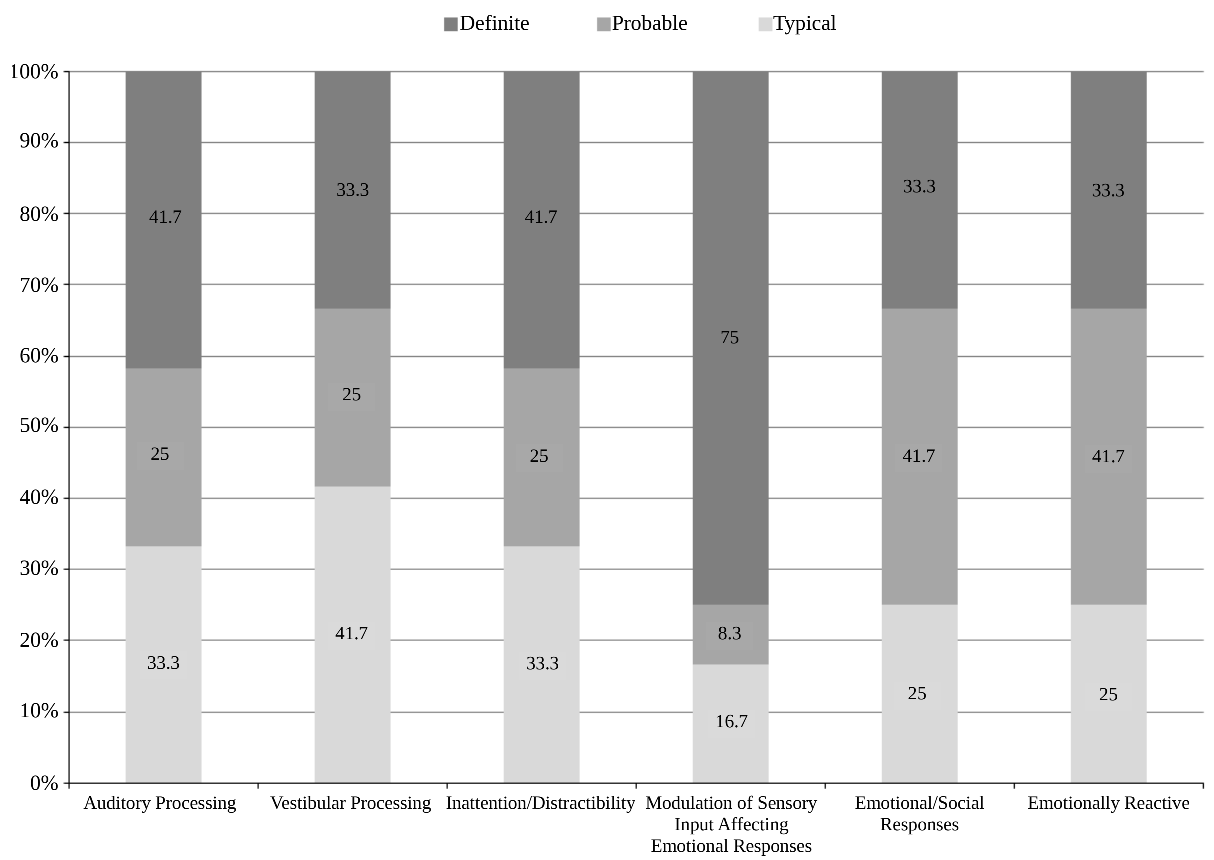


Figure 2. Percentage of children with ASC showing typical performance, probable differences (1 SD or more from the normative mean) and definite differences (2 SD or more from the normative mean) in sensory processing.

Table 2. Percentages of children who always or frequently displayed behaviors on the SP.

Item	%
Auditory Processing	
1. Responds negatively to unexpected or loud noises (for example, cries or hides at noise from vacuum cleaner, dog barking, hair dryer)	33.3
2. Holds hands over ears to protect ears from sound	16.7
3. Has trouble completing tasks when the radio is on	25.0
4. **Is distracted or has trouble functioning if there is a lot of noise around**	**50.0**
5. Can't work with background noise (for example, fan, refrigerator)	16.7
6. Appears to not hear what you say (for example, does not "tune-in" to what you say, appears to ignore you)	25.0
7. Doesn't respond when name is called but you know the child's hearind is OK	16.7
8. Enjoys strange noises/seeks to make noise for noise's sake	25.0
Vestibular Processing	
18. Becomes anxious or distressed when feet leave the ground	8.3
19. Dislikes activities where head is upside down (for example, somersaults, roughhousing)	16.7
20. Avoids playground equipment or moving toys (for example, swing set, merry-go-round)	8.3
21. Dislikes riding in a car	0.0
22. Holds head upright, even when bending over or leaning (for example, maintains a rigid position/posture during activity)	0.0
23. Becomes disoriented after bending over sink or table (for example, falls or gets dizzy)	0.0
24. Seeks all kinds of movement and this interferes with daily routines (for example, can't sit still, fidgets)	33.3
25. Seeks out all kinds of movement activities (for example, being whirled by adult, merry-go-rounds, playground equipment)	25.0
26. Twirls/spins self frequently throughout the day (for example, likes dizzy feeling)	8.3
27. Rocks unconsciously (for example, while watching TV)	0.0
28. Rocks in desk/chair/on floor	0.0
Modulation of Sensory Input Affecting Emotional Responses	
92. Needs more protection from life than other children (for example, defenseless physically or emotionally)	41.7
93. Rigid rituals in personal hygiene	25.0
94. Is overly affectionated with others	41.7
95. **Doesn't perceive body language or facial expressions (for example, unable to interpret)**	**50.0**
Emotional/Social Responses	
100. Seems to have difficulty liking self (for example, low self-esteem)	16.7
101. **Has trouble "growing up" (for example, reacts immaturely to situations)**	**50.0**
102. **Is sensitive to criticisms**	**50.0**
103. Has definite fears (for example, fears are predictable)	41.7
104. Seems anxious	33.3
105. **Displays excessive emotional outbursts when unsuccessful at a task**	**50.0**
106. Expresses feeling like a failure	16.7
107. Is stubborn or uncooperative	33.3
108. Has temper tantrums	25.0
109. Poor frustration tolerance	33.3
110. Cries easily	41.7
111. Overly serious	8.3
112. Has difficulty making friends (for example, does not interact or participate in gropu play)	33.3
113. Has nightmares	0.0
114. Has fears that interfere with daily routine	25.0
115. Doesn't have a sense of humor	16.7
116. Doesn't express emotions	0.0
Emotionally Reactive	
121. Has difficulty tolerating changes in plans and expectations	16.7
122. Has difficulty tolerating changes in routines	25.0
Inattention/Distractibility	
48. **Has difficulty paying attention**	**50.0**
49. **Looks away from tasks to notice all actions in the room**	**58.3**

Note: Bold items are those with "always" or "frequently" reported behaviors by 50% or more of the caregivers of children with ASC. Emotionally Reactive factor also includes items 92, 100, 101, 102, 103, 104, 105, 106, 107, 108, 109, 110, 111 and 112. Inattention/Distractibility factor also includes items 3, 4, 5, 6 and 7.

Table 3. Pearson correlation coefficients among sensory variables ($^{**}p < 0.01$, $^{*}p < 0.05$).

	Vestibular	Inattention/Distractibility	Emotionally Reactive	Emotional/Social Responses
Auditory Processing	0.774**	0.913**		
Vestibular Processing		0.616*		
Emotional/Social Responses			0.959**	
Modulation of Sensory Input Affecting Emotional Responses			0.778**	0.655*

persons with ASC, only a few studies have been carried out in high-functioning children with ASC. Additionally, scarce literature has been published in the ASC field using the DL task, which has been proved to be a reliable non-invasive instrument to evaluate language laterality and hemisphere functioning in typically developing controls and clinical conditions [37].

Contrary to results found in controls, individuals from the ASC group did not exhibit either the REA or the significant negative correlation between data from both ears, which could indicate an abnormal linguistic lateralization pattern (either bilateral or mixed processing dominance) and a lack of interhemispheric integration of the information. The latter was found in fathers but not mothers of this ASC sample, supporting the existence of a certain genetic vulnerability [38]. In a recent systematic review, Lindell and Hudry [11] have stated that contradictory results found in the previous studies using DL in children with ASC could be due to the sample size. For these authors, a sample of 19 subjects is enough to power the analysis as in the study carried out by Prior and Bradshaw [26], although up to date there has been no replication. In the current study, size effect was calculated (Cohen's d and r) and revealed that the differences between groups were large or huge (see **Figure 1**). Nevertheless, it would be convenient in future research to increase the sample and the age interval, and also include other comparison groups with sensory modulation difficulties without ASC.

Cardinale, Shih, Fishman, Ford, and Müller [39] have examined hemispheric asymmetry of several functional networks in a group of high-functioning children and adolescents (9 - 18 years old) and found an atypical rightward asymmetry not only in the auditory network but also in components involved in visual, sensorimotor, visuospatial, executive and attentional processing. These findings support the strong association between abnormal linguistic lateralization and atypical sensorimotor processing in ASC. Ludlow *et al*. [40] in high-functioning children with ASC found that the greater the sensory disturbances (especially auditory sensitivity) the worse the auditory processing during automatic language tasks (using event-related potentials to meaningless and meaningful speech stimuli).

In concordance with previous studies, modulation disorders in more than one sensory channel were found in our sample. The sensory profile of our sample of children with ASC was characterized by auditory hypersensitivity, vestibular hyposensitivity and high distractibility. This profile is similar to the postural inattentive subtype, one of the four subtypes described by Lane *et al*. [41], and is characterized by an under-responsive seeking sensation as well as difficulties in postural processing and auditory filtering. The sensory symptoms are frequently associated with increased autism severity and contribute to social interaction [41] [42]. Hence, although people with high-functioning ASC have no intellectual disability, their sensory quotidian difficulties should not be underestimated considering their impact on communication and social cognition [43]. One of the main recent associations between sensory disturbances and the core ASC features is sensory hyper-responsiveness and communication competence [41]. Taking into account this relationship, we could conclude that as soon as the children are overloaded by auditory information, especially when it is verbal, attention could be seriously impaired. At vestibular level, many people within the autistic spectrum are hypo-responsive and seek this type of stimulation by spinning and rocking themselves, and in our sample this pattern seems to be related to the distractibility and auditory hyper-responsiveness exhibited [42]. Similarly, the intense affective responses to quotidian sensory experiences were closely associated with poor coping strategies and impairments in the interpretation of body and facial language, as revealed by the correlations.

5. Conclusion

To conclude, it could be said that a comprehensive neuropsychological evaluation in the ASC population would allow professionals to build a profile about cognitive deficits and strengths in order to orientate the intervention from a multidisciplinary approach, including not only psychologists, pedagogues or speech therapists but also occupational therapists. Moreover, in terms of research, it would allow the exploration of variations throughout the spectrum. The collection of data referring to language lateralization and the sensory profile would allow professionals to design individualized intervention protocols including sensory-based therapies [44], and psycho-educative strategies based on structured teaching relying on visual information like the TEACCH program (Treatment and Education of Autistic and related Communication-handicapped Children [45] [46]).

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