Title:

The impact of sensory processing on executive and cognitive functions in children with autism spectrum disorder in the school context.

Abstract

Background: Theoretical approaches propose a hierarchical organization of sensory and higher-order cognitive processes, in which sensory processing influence some cognitive and executive functions. Aims: The main objective of this study was to analyze whether sensory processing dysfunctions can predict the cognitive and executive dysfunctions evaluated in a group of children with level 2 autism spectrum disorder (ASD) in the school context. Methods and Procedures: Two groups of children participated: an ASD group (*n* = 40) and a group of children with typical development (the comparison group, *n* = 40). The children's sensory processing was evaluated based on their teachers' perceptions, and the children's executive and cognitive functions were evaluated using direct performance measures. Results: In the ASD group, the sensory processing difficulties predicted executive and cognitive dysfunctions in the specific domains of inhibitory control, auditory sustained attention, and short-term verbal memory, after controlling the possible effect of ASD severity. Moreover, the ASD group showed higher levels of sensory, executive, and cognitive dysfunction than the comparison group. Conclusions and implications: Future research should investigate whether adequate sensory interventions in children with ASD in the school context can improve these specific executive and cognitive functions.

What this paper adds

The main contribution of the present paper lies in the study of sensory processing dysfunction as a predictor of executive and cognitive dysfunctions in the school context in a group of children with level 2 ASD severity, a part of the autistic spectrum that has hardly been studied until now. The executive and cognitive functions were evaluated through direct performance measures. Children's sensory processing was evaluated based on their teachers' perception, which was one of the study strengths because teachers have the opportunity to compare children's functioning with that of their peers. The results obtained, which are novel, indicate that the sensory processing difficulties in the ASD children predicted executive and cognitive dysfunctions in the specific domains of inhibitory control, auditory sustained attention, and short-term verbal memory, after controlling the possible effect of ASD severity. Future research should test the hypothesis that adequate sensory interventions in children with ASD in the school context can improve these specific executive and cognitive functions.

1. Introduction

Autism spectrum disorder (ASD) is a neurodevelopmental disorder characterized by impairments in social interaction and communication across multiple contexts and by the presence of repetitive and stereotyped behaviors (DSM-5; American Psychiatric Association, APA, 2013). The severity of these two criteria determines the severity of the disorder, with three possible levels, 1, 2, and 3: level 1 would be the least severe (the person needs support), and level 3 would be the most severe (the person needs considerable support).

1.1. Sensory processing as the basis of cognitive and executive functions

The DSM-5 (APA, 2013) includes the possible presence of sensory issues as part of the diagnostic criteria for ASD. Sensory processing refers to the way the central and peripheral nervous systems manage incoming sensory information from the sensory organs, namely, visual, auditory, tactile, taste, smell, proprioception, and vestibular information. Sensory processing impairment is a neurological dysfunction affecting the adequate reception, modulation, integration, discrimination or organization of sensory stimuli, and the behavioral responses to sensory input (Tomchek, 2001). According to the Sensory Integration Theory (SIT, Ayres, 1979), the processing and integration of sensory inputs is a critical neurobehavioral process that strongly affects development. Difficulties at the level of sensory processing could contribute to impairments in higher-level integrative functions, so that sensory issues could affect the successful performance of adaptive responses to situational demands and, thus, meaningful engagement in daily activities (Humphry, 2002), social interactions, and play (Kuhaneck & Britner, 2013).

The SIT (Ayres, 1979) proposes that sensory and cognitive processes can be considered within a hierarchical structure where sensory processes would be located at the bottom and cognitive processes at the top. Theoretical approaches such as those of Williams & Shellenberger (1994) and Lázaro & Berruezo (2009), based on this hierarchical organization, propose a human development and learning pyramid in which cognitive and executive functions (higher-order processes) would depend on sensory processing characteristics, which would be located in the basal part of the pyramid. The present study is based on this hierarchical organization of sensory processes and higher-order cognitive processes, which also has neuroanatomic underpinnings (see the review by Koziol, Budding, & Chidekel, 2011, on the impact of sensory processing on certain cognitive and executing functions).

Sensory processing is the base on which the human cognitive system is built. Thus, information processing takes place in two directions: bottom-up and top-down, referred to, respectively, as stimulus-driven processing and knowledge-driven processing. Although both types of processing are fundamental in the functioning of cognitive and executive processes, in our study we focus specifically on the role of bottom-up processing in these processes. Hence, although sensory information enters through the sensory receptors (located in the sensory organs), the processing of this information takes place in the brain’s sensory centers. Specifically, the primary receptor area of each sensory modality first processes the information coming from this sensory system, to later move to higher processing areas and areas of association. In these areas, the integration and higher-order processing of the information occur, which are necessarily involved in cognitive and executive processes such as attention, memory, inhibition, and planning, among others. Thus, difficulties in this bottom-up processing flow can have an effect on the cognitive and executive functions.

1.2. Sensory, executive and cognitive dysfunctions in ASD

Sensory processing dysfunctions are highly prevalent in ASD (Caminha & Lampreia, 2012). Several studies that have compared the sensory processing characteristics of children with ASD and children with typical development found significantly greater impairments in children with ASD (Little, Dean, Tomchek, & Dunn, 2018; see the meta-analysis by Ben-Sasson et al., 2009).

Moreover, according to the theory of executive dysfunction (Hill, 2004; Ozonoff, 1997), people with ASD would present a deficit in the executive functions, which are understood as a variety of interrelated cognitive processes for the correct coordination of thoughts, emotions, and behaviors that are set in motion before the resolution of new tasks or problems with greater complexity (Corbett, Constantine, Hendren, Rocke, & Ozonoff, 2009; Robinson, Goddard, Dritschel, Wisley, & Howlin, 2009). Several studies have compared performance on executive tasks in children with ASD and children with typical development, with significantly greater impairments found in children with ASD (Berenguer, Roselló, Colomer, Baixauli, & Miranda, 2018; Filipe, Frota, & Vicente, 2018; see the meta-analysis by Demetriou et al., 2018). Likewise, evidence has shown worse performance in children with ASD than in children with typical development on specific executive functioning domains or components, such as planning (see the meta-analysis by Dubbelink & Geurts, 2017) and inhibitory control (see the meta-analysis by Geurts, van den Bergh & Ruzzano, 2014).

In addition to the executive functions, children with ASD have also shown deficits in other higher-order cognitive processes that are not exclusively executive in nature, such as verbal fluency (e. g. Begeer et al., 2014; Pastor-Cerezuela, Fernández-Andrés, Feo-Álvarez & González-Sala, 2016), sustained attention (visual: e. g. Chien et al., 2014; and auditory: Corbett & Constantine, 2006), and short-term memory (visual: e. g. Chien et al., 2015; Jaworski & Eigsti, 2017; and auditory / verbal: e. g. Lalani et al., 2018).

Some studies carried out with samples with no clinical diagnosis have found a link between sensory and cognitive processing (e. g. Humes, Busey, Craig, & Kewley-Port, 2013, carried out with adults) and between sensory processing and executive functioning (Adams, Feldman, Huffman, & Loe, 2015, carried out with preterm preschoolers). Regarding the analysis of these relations in ASD, Boyd, McBee, Holtzclaw, Baranek, & Bodfish (2009) did not find a significant relationship between sensory issues and executive functioning (evaluated by means of report tests) in a group of children and adolescents with high functioning autism. In another study (Wodka et al., 2016), a significant relationship was found between attention and somatosensory (tactile) processing in children with ASD. Other studies have investigated the possible contribution of sensory issues and executive functioning to the prediction of variables such as emotion recognition (Erfanian, Razini, & Ramshini, 2018) and school participation (Zingerevich & LaVesser, 2009) in children with ASD, although they did not directly analyze the relationship between these constructs.

Based on the hierarchical organization of sensory processes and higher-order cognitive processes above mentioned, the present study starts from the hypothesis that dysfunctions in sensory processing are related to cognitive and executive dysfunctions, so that sensory processing skills have an impact on cognitive and executive functions. In this study, we evaluated this hypothesis in a sample of children with level 2 ASD in the school context.

Objectives and hypotheses of the present study

The main objective of the present study was to analyze the relationship between sensory processing and executive functioning (inhibition and planning) and the cognitive functions of verbal fluency, sustained attention, and short-term memory in a group of children with level 2 ASD in the school context. We hypothesized that the greater sensory processing difficulties are, the greater the cognitive and executive dysfunctions are, so that the sensory processing dysfunctions will predict the cognitive and executive dysfunctions evaluated.

With regard to the study of the relationship between sensory issues and executive functioning, the previous work by Boyd et al. (2009) used report measures to evaluate executive functions in a sample of children and adolescents with high functioning ASD. In the present study, however, we evaluated executive and cognitive functioning through direct performance measures, which is a more objective measure (although it may have a more limited ecological validity), and we used a sample of children with level 2 ASD severity. Including children with level 2 severity in the sample is an important contribution of our study, given that the children included in the samples of previous studies were from level 1 and had high cognitive and verbal functioning. Therefore, our study focuses on a type of population that has hardly been investigated, and so we address a part of the autism spectrum that differs from what has commonly been studied. In addition, evaluating sensory, executive, and cognitive functions in the school context is relevant because: 1) In the school context, there are usually greater demands and possibly more stimulation overload than in the family context; and 2) Teachers have the opportunity to compare children's functioning with that of their peers.

Also, in the present study data from a group of children with typical development (comparison group) was collected in order to compare the sensory, executive and cognitive functions evaluated with the ASD group. Thus, first we compared overall sensory processing and auditory and visual processing of the two groups. Visual and auditory sensory modalities were specifically selected for two reasons: 1) The executive and cognitive functions evaluated are visual and auditory; and 2) In the absence of sensory deficits (e. g. blindness, deafness…), vision and hearing are usually the two most dominant and relevant sensory modalities in the human being, and the most important for social interactions and language. Second, we compared the executive functions (specifically, inhibition, and planning) and the cognitive functions (specifically, verbal fluency, sustained attention, and short-term memory) of the two groups. We hypothesized that the ASD group would obtain higher levels of sensory, cognitive, and executive dysfunctions than the comparison group.

2. Material and Method

2.1. Participants

In the present study, two groups of children participated: the ASD group (*n* = 40), and the comparison group (*n* = 40). The children's ages ranged from 5 to 8 years old. The ASD group was composed of 33 males and 7 females with a mean age of 81.20 months (*SD* = 11.18), a mean non-verbal IQ of 100.88 (*SD* = 16.84) on Raven's Colored Progressive Matrices Test (Raven, 1996), and a mean verbal IQ of 72.68 (*SD* = 18.19) on the Peabody test (Dunn, Dunn & Arribas, 2006). The comparison group was composed of 33 males and 7 females with a mean age of 81.88 months (*SD* = 12.57), a mean non-verbal IQ of 99.25 (*SD* = 15.69) on the Raven test, and a mean verbal IQ of 95.48 (*SD* = 13.25) on the Peabody test. Children in the ASD group had a clinical diagnosis of ASD, according to the DSM-IV-TR criteria (APA, 2000), and they met the DSM-5 diagnostic criteria for level 2 (APA, 2013). They were diagnosed by neuropediatric services from different hospitals in the national health system. These neuropediatric services were responsible for checking compliance with these diagnostic criteria, and they referred the children who met the criteria to early care units where the diagnosis was confirmed using a more specific instrument, the Autism Diagnostic Observation Schedule (ADOS; Lord, Rutter, DiLavore & Risi, 2000). This instrument was administered by specialized psychologists who had the appropriate formal training to use it. The children in the ASD group were attending schools with specific classrooms where the Treatment and Education of Autistic and Related Communication Handicapped Children (TEACCH) methodology was carried out. These are integrated classrooms included in regular state schools in XXXX (XXXX), where a maximum of 8 students with disorders affecting language and communication are enrolled. In general, in XXXX, children who are enrolled in these types of classrooms have level 2 ASD severity. The children in the comparison group had typical development, without any clinical diagnosis, and they attended the same schools as the ASD group, but in the regular modality.

The ASD group was composed of a total of 40 children. This sample was sufficiently representative, given that ASD level 2 children in this age range are usually enrolled in this type of classroom in XXXX. All children with ASD for whom consent was obtained and who studied in one of the selected schools were included in the study, which represented approximately 50% of the total of children with these characteristics. The comparison group was initially made up of 350 children who attended 11 of the 20 schools where the children with ASD were enrolled. The two groups of children were matched one-to-one on non-verbal IQ, chronological age, and gender, so that of the initial 350 children without ASD, 40 were selected.

No statistically significant differences were found between the two groups of children on chronological age ($F_{(1,78)} = 0.64$, $p = .800$, $\eta^2_p = .001$) or non-verbal IQ ($F_{(1,78)} = 0.70$, $p = .657$, $\eta^2_p = .003$). Nonetheless, statistically significant differences were found on verbal IQ ($F_{(1,78)} = 41.05$, $p < .001$, $\eta^2_p = .345$), which was higher in the comparison group than in the ASD group.

A total of 33 teachers participated. Eleven were the regular classroom teachers who completed the SPM-Main Classroom Form questionnaire (Miller Kuhaneck, Henry, & Glennon, 2007) for the children in the comparison group, and 22 were the teachers in the TEACCH classrooms (Therapeutic Education Teachers or Hearing and Language Teachers) who completed the SPM-Main Classroom Form questionnaire (Miller Kuhaneck et al., 2007) for the children in the ASD group. In the two groups, almost 100% of the participating teachers were female, and their ages ranged from 26 to 60 years. Statistically significant differences were found for the teachers' age ($F_{(1,31)} = 8.53$; $p = .006$; $\eta^2_p = .216$), which was higher in the comparison group ($M = 43.09$, $SD = 11.18$) than in the ASD group ($M = 34.32$, $SD = 6.15$). All the teachers had between five and 36 academic years of teaching experience. Regarding the number of academic years of contact with students, in the ASD group, teachers had between one and five academic years ($M = 2.32$, $SD = 0.99$) of contact with the children, whereas in the comparison group, teachers had between one and two academic years ($M = 1.36$, $SD = .51$) of contact with the children, and this difference was statistically significant ($F_{(1,31)}$ = 8.88; p = .006; η^2_p = .22).

2.2. Ethics Statement

This study was approved and funded by the University of XXXX (Helsinki Declaration in the Convention of the European Council, 1964), and it had the official and written authorization of the General Direction and Management of Schools (XXXX, Training and Employment Department). All of the XXXX state schools with TEACCH integrated classrooms were invited, via an informative meeting, to participate in the research. From the schools that voluntarily agreed to participate, the classrooms of five- to eight-year-old children were selected. The parents gave written informed consent for their children's participation in the research.

2.3. Procedures

Each child's non-verbal IQ, verbal IQ, and the other measures (executive and cognitive functions) were individually evaluated by the research team in the participating school on different days. Teachers of all the selected children were asked to participate in an interview in order to provide demographic information and fill out the SPM-Main Classroom Form questionnaire (Miller Kuhaneck et al., 2007).

2.4. Measures

2.4.1. Executive functions

2.4.1.1. Inhibitory errors. The Auditory Attention subtest of the Nepsy-II (Korkman, Kirk, & Kemp, 2007) evaluates auditory selective attention and the ability to maintain or sustain it over time (surveillance), and it also includes an assessment of inhibitory control. The child has to listen to a series of words and touch the appropriate circle every time s/he hears a key word ("red"), indicated at the beginning. The dependent variable used in this study to evaluate inhibition was the number of inhibitory errors (every time the child touched a circle of another color after the word that designated that color, with the exception of "red"). This measure had a test-retest reliability of 0.93 in the validation of the test (Korkman et al., 2007).

2.4.1.2. Inhibitory RT. A Stroop-type interference task (developed by the authors) was designed using the E-prime software to evaluate inhibitory control in an interference situation through an adapted version of one of the variants of the classic Stroop task (Stroop, 1935): the Counting Stroop (Bush, Whalen, Shin, & Rauch, 2006). On this task, in each trial, the subject is asked to respond by indicating how many stimuli appear on the screen. On some trials, the stimuli are numerical (they compete with the response the subject has to give, in this case, numbers 1, 2, or 3), and on other trials, the stimuli are non-numerical (they do not compete with the response the subject has to give, in this case, geometric figures: circles, squares, and triangles). A total of 16 trials were used in two conditions: eight trials for the conflict condition and eight trials for the non-conflict condition. The trials were presented in random order, so that the two conditions (conflict and non-conflict) were intermixed. In the conflict condition (numbers), the subject had to inhibit the information of what numbers appeared and press the key corresponding to the number of stimuli that appeared on the screen. All trials in the conflict condition (numbers) were incongruent, that is, in no trial the number of stimuli coincided with the number that appeared on the screen. The measure used for this study was the difference between the average time the child took to respond in the conflict condition minus the average time the child took to respond in the non-conflict condition. This interference measure was called inhibitory RT. Cronbach's alpha internal consistency index was 0.70 for the current study, indicating that it has acceptable reliability.

2.4.1.3. Planning errors. The Labyrinths subtest of the Labrev (Billard et al., 2000), carried out with digital support using the IPad as the device, was used to evaluate the planning ability. It consists of using one's finger to trace the route from the exit to a goal point, without touching or crossing the walls of the labyrinth. The variable used for this study was the number of errors made on the test. This measure had a Cronbach's alpha internal consistency index of 0.71 for the current study.

2.4.2. Cognitive functions

2.4.2.1. Verbal fluency. The Verbal Expression subtest of the ITPA (Illinois Test of Psycholinguistic Aptitudes, Kirk, McCarthy, & Kirk, 2004) evaluates the child's lexical expression and verbal fluency in relation to certain semantic fields. The task consists of eliciting as many words as possible from a specific semantic category within a time limit of 60 seconds. It has four different categories: words, body parts, animals, and fruits. We used the total number of correct words produced. This measure had a Cronbach's alpha internal consistency index of 0.80 in the validation of the test (Kirk et al., 2004).

2.4.2.2. Induced verbal fluency RT. The Speeded Naming subtest of the Nepsy-II (Korkman et al., 2007) evaluates semantic access speed and induced verbal fluency. On this test, the child should name, as quickly as possible, in the same order, and without making any mistakes, the color of the circles presented on a first sheet and the color, size, and shape presented on a second sheet. We used the total time the child takes to complete the task. This measure had a Cronbach's alpha internal consistency index of 0.85 in the validation of the test (Korkman et al., 2007).

2.4.2.3. Auditory sustained attention. The Auditory Attention subtest of the Nepsy-II (Korkman et al., 2007), previously described, was also used to evaluate auditory sustained attention. In this case, the dependent variable used was the number of hits (every time the child touched the red circle after s/he heard the word “red”). This measure had a test-retest reliability of 0.86 in the validation of the test (Korkman et al., 2007).

2.4.2.4. Visual sustained attention. The Visual Sustained Attention subscale of the Leiter- R (Roid & Miller, 2000) evaluates the individual’s ability to maintain his/her attention on a task consisting of marking or circling, in a limited time, the largest number of drawings equal to the target drawing or model visible at the top of the page. We used the number of correct answers obtained on the test. This measure had a Cronbach's alpha internal consistency index of 0.83 in the validation of the test (Roid & Miller, 2000).

2.4.2.5. Short-term verbal memory. The Auditory Sequential Memory subtest (Digits) of the ITPA (Illinois Test of Psycholinguistic Aptitudes, Kirk et al., 2004) is an auditory perception and short-term verbal memory test that evaluates the immediate recall of verbal material through the repetition of series ranging from two to eight digits. The task requires the child to repeat increasingly longer series of digits in the same order in which they were presented. We used the number of correct answers obtained on the test. This measure had a Cronbach's alpha internal consistency index of 0.85 in the validation of the test (Kirk et al., 2004).

2.4.2.6. Short-term visual memory. The Immediate Recognition subscale of the Leiter-R (Roid & Miller, 2000) evaluates the subject's short-term visual memory. The test consists of identifying present and absent objects after viewing a sheet of paper for five seconds. We used the number of correct answers obtained on the test. This measure had a Cronbach's alpha internal consistency index of 0.84 in the validation of the test (Roid & Miller, 2000).

2.4.3. Sensory Processing

The *Sensory Processing Measure (SPM*, Parham, Ecker, Miller Kuhaneck, Henry, & Glennon, 2007), based on the SIT (Ayres, 1979), is an integrated system of rating scales that assess sensory processing issues, praxis, and social participation in elementary school-aged children (ages 5-12). In our research, we used a Spanish translated version (unpublished) of the original SPM (Parham et al., 2007). Translations and back translations were carried out, and the equivalence of the translation was first reviewed by eight expert panel members (including four occupational therapists, three psychologists, and one speech therapist). The original SPM consists of three forms that evaluate the child's functioning in different environments. In this study, we specifically used the aforementioned translation of the original SPM-Main Classroom Form (Miller Kuhaneck et al., 2007) to evaluate the child's functioning in the classroom environment; it consists of 62 items and is completed by the child's primary school teacher. Each item is rated in terms of the frequency of the behavior on a 4-point Likert-type scale. The response options are: Never, Occasionally, Frequently, and Always. On the SPM, higher scores indicate greater dysfunction.

Of all the subscales included in the SPM-Main Classroom Form (Miller Kuhaneck et al., 2007), we used the Total Sensory Systems (TOT) and the Vision (VIS) and Hearing (HEA) subscales for this study. The TOT subscale is a total score obtained from five sensory modality subscales (vision, hearing, touch, body awareness, balance and motion, plus some additional items representing taste and smell processing), and it represents a general sensory processing dysfunction. Regarding the reliability of these subscales, Cronbach's alpha internal consistency indexes were 0.69 for the VIS subscale, 0.75 for the HEA subscale, and 0.91 for the TOT subscale in the validation studies carried out by Miller Kuhaneck et al. (2007).

3. Data analysis

Analyses were performed with the SPSS statistical package, version 19 for Windows. Multiple regression analyses were carried out in the ASD group to investigate whether sensory processing characteristics contributed significantly to the explained variance of the executive and cognitive measures (inhibitory errors, inhibitory RT, and planning errors, as executive measures; and verbal fluency, induced verbal fluency RT, auditory sustained attention, visual sustained attention, short-term verbal memory, and short-term visual memory, as cognitive measures). We selected the SPM TOT score as a sensory processing variable, and the ASD index severity of the ADOS as a control variable. These two variables were introduced as independent or predictor variables in order to determine the contribution of each one to the explained variance of the executive and cognitive measures.

In order to examine the sensory, executive and cognitive differences between the ASD group and the comparison group, ANCOVAs and MANOVAs were performed. First, three ANCOVAs were conducted to compare the Total Sensory Systems (TOT), the Vision (VIS) and the Hearing (HEA) scores of the two groups of children. For these analyses, the age of the teachers and the number of academic years that the teachers had been working as teachers of the students were introduced as co-variates because the evaluation of the sensory processing measures was carried out by the teachers. Second, two MANOVAs were conducted: one to compare the differences between the two groups of children in the measures of executive functioning (inhibitory errors, inhibitory RT, and planning errors); and another for the cognitive functioning measures (verbal fluency, induced verbal fluency RT, auditory sustained attention, visual sustained attention, short-term verbal memory, and short-term visual memory). In all these between-group comparison analyses, effect sizes were calculated using partial η^2 values, according to Cohen: η^2 < .06, small effect size; η^2 = .06 to .14, moderate; η^2 > .14, large. Previously, the identification of the possible outliers in the data was carried out by the boxplot method.

4. Results

4.1. Sensory processing as predictor of executive and cognitive functions in the ASD group.

The results obtained in the multiple regression analyses performed for the ASD group are presented in Table 1. Regarding the executive measures, the prediction models were statistically significant in all cases. The independent variables together predicted percentages of total variance that were 35% for inhibitory errors, 29% for inhibitory RT, and 19% for planning errors. Regarding the inhibitory errors and inhibitory RT, only the SPM TOT score contributed significantly to the explained variances. In the case of planning errors, only the ASD severity index contributed significantly to the explained variance.

-INSERT TABLE 1 ABOUT HERE-

With regard to the cognitive measures, the prediction models were statistically significant in the cases of verbal fluency, auditory sustained attention, short-term verbal memory, and short-term visual memory. The independent variables together predicted percentages of total variance that were 39% for short-term verbal memory, 33% for verbal fluency, 32% for short-term visual memory, and 24% for auditory sustained attention. For short-term verbal memory, both the SPM TOT score and the ASD severity index contributed significantly to the explained variance. For auditory sustained attention, only the SPM TOT score contributed significantly to the explained variance. Finally, for verbal fluency and short-term visual memory, only the ASD severity index contributed significantly to the explained variances.

4.2. Group differences in sensory processing, executive and cognitive functions

First, the results of the ANCOVAs carried out with the SPM TOT, VIS and HEA scores revealed statistically significant differences between the two groups, with the ASD group demonstrating more dysfunctional sensory processing than the comparison group, according to their teachers' perceptions. The results were: for the Total Sensory Systems subscale: ($F_{(1,76)} = 27.90$; $p < .001$; $\eta^2_p = .27$); ASD group: M = 67.93, SD = 13.80; Comparison group: M = 49.23, SD = 7.25); for the Hearing subscale: $F_{(1,76)} = 25.59$; $p < .001$; $\eta^2_p = .252$; ASD group: M = 12.13, SD = 3.48; Comparison group: M = 7.90, SD = 1.82; and for the Vision subscale: $F_{(1,76)} = 9.11$; $p = .003$; $\eta^2_p =$ .107; ASD group: M = 12.18, SD = 2.95; Comparison group: M = 9.70, SD = 2.47). The effect sizes were large for the Total Sensory Systems and the Hearing subscales, and moderate for the Vision subscale.

Second, the MANOVA performed with the scores obtained on the executive functions evaluated revealed statistically significant differences between the ASD group and the comparison group on all the measures used [Wilk's Lambda (λ) = .697; $F_{(3,76)}$ = 11.01; p = < .001; η^2_p = .303], with a large effect size. As Table 2 shows, in all cases, the children in the ASD group obtained scores indicating significantly lower task performance than the children in the comparison group, with effect sizes that were large for inhibitory RT, and moderate for planning errors and inhibitory errors.

-INSERT TABLE 2 ABOUT HERE-

Last, the MANOVA performed with the scores obtained on the cognitive functions evaluated also revealed statistically significant differences between the two groups on all the measures used [Wilk's Lambda (λ) = .404; $F_{(6,73)}$ = 17.96; p = < .001; η^2_p = .596], with a large effect size. As Table 2 shows, in all cases, the children in the ASD group obtained scores indicating significantly lower task performance than the children in the comparison group, with effect sizes that were large for verbal fluency, induced verbal fluency RT, auditory sustained attention, visual sustained attention, and short-term verbal memory, and moderate for short-term visual memory.

5. Discussion

The main objective of the present study was to investigate the relationship between sensory processing and some executive functions (inhibition and planning), as well as some cognitive functions (verbal fluency, sustained attention, and short-term memory), in a group of children with level 2 ASD severity in the school context. The children's sensory processing was evaluated based on their teachers' perceptions, and their executive and cognitive functioning were assessed using direct performance measures. Our hypothesis about the possible directionality of these relations is based on theoretical proposals of a hierarchical organization of sensory and higher-order cognitive processes (Ayres, 1979; Koziol et al., 2011; Lázaro & Berruezo, 2009; Williams & Shellenberger, 1994). Thus, based on the hypothesis that sensory processing influence certain cognitive and executive functions, we investigated whether sensory processing characteristics contributed significantly to the explained variance of the executive and cognitive measures evaluated, controlling the possible effect of ASD severity. Regarding the executive measures, the difficulties in sensory processing predicted, to a large degree, the difficulties on the inhibitory control task performance. Regarding the cognitive measures evaluated, the difficulties in sensory processing predicted, to a large degree, the difficulties on the auditory sustained attention and short-term verbal memory task performance.

In a previous study, a significant association between sensory and executive functions was obtained in preterm preschoolers with no clinical diagnosis (Adams et al., 2015). However, no significant relationship was obtained in the Boyd et al. study (2009), which was carried out in high functioning children with ASD and the executive functions were evaluated through report measures, unlike in our study, where the ASD children had level 2 severity and the executive functions were evaluated through direct performance measures. The results obtained in the present study, which are novel, lead us to hypothesize that sensory processing dysfunctions, which are common in ASD, would have an impact on inhibitory control, auditory sustained attention, and short-term verbal memory. Therefore, the executive abilities related to the inhibition of dominant responses, resistance to interference, and impulsivity control, as well as the cognitive skills related to the maintenance of auditory attention over time and the immediate recall of verbal information, might improve with a sensory-type intervention that addresses the sensory processing difficulties of children with ASD. However, future research will have to address this question.

The literature reports common difficulties in children with ASD in tasks where inhibitory control, auditory sustained attention, and short-term verbal memory are involved (e. g. Corbett & Constantine, 2006; Geurts et al., 2014; Lalani et al., 2018). In fact, in the present study we used a group of children with typical development as a comparison group. As expected, the ASD group showed higher levels of sensory, executive and cognitive dysfunctions than the comparison group.

First, regarding sensory processing, the largest effect sizes were obtained on total sensory processing (indicating a general sensory processing dysfunction in the ASD group) and, specifically, auditory processing. This result is consistent with previous studies (Ashburner, Ziviani, & Rodger, 2008; Fernández-Andrés, Pastor-Cerezuela, Sanz-Cervera, & Tárraga-Mínguez, 2015; Wiggins, Robins, Bakeman, & Adamson, 2009), and reinforces the idea that auditory processing is usually one of the most affected sensory modalities in the ASD population (Ocak, Eshraghi, Danesh, Mittal, & Eshraghi, 2018; O'Connor, 2012). Second, the results obtained for the executive functioning measures –related to inhibition and planning-, were consistent with previous studies (Berenguer et al., 2018; Corbett et al., 2009; Demetriou et al., 2018; Dubbelink & Geurts, 2017; Geurts et al., 2014; Robinson et al., 2009), and they seem to confirm the executive dysfunction attributed to ASD (Hill, 2004; Ozonoff, 1997). Last, the results obtained for the higher-order cognitive measures –related to verbal fluency, sustained attention, and short-term memory- were also consistent with previous studies (Begeer et al., 2014; Chien et al., 2014, 2015; Corbett & Constantine, 2006; Jaworski & Eigsti, 2017; Lalani et al., 2018; Pastor-Cerezuela et al., 2016). The largest effect sizes (with values of η^2_p above 0.3) were obtained on the auditory sustained attention, short-term verbal memory, and verbal fluency measures, whereas the smallest effect size was found on the short-term visual memory measure. These results would be consistent with limitations on auditory and verbal tasks frequently documented in people with ASD (Lin, Shirama, Kato & Kashino, 2017). In the case of the school context, the limitations and deficits on auditory tasks –especially on verbal tasks- could be exacerbated by the inherent characteristics of this context, where there is usually an overload of auditory and verbal stimulation that could interfere with the performance on these types of tasks in people with special sensitivity.

Conclusions

Sensory processing dysfunctions seem to be related to executive and cognitive dysfunctions in children with ASD. Specifically in this study, which was carried out in the school context, the sensory processing difficulties of a group of children with level 2 ASD severity predicted executive and cognitive dysfunctions in the specific domains of inhibitory control, auditory sustained attention, and short-term verbal memory. Future studies will have to investigate whether an adequate sensory intervention in children with ASD in the school context could contribute to improving these executive and cognitive functions. In particular, the school context can be an ideal context for launching intervention programs based on sensory integration therapy (Beaudry, 2011), a child-centered intervention that uses playful and goal-directed activities that provide a sensory motor challenge. Although the results from some studies on the efficacy of this therapy are inconclusive (Schaaf, Dumont, Arbesman & May-Benson, 2018; Weitlauf, Sathe, McPheeters &Warren, 2017), a recent systematic review concludes that it can be considered as an evidence-based practice for children with autism ages 4-12 years old

(Schoen et al., 2019). In any case, it seems essential to make an early diagnosis and that a multi-disciplinary team coordinates the intervention.

Limitations

Our study has some limitations. First, the specific characteristics of the group of children with ASD in our sample limit the reach of the results to only children with these characteristics (ASD level 2, between 5 and 8 years old). Thus, the sample used in the present study was limited and not selected by randomized procedures, given the educational context where the data were collected. Moreover, the autism spectrum was not completely represented because there were no children in the sample with levels 1 or 3. Second, this study did not have a comparison group with a different psychological disorder, and so we cannot conclude that the differences found compared to the comparison group were only attributable to the condition of autism. Third, no information about children's sensory processing characteristics was obtained from the families, which could have been useful to triangulate the data and analyze the possible differences between the perceptions of the teachers and the family. It would also be interesting to analyze the possible differences obtained in the different contexts where the participants are enrolled, such as mainstream schools, TEACCH classrooms, or special education centers. In this way, we could compare possible differences among students with ASD depending on the different schooling modalities in an inclusive context. Finally, because the study is cross-sectional, the variables were not studied over time, and so it would also be interesting to complete the study with longitudinal research.

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Table 1.

Multiple regression analyses of overall sensory processing and autism severity predicting executive and cognitive functions in the ASD group

Variables	*B*	*SE*	*β*	*p*
Inhibitory errors				
$F_{(2,37)} = 9.98^{**}; R^2 = .35$				
Autism severity	-0.41	0.90	-.06	.650
Total sensory systems	0.21	0.04	.60	.001
Inhibitory RT				
$F_{(2,37)} = 7.46^{**}; R^2 = .29$				
Autism severity	184.78	169.09	.15	.282
Total sensory systems	29.48	8.94	.47	.002
Planning errors				
$F_{(2,37)} = 4.40^{*}; R^2 = .19$				
Autism severity	4.94	1.74	.43	.007
Total sensory systems	0.01	0.09	.01	.917
Verbal fluency				
$F_{(2,37)} = 9.15^{**}; R^2 = .33$				
Autism severity	-8.89	2.09	-.59	.001
Total sensory systems	0.07	0.11	.09	.516
Induced verbal fluency RT				
$F_{(2,37)} = 2.83; R^2 = .13$				
Autism severity	23.06	26.86	.13	.396
Total sensory systems	2.73	1.42	.30	.062
Auditory sustained attention				
$F_{(2,37)} = 5.92^{**}; R^2 = .24$				
Autism severity	-4.18	2.25	-.27	.071
Total sensory systems	-0.27	0.11	-.34	.026
Visual sustained attention				
$F_{(2,37)} = 1.41; R^2 = .07$				
Autism severity	-4.10	2.99	-.22	.179
Total sensory systems	-0.09	0.15	-.09	.562
Short-term verbal memory				
$F_{(2,37)} = 11.95^{**}; R^2 = .39$				
Autism severity	-1.12	0.43	-.34	.014
Total sensory systems	-0.07	0.02	-.44	.002
Short-term visual memory				
$F_{(2,37)} = 8.81^{**}; R^2 = .32$				
Autism severity	-2.98	0.72	-.57	.001
Total sensory systems	0.01	0.03	.05	.724

$^{*}p<.05$; $^{**}p<.01$

Table 2.

Means, Standard Deviations, and F-values for executive and cognitive functions

	ASD group (n = 40)		Comparison group (n= 40)			
	M	***SD***	***M***	***SD***	F**(1,78)**	η^2p
Executive functions						
Inhibitory errors	2.08	4.81	0.18	0.71	6.09*	.072
Inhibitory RT	5.05	0.85	3.47	2.12	19.24**	.198
Planning errors	9.75	8.31	4.83	3.34	12.07**	.134
Cognitive functions						
Verbal fluency	22.48	10.96	36.78	9.71	38.11**	.328
Induced verbal fluency RT	275.13	123.74	178.33	80.74	17.17**	.180
Auditory sustained attention	11.98	11.10	27.88	2.31	78.60**	.502
Visual sustained attention	47.85	13.31	62.90	14.87	22.74**	.226
Short-term verbal memory	6.03	2.39	9.80	2.81	41.84**	.349
Short-term visual memory	13.23	3.76	15.25	4.06	5.34*	.064

*p<.05; **p<.01