# Linguistic experience as a behavioral and social factor in children with Autism Spectrum Disorder

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**Summary**
Current studies reveal the structural and functional conditions of the brain with atypical development during language processing in childhood, and specifically, in this study, in autism spectrum disorder (ASD). Language acquisition, or linguistic experience, is a process that involves emotion and cognition, and is therefore intrinsically related to brain plasticity in childhood. The objective of this review is to provide an overview of the neuroscientific relationship between linguistic experience, childhood and ASD in three moments: language acquisition and age, language acquisition and environmental demand, and language acquisition and brain structure. Also, other complementary studies (brain plasticity and myelination, for example) were necessary to understand these relationships. The studies reviewed include human and animal methods that reveal the language profiles in ASD as variable and atypical, and that language form is relatively spared while receptive and pragmatic language skills show the most significant deficits, as well as communication nonverbal. Linguistic experience acts as a determining factor in the social and communicative behaviors of children with autism spectrum disorder.

## 1 Introduction

Current research on the structural and functional development of the human brain throughout childhood highlights the rapid evolution of brain structures and their interconnectivity (Hernandez *et al.*, 2024; Bosseler *et al.*, 2024; Velde, White, & Kemner, 2021). Some regional functional specializations emerge within the first month after birth, while others have a more protracted course of development that extends over the first decade or more (Petrican, Taylor, & Grady, 2017; Longo *et al.*, 2017; Haartsen, John & Johnson, 2016).

Experience-related neural profile changes can result from many aspects of environmental input, cognitive demand, or behavior (Bialystok & Barac, 2013; Meltzoff & Marshall, 2018; Weiss-Croft & Baldeweg, 2015). The intensity and frequency of language use, or linguistic experience, can be particularly powerful in bringing about such changes in the brain and is related to the environment, cognition and behavior (**Figure 01**).

However, in atypical development, differences in brain structure and function arise, and linguistic experience in childhood often precedes the emergence of later diagnostic behavioral symptoms (Min Li *et al.*, 2024; Haartsen *et al.* , 2016). For example, neuroimaging studies attribute the language impairment of autism spectrum disorder (ASD) to damage to the brain's language network, which supports the idea that communication dysfunction results from this direct language network interference in brain structure (Li *et al.*, 2022; Yoo *et al.*, 2024; Park *et al.*, 2024; Li *et al.*, 2024; Traut *et al.*, 2022) (**Figure 01**).

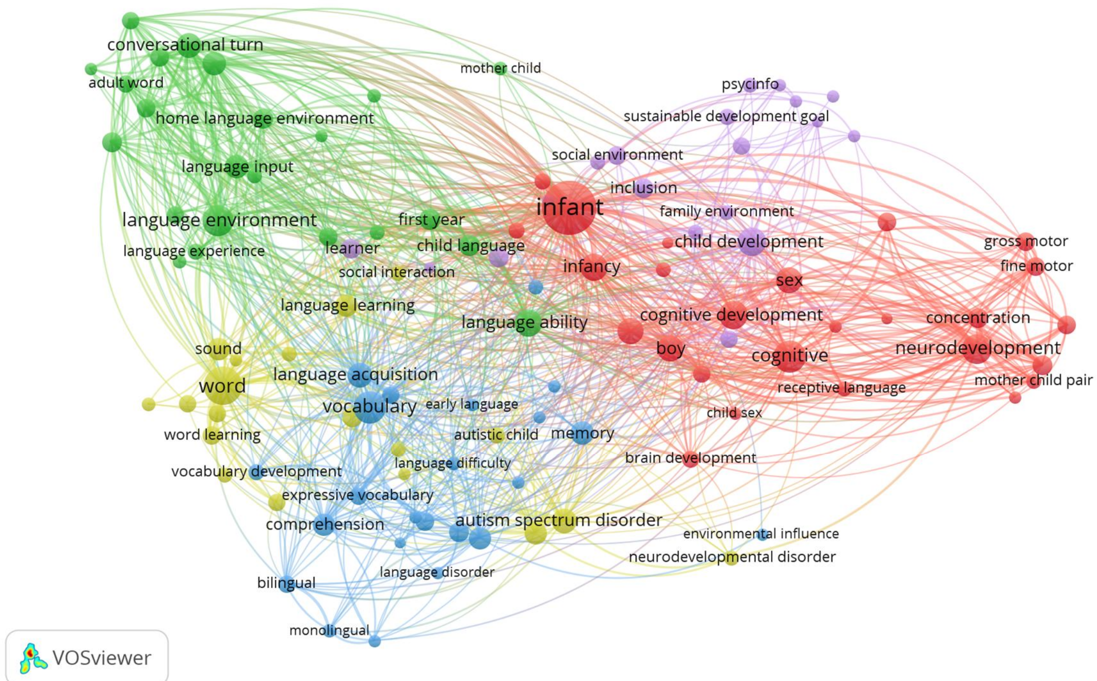


**Figure 01**. This interactive network connects the influences that childhood suffers, from a linguistic perspective, during the period of language acquisition in various cognitive, neurological, behavioral and social domains. The central node, labeled "infant", is divided into five interrelated groups that represent different moments and different means of this process (characterized by colors). This network compresses data from articles published on the PubMed platform between 2020 and 2024. Approximately 610 articles were selected in this period, and the frequency necessary for the term to appear is its accelerated occurrence in the literature (approximately 175 times). Initially, this model highlights the fundamental role of the childhood period for language acquisition. During this period, specifically in the first year of life, the child is influenced by the environment in which he or she finds himself (adults, parents, home...). The linguistic environment promotes the language input process and, consequently, develops innate linguistic skills. Furthermore, childhood is related to several linguistic spheres in this process. Language acquisition involves learning vocabulary, comprehension and expression, for example. In this study, childhood establishes an intrinsic relationship with ASD, and from this some specific processes arise, such as child inclusion and development in the social environment and linguistic neurodevelopment from a perspective of atypical development (learning words, sounds, meanings, interaction in the disorder).

In this specialization, the myelination of axons, which increases the speed of signal transmission between neurons and progresses at an accelerated pace early in life, may play an important role in this language-experience-plasticity-childhood relationship, and also serves as a characteristic of the atypical development (de Faria *et al.*, 2021; Steadman *et al.*, 2020). The processing and production of language and non-verbal communication are complex processes that in children require the rapid transfer of information between neurons located in different regions of the brain, involving, for example, motor skills, phonological processing, auditory processing and syntactic processing (Corrigan *et al.*, 2022).

In this review, we systematize current data on the neuroscientific relationship between linguistic experience, childhood and ASD in three moments: i. acquisition of language and age; language acquisition and environmental demand and iii. language acquisition and brain structure.

## 2 Methods

The **Table 01** contains articles in the *Research Article* category that highlight the relationship between childhood, language and ASD. Other co-studies were incorporated into the results and discussions, related to i. linguistic spheres and specialized brain areas and ii. axonal myelination and language, both described in tables, which may or may not be related to ASD or childhood, but which are important for understanding brain plasticity based on linguistic experience.

**Table 01.** Basic characteristics of included studies.

| Study | Investigation | Methods | Participants and age |
|---|---|---|---|
| Lombardo *et al.*, 2015 | Response of neural systems to speech in the first years of life | Functional neuroimaging biomarkers | Children aged 12 to 48 months with ASD (n = 60), individuals with language delay (n = 19) without ASD and individuals with typical development (n = 24). |
| Blasi *et al.*, 2015 | Cortical sensitivity to auditory stimuli in infants | Functional magnetic resonance imaging | Babies (aged between 4 and 7 months), high familial risk for ASD (n=15); babies without a family history of ASD (N = 18) |
| Solso *et al.*, 2016 | Connectivity between cerebral atypicality in ASD and social deficits | Diffusion tensor imaging | 94 children with ASD and TD aged 1 to 4 years |
| Karamanoglu *et al.*, 2018 | White matter atypicalities | Diffusion weighted magnetic resonance imaging | 38 participants with high-functioning ASD and 35 with TD, aged between 8 and 25 years |
| Linke *et al.*, 2018 | Relationships between atypical sound processing, social skills and atypical | MRI | Children with ASD (n=40) and typically developing control participants (n=38) between 8–17 years |

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| | interhemispheric auditory and thalamocortical functional connectivity | | |
| Denisova, 2019 | Vocal learning, language acquisition and environment | Functional magnetic resonance imaging | 52 babies aged 9 to 10 months |
| Cárdenas-de-la-Parra *et al.*, 2021 | Differences in brain growth and volume and brain-behavior associations | Based morphometrics in tensor longitudinal | Individuals between 6 and 24 months of age (3 groups= i. with high familial risk for ASD diagnosis at 24 months, ii. high-risk infants who do not receive a diagnosis at 24 months, and iii. controls with typical development. |
| Godel *et al.*, 2021 | Changes in the contrast of gray and white matter | Contrast Regional Structural MRI Index | Babies between 12 and 24 months (n = 20) (ASD, n = 9; TD, n = 8; AT, n = 3) and subsequent testing at 3 years of age. |
| Leno *et al.*, 2021 | Cognitive Data Statistics to Assess Nonverbal/Verbal Cognitive Developmental Trajectories | Longitudinal dataset | 196 babies aged 12 to 36 months. |
| Dolatta, 2022 | Pragmatic language markers of ASD diagnosis and severity | Children's communication Checklist (CCC-2) and Social Responsivene ss Scale | 174 children aged 7 to 17 years (101 with ASD, 45 with ADHD, 28 with TD) |
| Reindal *et al.*, 2022 | Co-occurrence of motor and language impairments | Tests: engine (MABC-2); current motor skills (DCDQ'07); language (CCC-2); and social (SRS) | 20 children and adolescents of 6 to 17 years (15 with ASD) |
| Miranda *et al.*, 2023 | Childhood language skills as predictors of | Children's communication | 45 children with ASD aged 7 to 11 |

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|---|---|---|---|
| | social, adaptive, and behavioral outcomes in adolescence | Checklist (CCC-2) | |
| Lau, Losh and Spreight, 2023 | Speech articulatory time and associations with pragmatic language capacity in ASD | Speechmark Analysis ASD | ASD group = 55 individuals with ASD; TD group = 39 individuals with TD, without a family history of ASD; Group of parents with ASD = 96 parents of individuals with ASD; Control parent group= 48 control parents with no family history of ASD |
| Reindal *et al.*, 2023 | Structural and pragmatic language impairments in children with ASD | Children's communication Checklist (CCC-2) | 177 children with a mean age at inclusion of 12.3 years |
| Marquez-Garcia, 2023 | Atypical associations between functional connectivity in pragmatic and semantic language processing and cognitive abilities | Structural, functional and anatomical magnetic resonance imaging (MRI) | ASD group = 16 children aged between 7.2 and 12 years (3 girls, 13 boys). Control group = 19 children who did not have ASD or other neurodevelopmental disorders (6 girls, 13 boys) from 7 to 12 years |
| Li *et al.*, 2024 | Altered white matter connectivity of ventral language networks | MRI | Children with ASD (age range: 6–16 years) at Osaka University Hospital (48 with ASD; 45 with TD) and Fukui University Hospital in Japan (35 with ASD; 38 with TD) |
| Berenguer *et al.*, 2024 | Sleep quality and language impairment in children with ASD | The Sleep Disturbance Scale for Children (SDSC); The Children's Communication Checklist; The Clinical Evaluation of Language Function, 5th edition observation rating scale [CELF-5 ORS | 47 children with ASD without intellectual disability (ID) and 32 children with TD between 8 and 12 years old |
| Saban- | Age is associated with | Social | Young group (n = 35) aged between 34 |

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|---|---|---|---|
| Bezalel *et al.*, 2024 | better outcomes in ASD severity, language and adaptive skills after one year of school in special education classes for autistic people | Responsiveness Scale; Vineland Adaptive Behavior Scale; The Goralnik screening test for Hebrew | and 59 months and an old group (n = 38) aged between 60 and 91 months |

Abbreviations= ASD (Autism Spectrum Disorder); TD (Typical Development); AD (Atypical development); ADHD (Attention deficit hyperactivity disorder).

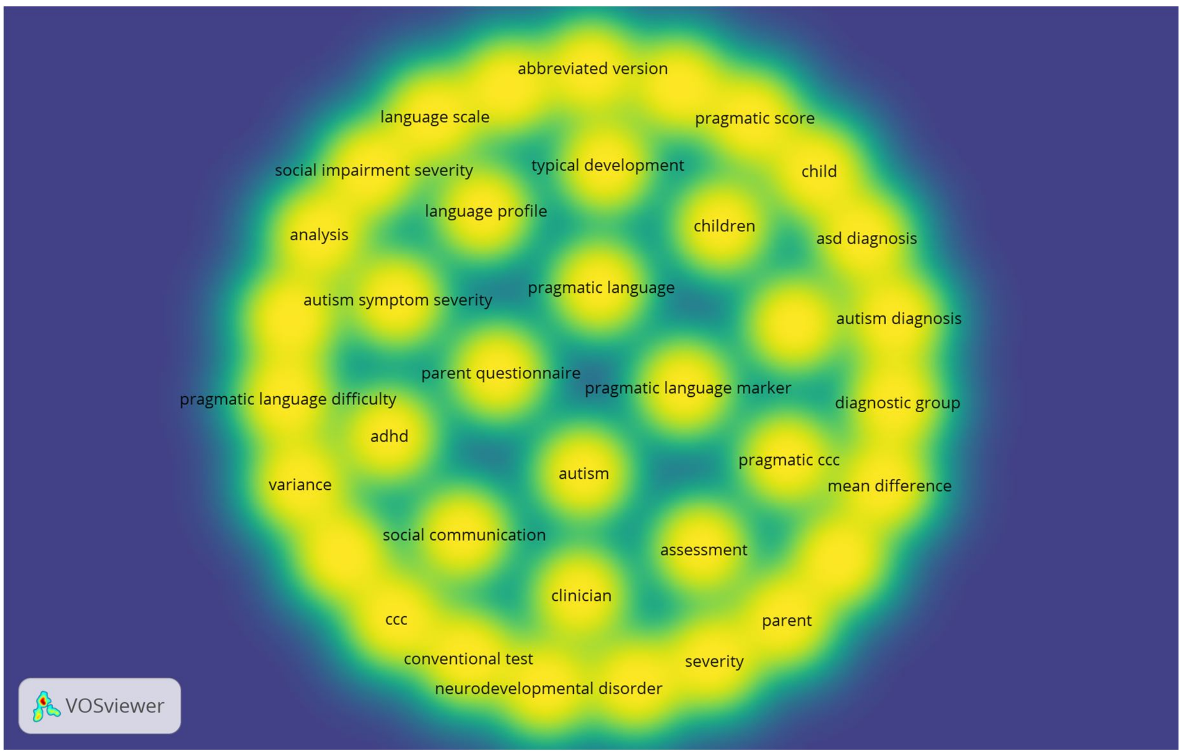


**Figure 02**. The 18 articles selected to compose the table show a strong relationship between pragmatic language, social communication and atypical neurodevelopment for ASD.

**3 Results**

Language covers different fields essential for human communication (phonological, lexical, semantic, syntactic, pragmatic processing and working memory/executive functions) and involves specialized areas of the brain (**Table 02**). It is known that several cognitive domains in children with ASD are associated with consciousness, decreased communication subdomains, restricted interests, repetitive behavior, and adaptive motor skills (Saban-Bezalel *et al.*, 2024).

**Table 02**. Brain regions involved in linguistic processing.

| Study | Linguistic sphere | Language processing in the brain region |
|---|---|---|
| Romeu *et al.*, (2018,a)<br>Romeu *et al.*, 2018, b) | Adult-child conversation | Left lower frontal regions (a)<br>White matter in the left arcuate and superior longitudinal fascicles (b) |
| Nguyen *et al.*, 2024 | Bilingual study with children | Organization and reorganization of neural regions responsible for sensorimotor learning and coordination, such as the basal ganglia; expansion of subcortical networks |
| Wilcox *et al.*, 2022 | Reading | Inferior frontal/precentral gyri, superior temporal gyrus/sulcus, temporoparietal cortex, and occipitotemporal cortex |
| Matchin *et al.* 2020 | Syntax | Bilateral anterior insula, medial frontal gyrus, and bilateral angular gyrus |

From a neurodevelopmental perspective, studies reveal that language profiles in ASD are variable and atypical, with frequent delays in the beginning of speech, but also, in some cases, abnormally accentuated growth in structural language skills (Kissine *et al.*, 2024) . Bilingual study with children In previous studies on speech and language in ASD, results in the domains of speech and language show heterogeneity (Traivick *et al.*, 2024). Language form (syntax, morphology, phonology) is relatively spared, while receptive language skills and pragmatics (social use of language) show the most significant deficits, as does nonverbal communication (e.g., gestures, gaze, communicative intention) (Chen *et al.*, 2023).

**3.1 Myelin plasticity and neurolinguistic aspects in ASD**

The myelin sheath, an axon envelope, is made up of glial cells of the central nervous system called oligodendrocytes. The myelin sheath plays a critical role in the stability of neural electrical function, enabling the transmission of neuronal information, promoting rapid saltatory conduction of action potentials, and providing neurons with structural and metabolic support, and this process is fundamental to the performance of neural processes. emotional and cognitive neurological disorders (Khelfaoui *et al.*, 2024) (**Figure 03**).

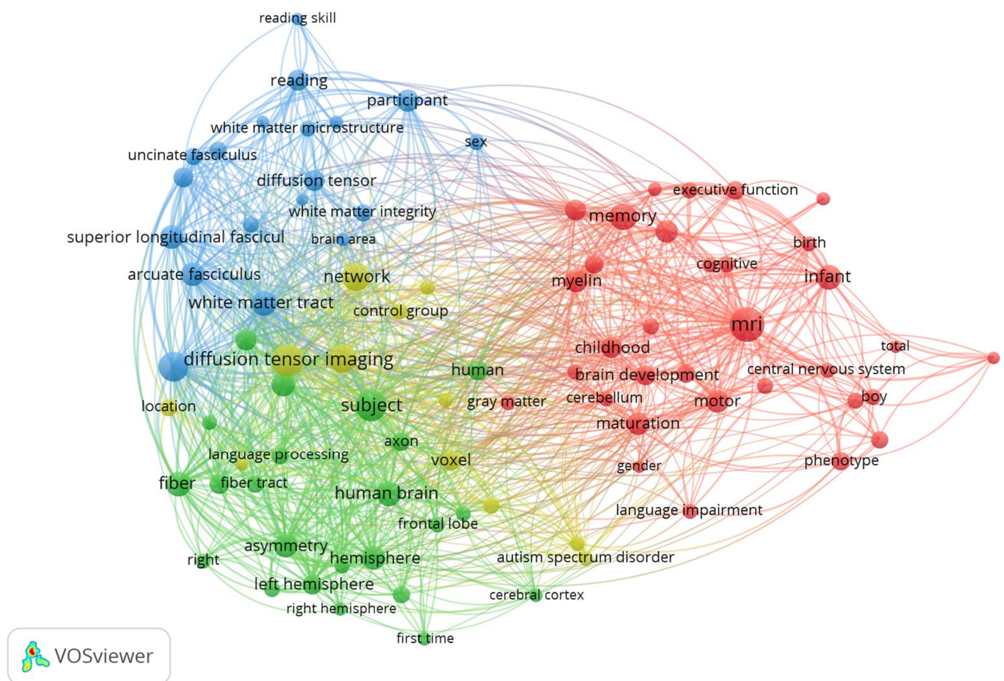


**Figure 03**. In this connection established between terms, we investigate the strong relationships between myelination in specific brain areas in language development and relate them to ASD. This network compresses data from articles published in the PubMed database between the years 2020 and 2024, based on the keywords *autism* and *myelination*, totaling around 147 articles with a keyword frequency of approximately 175 times in the literature. The large "mri" node represents one of the most used methods to infer changes in brain structures. In the present context, MRI studies highlight an early relationship between childhood and linguistic development from a neurolinguistic perspective. In the early years of life, there is rapid maturation in cognitive, executive, motor, memory and attention functions. This involves specific areas of the brain that process language, such as: left hemisphere, cerebellum, white matter, cerebral cortex, frontal lobe, uncinate fasciculus, superior longitudinal fasciculus, and arcuate fasciculus. Furthermore, this brain development that promotes cognition is a result of the myelination process of axons. In ASD, this entire process involves an impairment of language in the previously mentioned functions and specifically in the structure of white matter. This impairment interferes with brain morphometry, neural networks and functional connectivity, and this asymmetry becomes prominent in the atypical characteristics of ASD.

In this, neuroplasticity consists of increasing myelination and axon diameter during the efficiency of transmission of action potentials (Sampaio-Baptista and Johansen-Berg, 2017). This supports learning and memory, and depends on several processes to alter the structure and function of neuronal activity (Magee, 2020) (**Figure 03**). Myelination of appropriate brain regions is associated with the development of specific cognitive functions, such as reading and decision-making, and several studies demonstrate the involvement of myelin in cognition, learning, skill development, memory and language (Zhang *et al.*, 2024 ) (**Table 03**).

**Table 03.** Studies on brain myelination in rat models with autism spectrum disorder.

| Study | Mouse model | Search Scenario | Insights |
|---|---|---|---|
| Makinodan *et al.*, 2018 | BTBR Mice C57BL/6J mice | Housing BTBR with C57BL/6J after weaning to adulthood increased myelin thickness in the mPFC, but not in the motor cortex, of BTBR mice | Socialization promotes myelination |
| van Tilborg *et al.*, 2018 | Wistar Rats - Envigo, Horst, Netherlands | Combined fetal inflammation and postnatal hypoxia cause myelination deficits in diffuse-induced white matter lesion; Impaired motor performance, increased anxiety, reduced social play behavior, and increased repetitive cleaning | Diffuse white matter injury may be related to adverse neurodevelopmental outcomes |
| Khanbabaei *et al.*, 2019 | BTBR mice | Fiber tracts in the frontal brain increased in volume on postnatal day 06; Myelination in the frontal brain of male and female newborn mice was increased, associated with elevated levels of the basic protein myelin; The myelin pattern was not altered in adult BTBR mice | Early myelination serves as a model to investigate atypical development in ASD |
| Yongxiang *et al.*, 2024 | C57BL/6N mice | Somatic sensory deprivation in newborn C57BL/6N mice; Whiskers trimmed on both sides of the muzzle daily | Sensory deprivation of whiskers from birth impairs myelination, reduces the number of oligodendrocytes, and deficits in social novelty |
| Zhu *et al.*, 2024 | Tdrd3-null mice Top3b-null mice | TOP3B mutations in humans are associated with cognitive disorders; Top3b-null mice exhibit phenotypes seen in psychiatric and cognitive disorders, including behaviors and synaptic plasticity. | Tdrd3-null mice exhibit some neurological and behavioral problems similar to Top3b-null mice; Behavioral phenotypes include memory deficits and reduced anxiety; Neurological defects are seen in synaptic plasticity, adult neurogenesis, and |

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| | | | myelination. |
| Zhang *et al.*, 2024 | Dawley Sprague Rats | Prenatal neurodevelopmental toxicity; The impact of exposure to nanoplastics on the cell responsible for myelin synthesis in the oligodendrocytes of the cerebellum of offspring. | PNs accumulated mainly in the brain regions of medium to late development (cerebellum, hippocampus, striatum, and prefrontal cortex). Nanoplastics cause oligodendrocyte apoptosis and impaired motor coordination in offspring; NPs transferred to the offspring through the placenta and breastfeeding. |
| Gilbert *et al.*, 2020 (a)<br><br>O'Connor *et al.*, 2024 (b) | Mice Nexmif KO<br><br>Nexmif Female Mice | Communication behavior in Nexmif (a)<br><br>Mice from ultrasonic vocalizations (b) | Reduction in dendritic complexity, spine and synapse density related to complete loss of X-linked gene associated with Nexmif (a)<br><br>Nexmif ± females showed moderate communication deficits compared to males, who had a drastic reduction in vocalization (b) |

In this sense, there is evidence that children with ASD showed generalized reductions in cortical myelination and greater myelination deficits were associated with more severe autistic symptoms (Zhang *et al.*, 2024). MRI demonstrates that, in children with ASD, there are widespread reductions in cortical myelination within specific brain regions (inferior frontal gyrus, bilateral insula, left fusiform gyrus, bilateral hippocampus, right calcarine sulcus, bilateral precentral gyrus, and left posterior cingulate gyrus). ) and reduced myelination in regions with greater gray matter volume (left insula, left side of the cerebellum, left posterior cingulate gyrus, and right calcarine sulcus) (Zhang *et al.*, 2024).

**3.2 Language acquisition and age**

Different language trajectories emerge in ASD subgroups in the first 4 years of life (Lombardo *et al.*, 2015). Between 7 and 11 months of life, babies are developing the brain architecture essential for language through cognitive skills, and these structural changes continue until the second year of life (Neva *et al.*, 2022). Between 12 and 24 months, cortical regions involved in social processing and language acquisition may experience early onset of ASD symptoms (before 18 months) (Godel *et al.*, 2021). At 30 months, magnetic resonance images show the relationship between myelin concentration in the white matter tracts most associated with language, and regions of the right hemisphere also undergo language development in these children exposed to greater amounts of adult input at home. (Fibla *et al.*, 2024).

In older children with ASD (8 and 12 years old), there is difficulty in effectively using language for acts of communication (Berenguer *et al.*, 2024), and grammatical and phonetic characteristics should be the basis for the early diagnosis of this atypicality (Saban -Bezalel *et al.*, 2024). Although the structure and semantics of language do not appear as specific characteristics of the disorder, they appear as symptoms concomitant with difficulty in social interactions and, therefore, difficulty in pragmatic skills (Berenguer *et al.*, 2024).

Structural and pragmatic language in 45 children with ASD was assessed at ages 7 to 11 (Miranda *et al.*, 2023). Analysis of the relationship between structural and pragmatic language showed that pragmatic language significantly predicted stereotypical language and context use, and structural language - semantics in particular - accounted for only a significant proportion of the variance in prosocial behavior and in socialization skills (Miranda *et al.*, 2023). In the same sense, Dolatta (2022) evaluated that, among children aged 7 to 17 years (101 with ASD, 45 with ADHD, 28 with TD), the severity of social behavior was associated with pragmatic, but not structural, language profiles. Thus, from the perspective of linguistic use, pragmatic language ability in ASD is related to social cognition (Lau, Losh & Speights, 2023).

### 3.3 Language acquisition and environmental demands

Continued exposure to spoken language in a wide variety of contexts makes its acquisition appear spontaneous and effortless (Perez-Navarro *et al.*, 2024). Prenatal experience with speech already begins to shape perception and learning abilities, and the newborn's brain already shows specialization for this process, resembling that of the adult brain (Gervain *et al.*, the linguistic experience of Speech perception allows the child to become a native listener and speaker, and this causes the neural correlates of speech and language processing to become increasingly specialized (Gervain *et al.*, 2015).

Usai *et al.* (2020) investigated that 78% of the variance in vocabulary in children between 2 and 3 years old is related to social orientation, motor activity and attention, and that inhibitory control interacts significantly with vocabulary.

Denisova (2019) found that infants at high genetic risk for ASD have atypical sensitivity to language input, and that atypical sensorimotor signatures during language perception in a still-developing central nervous system have adverse consequences on concurrent linguistic competence, linguistic competence receptiveness and communication competence in childhood.

Furthermore, parental language input, child speech output, and parent-child conversational turns correlated with preliteracy skills, as well as estimates of myelin density within the left superior arcuate and longitudinal fasciculus (Weiss *et al.* al., 2022). From an environmental perspective, conversations between parents and children help in the myelination process of the white matter (left arcuate fasciculus, superior longitudinal fasciculus) at 2 years of age, and suggest that early interactive experiences with language contribute exclusively to the development of the substance white associated with long-term language and expressive language ability (Huber *et al.*, 2023).

### 3.4 Language acquisition and brain structure and function

Atypical development gains prominence in some atypical characteristics related to language in ASD. First, the ASD brain showed unbalanced and overall lower structure-function coupling in polysynaptic regions and transmodal regions (Park *et al.*, 2024). Li *et al.*, (2022) investigated a reduction of white matter in all language-associated tracts in individuals with ASD compared to TD controls. Furthermore, structural disorders of language networks exhibit a left bias, and more prominent atypical features are observed in younger people with ASD than in adults (Li *et al.*, 2022).

These data corroborate the studies by Yoo *et al.* (2024), who determined changes in the asymmetry of the inter-hemispheric structural connectome in default mode sensory regions with more emphasis on the left hemisphere, and this atypical characteristic is related to non-verbal communication and intelligence. In this sense, the inferior temporal cortex and limbic and frontoparietal regions showed reduced efficiency in global network communication, sending and receiving networks in the inferior temporal and lateral visual cortices in individuals with ASD (Yoo *et al.*, 2024).

Furthermore, there is axonal hyperconnectivity in frontal lobes and abnormal age-related changes with greater fractional anisotropy (Solso *et al.*, 2016; Karamanoglu *et al.*, 2018). Frontal fiber tracts showed deviant early development and age-related changes that may underlie impaired brain functioning and impact social and social behaviors of communication in ASD (Solso *et al.*, 2016). In this sense, most of the affected tracts – cingulate bundle and inferior longitudinal fascicles – are regions associated with cognitive, social and emotional functions (Karamanoglu *et al.*, 2018).

Additionally, some studies describe the emotional function of language in the ASD brain. Linguistic deficit is related to linguistic atypicalities in the brain, and emotional words normally activate cortical motor systems involved in the expression of emotional actions, such as facial expressions (Lombardo *et al.*, 2015). In the study by Blasi *et al.* (2015), babies with no history of ASD showed i. early specialization for human voice processing in the right temporal and medial frontal regions, ii. stronger sensitivity than HR infants to sad vocalizations in the right fusiform gyrus and left hippocampus and iii. association between the degree of engagement of each baby during social interaction and the degree of voice sensitivity in important cortical regions, while babies with a history of ASD do not.

Also, motor and language development in early childhood is influenced by cortico-cerebellar circuits (connectivity within the cerebellum and with the prefrontal cortex), the migration of cerebellar granule cells and the structuring of mossy fiber circuits (D'Mello & Stoodley, 2015). There are differences in brain maturation in individuals with ASD compared to TD (Godel *et al.*, 2021).

## 4 Conclusion

Taking this set of data, linguistic experience acts as a determining factor in the social and communicative behaviors of children with autism spectrum disorder. These dimensions of social cognition are mainly associated with the pragmatic sphere of language. But, before that, there is an influence of linguistic experiences that cause the cognitive and emotional development of the child with ASD, which permeates the other linguistic dimensions (structure, semantics, syntax). This shows that the main issue surrounding the neuroscience of language today is the use of language in a social communicative context. In this sense, social communication is of interest to clinical research (use of different clinical methods to measure the scale and linguistic profile of children with ASD, for example: form tests, conventional tests, group diagnosis, etc.). Social communication, or linguistic use, or pragmatics, is related to other linguistic spheres acquired during linguistic experience, or language acquisition in childhood and the environment through brain functions and structures.

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