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Too Close to Focus? Neural Evidence of Altered Auditory Spatial Attention in Autism

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Abstract

Background: Children with Autism Spectrum Disorder (ASD) often display unusual auditory processing. However, intensity-based auditory spatial attention has been less studied in children with autism. Since attention to the source of sound is crucial for communication and learning in these children, it is necessary to investigate this aspect of auditory attention in this population.

Methods: Event-related potentials (ERP) data were recorded from 12 high-functioning boys with ASD and 15 age-matched typically developing (TD) boys (ages 7–12) while passively listening to short Romanian sentences presented at three simulated distances (0.5 m, 1 m, 2 m). Stimuli were normalized and their intensity (65, 59, and 53 dB SPL) was adjusted to simulate depth. The P300 component of ERPs was extracted and analyzed for amplitude and latency using Python and SPSS. Statistical analyses included MANOVA and follow-up ANOVAs.

Results: No significant multivariate effects of group were observed at any distance. However, in univariate between-group analyses at 0.5 m, the ASD group showed significantly shorter P300 latencies compared to the TD group ($p = 0.046$, partial $\eta^2 = 0.150$). The differences at 1 m and 2 m were not statistically significant.

Conclusions: Children with ASD exhibited altered neural responses to nearby speech stimuli, indicating atypical auditory spatial processing and potentially increased cognitive demands during close-distance speech perception. These results align with theories of social attention and impaired sensory processing in autism.

Key Words: Auditory Spatial Attention; Auditory Distance Processing; Autism; ERP; P300.

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1- INTRODUCTION

Autism Spectrum Disorder (ASD) is a neurodevelopmental disorder characterized by severe deficits in social communication and language, repetitive and restricted interests, and atypical sensory processing (1, 2). Among sensory processing, auditory processing, particularly the brain's ability to locate the source of sounds and speech in space, called social orientation, can play a critical role in how individuals with ASD communicate and interact socially with their environment (3,4,5). Deficits in social orientation can lead to serious deficits in the learning and social development of children with ASD (6,7). However, auditory spatial attention, especially for speech stimuli, has not yet been sufficiently investigated in autism.

Auditory spatial attention is essential for processing social information. It is a unique ability of the brain that allows humans to focus on a specific sound source in their environment (8). The auditory spatial environment is divided into three planes: vertical, depth, and horizontal, with the depth dimension helping to estimate the distance to sound sources (9). Although much research has examined auditory perception in ASD, less is known about how individuals with ASD allocate spatial attention to auditory cues at different spatial levels, especially the depth dimension. However, several studies have explored differences between autistic and neurotypical groups in this area, particularly using target stimulus detection tasks. For example, research has shown that autistic children respond to non-target stimuli at close range. Additionally, children with autism have difficulty perceiving the distance of a sound source from the ear compared to neurotypical individuals (10). Other studies have indicated that children with ASD have more diffuse spatial attention and find it harder to accurately localize sounds (11). Although previous research has documented deficits in auditory spatial attention among individuals with autism, most studies have primarily focused on target selection amidst spatially distributed distractors. Furthermore, relatively little attention has been given to understanding the mechanisms of spatial attention in response to speech stimuli in isolation.

To examine these differences in attention between individuals with autism and neurotypical individuals, neurophysiological methods such as EEG to continuously monitor brain activity (12) and event-related potentials (ERPs), which are considered as brain responses to stimuli, can provide important insights into individual differences in processing and attention processes (13, 14). One ERP component that can be used to assess auditory spatial attention is the P300. The auditory P300 is characterized by a positive deflection in the EEG waveform that typically appears after the presentation of a rare auditory stimulus in a series of standard stimuli. This component generally peaks around 300 ms or later after stimulus onset (15). Depending on the nature of the task and interindividual variability, the P300 exhibits an amplitude to 20 μV and occurs within a latency window of 250–500 ms after the stimulus (16, 17). Topographically, it is prominently observed in parietal areas of the scalp, particularly in the parieto-central area (18). Its latency reflects the timing of cognitive processes such as stimulus evaluation, while its amplitude highlights the amount of attention involved during the task (19).

Therefore, based on the gap in the research literature, this study aimed to investigate auditory spatial attention to distance cues in children with ASD and to compare it with the typically developing (TD) group by analyzing the amplitudes and latencies of the P300 component of ERP across three different distance conditions.

2- MATERIALS AND METHODS

2-1. Participants

We recruited 12 boys with high-functioning autism spectrum disorder (ASD) (mean age = 9.7 years, age range = 7–12 years) and 15 neurotypical boys (mean age = 9.3 years, age range = 7–12 years). Participants in both groups were individually matched for ethnicity, chronological age, socioeconomic status , culture, intelligence, and handedness. According to medical records, all participants had normal hearing thresholds (≤25 dB HL) at frequencies ranging from 250 to 8000 Hz, and all were native Romanian speakers. ASD diagnoses were based on clinical evaluations and confirmed using the Autism Diagnostic Interview–Revised (ADI-R) (20), supplemented by information from participants' records, including results from the Autism Diagnostic Observation Schedule (ADOS), Vineland Adaptive Behavior Scales, and Childhood Autism Rating Scale (CARS) Level 1 or high-functioning classifications. To ensure sample homogeneity, participants with a history of neurological, psychological, or psychiatric comorbidities were excluded. Additionally, none of the participants in either group were taking any medications. Written informed consent was obtained from the parents or legal guardians of all participants, following the Declaration of Helsinki (21). The study protocol was approved by the Research Ethics Committees of Stefan cel Mare University and the University of Tabriz (approval code: IR.TABRIZU.REC.1403.172).

2-2. Stimuli

This study is a part of a larger study that used a set of short sentences on the topic of simple descriptions of objects in Romanian. The sentences were natural and included words appropriate to the subject's lexical resources, taken from elementary school textbooks (For example: “The apple is red = Marul este roșu”). The auditory stimuli consisted of 3 words, each with two syllables, recorded at a natural Romanian speech rate in the F3 range with a frequency of approximately 174 Hz in a noise-free studio. A fundamental frequency (F0) was applied to maintain a constant and homogeneous sound range. This normalization was done to minimize the influence of individual and physiological variations on the neural and brain responses. Specific acoustic features were systematically manipulated to align with the study objectives, including loudness (as an indicator of the sound source).

To manipulate distance, a sound level of 65 dB SPL at a reference distance of half a meter was assumed (22). Using the free-field attenuation formula derived from the inverse square law (23):

$$L2 = L1 - 20Log_{10}(r2/r1)$$

To simulate auditory distance realistically, multiple acoustic cues were used beyond adjusting intensity. Sound levels of 65, 59, and 53 dB SPL were systematically applied to represent source distances of 0.5 m, 1 m, and 2 m, respectively, based on free-field attenuation principles. Distance-dependent spectral shaping was employed by attenuating high-frequency components in more distant stimuli, mimicking natural sound propagation. Reverberation profiles suitable for each simulated distance were created using room impulse responses and applied via convolution to adjust the direct-to-reverberant energy ratio (DRR) for each condition. Binaural rendering through headphones ensured accurate delivery of spatial cues to both ears. Calibration to ensure precise sound intensity transmission through Apple AirPods Pro was performed using Room EQ Wizard (REW) software. Standard test signals were played, and output levels were adjusted until the desired SPL targets were reliably reached.

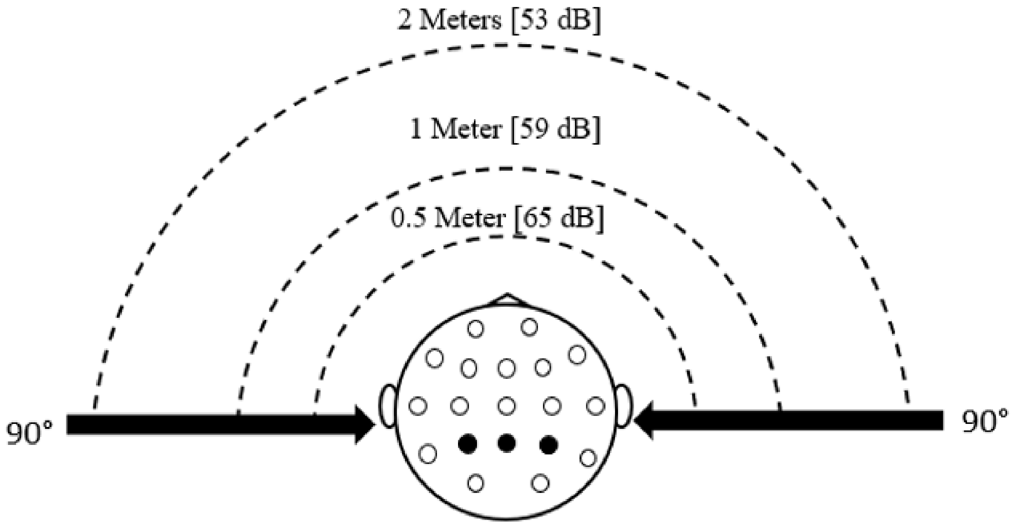

Figure-1**:** The conditions of stimuli presentation (intensity-based distance: 0.5 meter [65 dB SPL], 1 meter [59 dB SPL], and 2 meters [53 dB SPL]) and the location of the active electrodes.

2-3. Apparatus

Techniques such as ERPs, which are based on EEG, have significantly increased our understanding of brain function at both basic and higher levels. ERPs are changes in EEG signals that are induced by exposure to sensory stimuli (24). In the present study, we used the Ultracortex Mark IV EEG headset developed by OpenBCI. The device has 16 electrodes arranged according to the international 10-20 system, ensuring comprehensive coverage of key cortical areas. The data, sampled at a frequency of 250 Hz, were transmitted wirelessly to a computer via an RFduino Bluetooth module, which was connected via a USB dongle. This wireless, dry electrode arrangement minimizes movement restrictions and is particularly useful for experiments with children (25).

2-4. Experimental Procedure

Following initial screening, eligible participants engaged in individual EEG recording sessions in a quiet, controlled environment. Participants were equipped with an OpenBCI EEG headset, utilizing a 10-20 electrode placement system. They were comfortably seated with their eyes closed to minimize artifacts, and impedance was maintained below 10 kOhms. Brain activity was recorded via the OpenBCI Cyton Board.

At the start of the experiment, participants were instructed to actively listen to auditory stimuli. These stimuli included an oddball task with spoken Romanian sentences, delivered via Apple AirPods Pro at 65 dB SPL (about 0.5 m) for baseline sentences and 59 dB and 53 dB SPL for simulated 1- and 2-meter distance deviant sentences. The experiment consisted of three blocks, each with 100 trials. Each trial included a 1.71-second auditory sentence followed by a 1.2-second inter-stimulus interval (ISI). Stimuli were presented in a pseudorandom order with 75% standard and 25% target sentences. To reduce participant fatigue, a two-minute rest was taken between blocks. The entire task lasted roughly 18 minutes and 33 seconds. All stimuli were brief sentences, and ERP analysis was aligned to the start of each sentence for accurate timing.

We controlled stimulus presentation and synchronized ERP event markers with EEG recordings by creating a custom Python interface (26), allowing for subsequent detailed analysis of neural responses to the speech stimuli. At the end of the recording, to ensure that the subjects were actively listening to the sentences, they were asked questions about the auditory stimuli, and the recorded data from subjects who were unable to fully answer the questions were discarded for subsequent analyses.

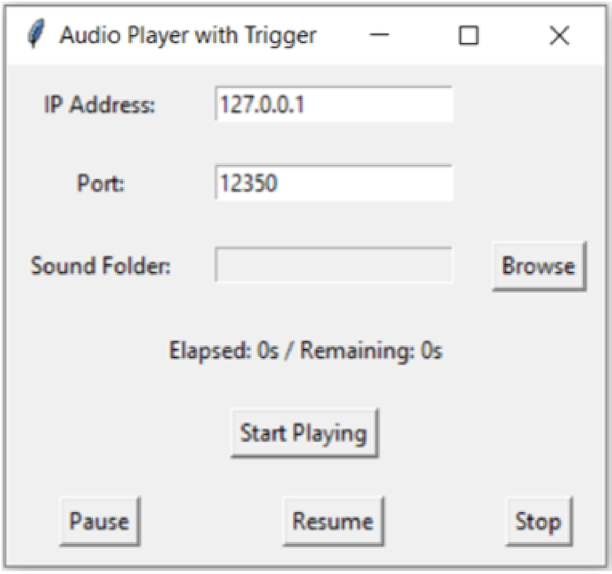

Figure-2: Custom Python interface for this project.

2-5. Data Analysis

2-5-1. Python

After collecting data, EEG signals containing ERP markers were processed using Python with the Pandas, NumPy, and Matplotlib libraries. Preprocessing was conducted to improve signal quality, reduce artifacts, and increase the signal-to-noise ratio. First, a fourth-order Butterworth bandpass filter (0.1–40 Hz) was applied to suppress low-frequency drift and high-frequency noise. Independent component analysis (ICA) was then performed to identify and remove artifacts caused by eye movements and muscle activity, preserving neurophysiologically relevant components. Baseline correction was applied by subtracting the average voltage in the 300 ms interval before stimulation from each trial to reduce slow voltage changes unrelated to event-locked activity. Trials with residual artifacts exceeding ±100 µV at any electrode after ICA were rejected from further analysis. Participants with more than 25% rejected trials in any condition were excluded from the final dataset.

Stimulus-locked epochs were extracted for each ERP marker, spanning from 300 ms before to 1000 ms after stimulus onset. Excluding time intervals with incomplete data. ERP analysis was restricted to the Pz, P3, and P4 electrodes, which are known to reliably capture components such as the auditory P300. For each trial, ERP components were quantified by calculating the amplitude (defined as the average peak-to-peak voltage) and latency (defined as the temporal position of the maximum or minimum within the expected component window). These features facilitating robust statistical analyses across subjects, experimental conditions, and cognitive domains, as reported in the Results section.

2-5-2. SPSS

Statistical analyses were conducted using IBM SPSS Statistics version 27.0.1 (IBM Corporation, Armonk, NY, USA). Multivariate analysis of variance (MANOVA) was used to examine the effects of group (ASD vs. TD) on the dependent variables, including the peak amplitude and latency of the P300 components. Before performing the MANOVA, the assumptions of multivariate normality, homogeneity of variance-covariance matrices (Box's M test), and absence of multiple collinearity were checked.

3- RESULTS

Univariate normality was confirmed using the Kolmogorov-Smirnov test, with all p-values exceeding 0.05, indicating no significant deviations from normality. The assumption of homogeneity of variance-covariance matrices was met, as indicated by a non-significant Box's M test. Linearity and absence of multicollinearity were confirmed through visual inspection of scatterplots and correlation analyses, both of which showed satisfactory patterns. Additionally, no multivariate outliers were identified based on standardized residuals and Mahalanobis distances. With all assumptions adequately satisfied, the dataset was deemed appropriate for MANOVA. The results regarding group differences in ERP amplitude and latency are reported below.

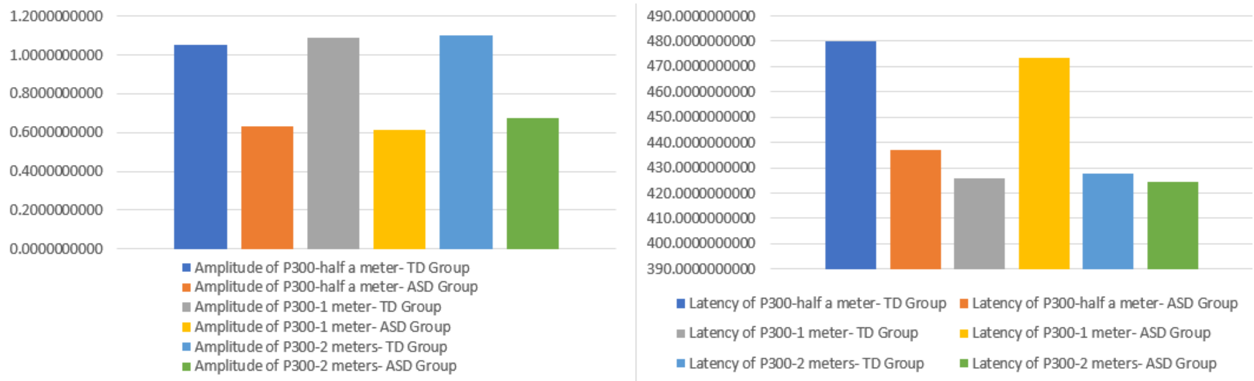

Figure-3: Comparison of P300 amplitude and latency between children with ASD and TD peers across three intensity-based distance conditions (half a meter, 1 meter, and 2 meters).

Descriptive statistics showed that the TD group consistently had higher P3b amplitudes than the autism group across all spatial distances. Mean latency values varied by condition, with the TD group showing longer latencies at 0.5 m, shorter latencies at 1 m, and similar values at 2 m. Standard deviations were similar across groups and conditions. These patterns guided subsequent inferential analyses.

Table-1. Summary of multivariate test results for the main effect of group on P300 amplitude and latency, considering all intensity-based distance deviation conditions combined.

Effect		Value	F	Hypothesis df	Error df	Sig.	Partial Eta Squared
Group	**Pillai's Trace**	0.344	1.747b	6.000	20.000	0.162	0.344
	Wilks' Lambda	0.656	1.747b	6.000	20.000	0.162	0.344
	Hotelling's Trace	0.524	1.747b	6.000	20.000	0.162	0.344
	Roy's Largest Root	0.524	1.747b	6.000	20.000	0.162	0.344

A one-way MANOVA was conducted to evaluate the effect of group (ASD vs. TD) on the combined dependent variables (P300 amplitude and latency across spatial conditions). The results showed no statistically significant multivariate effect of group, Pillai's Trace = 0.344, $F(6, 20) = 1.75$, $p = .162$, partial $\eta^2 = .344$. Similar non-significant outcomes were obtained with Wilks' Lambda = 0.656, Hotelling's Trace = 0.524, and Roy's Largest Root = 0.524. Effect sizes (partial η^2) were interpreted according to Cohen's guidelines: 0.01 = small, 0.06 = medium, and 0.14 = large effect (27). These findings suggest that, collectively, the six dependent measures did not differ significantly between groups. To further investigate potential group differences, a between-subjects analysis was conducted. Results for P300 amplitude and latency across stimulus types are presented in Table 2.

Table-2. Tests of between-subjects effects on P300 amplitude and latency across intensity-based distance comparing children with ASD and TD peers.

Source		Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Group	**Amplitude of P300- half a meter**	1.530	1	1.530	3.932	0.058	0.136
	Latency of P300- half a meter	14964.359	1	14964.359	4.402	0.046	0.150
	Amplitude of P300-1 meter	1.211	1	1.211	3.462	0.075	0.122
	Latency of P300-1 meter	12161.593	1	12161.593	2.461	0.129	0.090
	Amplitude of P300-2 meters	1.220	1	1.220	3.254	0.083	0.115
	Latency of P300- 2 meters	82.186	1	82.186	0.027	0.872	0.001

Follow-up univariate ANOVAs revealed a significant group difference in P300 latency at the half meter distance, $F(1, 25) = 4.40$, $p = .046$, partial $\eta^2 = .150$, indicating longer latencies in the TD group. A marginally significant effect was observed for P300 amplitude at the same distance, $F(1, 25) = 3.93$, $p = .058$, partial $\eta^2 = .136$. For the 1-meter and 2-meter distances, group differences in both amplitude and latency did not reach statistical significance (ps > .05), although small-to-moderate effect sizes were noted for amplitude (partial $\eta^2 = .122$ and .115, respectively). No significant difference was found for latency at 2 meters ($F = 0.027$, $p = .872$). These results suggest that spatial distance may influence group differences most prominently at closer proximity.

4- DISCUSSION

This study investigated differences in auditory distance processing between children with autism and TD peers by analyzing ERPs elicited by speech stimuli presented at varying simulated distances. While multivariate analyses revealed no significant group effects overall, univariate comparisons identified a significant prolongation of P300 latency in the ASD group at the closest auditory distance (0.5 meters). These findings suggest atypical neural processing of socially proximal speech stimuli in children with ASD, potentially indicative of increased cognitive demands during early attentional allocation.

Existing research on auditory source processing in ASD (28, 10) highlights difficulties in integrating complex spatial auditory cues, such as reverberation and binaural disparities, which may contribute to altered perception and neural responses to proximal sounds. According to the theory of weak central coherence in autism (29), speech stimulus input, especially at the sentence level, which includes phoneme, syllable, word, and prosody processing, and ultimately high sound intensity, causes attention to each of these features, reducing processing speed and consequently increasing latency (30). Furthermore, the social motivation theory (7) offers a complementary explanation, as reduced orientation to socially salient auditory cues in ASD could underlie the attenuated and delayed P300 responses relative to TD peers.

Additionally, the ASD group's overreliance on simple acoustic cues such as loudness, coupled with impaired integration of complex spatial auditory information, may contribute to altered distance perception and neural hyperactivation to proximal stimuli. These results align with existing models of atypical sensory processing in autism, characterized by abnormal cortical responsiveness despite normative hearing thresholds (31).

Finally, while some group differences did not reach conventional levels of statistical significance, the observed effect sizes suggest potentially meaningful patterns. The non-significant results may reflect limitations related to sample size or other factors rather than a true absence of effect. Therefore, further investigation with larger samples could help to better understand these preliminary trends in auditory spatial attention across varying distances.

5- CONCLUSION

In summary, our findings revealed a significant difference in P300 latency between children with ASD and typically developing peers at the closest simulated auditory distance (0.5 m). This result may reflect differences in auditory attention or perceptual processing of proximal speech stimuli in ASD. Although no significant effects were observed across all conditions, the trend at closer distances highlights the potential importance of spatial proximity in auditory processing among autistic children. Future studies with larger samples and broader paradigms are needed to clarify the neural mechanisms involved.

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7- FUNDING

This research did not receive any external funding.

8- DECLARATIONS

8-1. Conflict of Interest

None of the authors have any potential conflicts of interest to disclose.

8-2. Ethics Approval

All procedures involving human participants were conducted in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki Declaration and its later amendments or comparable ethical standards. The study was approved by the Research Ethics Committees of the University of Tabriz (IR.TABRIZU.REC.1403.172).

8-3. Consent to Publish

Written informed consent for publication was obtained from all participants or, where applicable, from their parents or legal guardians.

8-4. Consent to Participate

Written informed consent was obtained from all individual participants. For minors, consent was obtained from their parents or legal guardians.

8-5. Declaration of Generative AI and AI-assisted Technologies in the Writing Process

The authors did not use AI and AI-assisted technologies in the writing process.

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