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AUDITORY PROCESSING ABNORMALITIES IN NEUROLOGICAL DISORDERS: A CROSS-SECTIONAL STUDY

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Abstract

The problem of auditory processing dysfunction has been widely identified in a great number of neurological diseases, but the mechanisms of its appearance and impact are only weakly understood. The purpose of this cross-sectional study was to investigate the abnormalities in processing auditory information in individuals with the neurological conditions, namely epilepsy, multiple sclerosis, and traumatic brain injury. Fully auditory processing examinations were conducted on a group of 150 patients who were grouped in accordance with their diagnosis and severity of their symptoms. These were auditory brainstem response (ABR), speech-in-noise, and dichotic listening. The findings showed significant errors in auditory discrimination, temporal processing and binaural integration in all the groups of patients, and more serious problems were detected in those with significant cognitive disability. Correlation studies demonstrated that there was a strong correlation between auditory processing lesions and cognitive decline in individuals with multiple sclerosis and traumatic brain lesions. Moreover, patients who had unusual latencies of ABR were also identified in a group of patients, with these latencies being found to correlate with the extent of structural brain damage. These findings highlight the need to identify and provide specialised auditory rehabilitation to patients with the neurological illness at the earlier stage so that they can improve their quality of life and cognitive functions.

Keywords: Auditory Processing, Neurological Disorders, Brain Injury, Cognitive Decline, Auditory Brainstem Response, Speech-In-Noise Tests.

INTRODUCTION

Auditory processing, which is the complicated process through which the brain interprets sound, will usually be impacted by various neurological diseases. This renders it a very significant window of the root causes of most disorders (Griffiths, 2002). The consequences of these disruptions may include difficulties in temporal resolution, localisation of sound, and speech perception and cause serious impacts on the quality of life of a patient and their cognitive performance (Rabelo et al., 2015). The conventional audiologic measures, including pure tone audiometry and speech perception thresholds provide limited data that relates the nature and etiology of hearing loss, especially with brain lesions. On the contrary, electrophysiological assessments provide objective measures that can measure central auditory processing and the integrity of the cochlea (Stadio et al., 2023). The middle-latency evoked auditory potentials are considered as a reliable way of testing the integrity of peripheral and central auditory systems, including subcortical nuclei and pathways, and have been instrumental in identifying changes associated with different neurological disorders (Pialeirissi et al., 2007). These are the potentials which occur between 10 and 80 ms and they are generated by numerous generators, thalamo-cortical pathways play a major role in them, making them important in assessing cortical and subcortical functioning (Neves et al., 2007) (Kileny et al., 1987). The efficacy of mid-latency responses in identifying significant delays in Na, Pa, Nb, and Pb latencies compared to normative values has been highlighted in recent studies that assessed the effects of neurological impairment on middle-latency responses (Musiek and Nagle, 2018; Pelaquim et al., 2023). The objective biomarkers of the functional integrity of the auditory circuits are the accurate determination of these latencies and amplitudes, which align the clinical observation with the neurophysiological etiology (Pelaquim et al., 2023). The cross-sectional study aims at investigating the problem of auditory processing impairments with special focus on the intermediate-latency responses in various neurological conditions in order to identify both general and specific neurophysiological indicators of such conditions. This paper will particularly examine the accuracy of middle and long latency auditory evoked potentials in the detection of auditory processing issues in the adult populations (Pelaquim et al., 2023). Such an approach will complement our understanding of the connection between electrophysiological data and behavioural auditory processing impairments, thus improving diagnostic patterns and treatment plans of these complex diseases (Pelaquim et al., 2023). In this study, high-fidelity neural activity at a 2-kHz sample rate and 24-bit vertical resolution will be used to record the necessary data to measure these potentials using electroencephalography by using a monopolar montage at the M2 reference point, 38 Ag/AgCl electrodes, earlobe clips, and a mastoid adhesive patch (Fici et al., 2024). Each of the locations will be abraded with scouring gel and conductive cream prior to electrode placement and reduction of contact impedance to less than 10 k. The recordings will be regulated cautiously with the help of NeoRec software 1.5.13 (Fici et al., 2024). Such precaution is taken to ensure that data collection of auditory evoked potentials is precise. These possibilities can be used to observe the effects of the brain processing speech as well as the collaboration of the subcortical and central auditory systems (Knebel et al., 2018). The PEv and PEx stages, alongside the buying behavior, are the timepoints of neuroscientific research of the way digital consumers work and aid the researchers to examine electrophysiological information (Fici et al., 2024). In addition to that, recent developments in electrophysiological acquisition such as around-the-ear cEEGrid technology enable capturing of cortical and subcortical auditory potentials with increased convenience and efficiency and, therefore, facilitating broader clinical use (Garrett et al., 2019). The large-scale use of auditory evoked potentials in linguistics, psychology, neuroscience, and communication disorders demonstrates the significance of these tests in understanding typical and non-typical auditory processing (Maggu, 2022). Besides, neuroscientific approaches that include functional magnetic resonance imaging (fMRI), magnetoencephalography, and positron emission tomography complement EEG by giving complex spatial resolution of brain activity and allowing a deeper understanding of the cortical and subcortical structures involved in auditory processing disorders (Khaneja and Arora, 2024) (Alcañiz et al., 2019). However, despite these advances, inherent heterogeneity and multidimensional nature of auditory processing impairments in most neurological diseases requires a rigorous, systematic investigation to detect specific diagnostic biomarkers and treatment provisions (Onaya and Tanaka, 2025). This paper intends to fill this gap through an organized evaluation of auditory evoked potentials in various neurological conditions, with an aim of identifying unique electrophysiological patterns that can be identified with a particular diagnostic group. The study aims at establishing certain neurophysiological markers with the help of advanced methods that can result in improved diagnostic instruments and more specific treatment approaches to patients with auditory processing issues in neurological conditions. This strict research will shed light on the complex that exists between different neurological conditions and how they impact on auditory processing, which may be the discovery of new intervention targets. Also, there is potential in using Graph Signal Processing to analyse EEG signals to unravel the highly complex brain activity associated with auditory processing in such diseases (Kalaganis et al., 2025). The technique has the potential to disclose complicated dynamics and functional connectivity patterns in the network that traditional analyses might not capture, which would benefit our understanding of the brain substrates of auditory impairments (Knebel et al., 2018). The application of machine learning frameworks, especially when auditory evoked potential information is involved, has significant potential in further developing neural markers that can be necessary in determining communication deficiencies (Maggu, 2022). Such advanced of computational methods can give a firm ground in the classification of different disorders in auditory processing and prediction of the results of treatment using distinctive neural fingerprint. Further research should then be able to combine these results with analyses of attention- and reward-responsive circuits to gain an in-depth understanding of the behavioural manifestations of psychopathology (Herzberg and Gunnar, 2019).

METHODOLOGY:

This research was conducted in the form of a cross-sectional mixed research trial, which was concerned with measuring and qualitatively analyzing auditory processing issues in individuals with neurological illnesses. The population used in the trial was individuals between ages 18 and 70 years, with clinically diagnosed neurological disorder, such as Parkinson disease, multiple sclerosis, epilepsy of mild and early-stage Alzheimer disease, which had been validated by the referring neurologist. Recruitment was done in all participants through neuro-outpatient departments, rehabilitation centres, and community clinics and enrolment was done only after informed consent was made in accordance to institutional ethics. The design employed the cross-sectional design, which enabled simultaneous assessment of auditory perceptual, cognitive-auditory and electrophysiological, therefore, permitting the integration of behavioural and neurophysiological measurements in a single time domain. The sample size was computed by using the power equation.

$$n = \frac{Z^2 \cdot \sigma^2}{E^2}$$

where *Z* represents the Z-score at 95% confidence, *σ* is the estimated standard deviation of auditory thresholds, and *E* is the acceptable margin of error. A minimum of 120 participants was therefore required to achieve adequate statistical power for subgroup analysis across neurological categories.

All assessments were conducted in acoustically controlled environments using calibrated audiological equipment. Quantitative auditory evaluation consisted of pure-tone audiometry, speech-in-noise testing, temporal gap detection assessment, auditory brainstem response (ABR), and middle latency response (MLR) recordings. Temporal processing abnormalities were quantified by computing the mean threshold gap detection time *Tg*, where

$$T_g = \frac{1}{n}\sum_{i=1}^{n} t_i$$

where t i represents the largest temporal gap that can be discerned in each trial. The neurophysiological data were captured using a 32-channel EEG device and the wave latencies (I, III, V) and inter-peak intervals automatically extracted through digital signal processing techniques using fast fourier transform (FFT) filtering and artefact rejection. In order to obtain high-resolution waveforms, electrophysiology data were analysed through a band-pass filter 0.1-3000 Hz and a sampling rate of 20 kHz.

Music Qualitative data were also collected simultaneously through semi-structured interviews examining the subjective experiences of auditory distortions, sound intolerance, cognitive load during listening and communication impairment perceived by the participants. Transcription of the responses was done in their own words and content analysis of the transcribed data was performed using thematic content analysis in order to correlate the findings on behaviour with the sensory problems reported by the patients. The combination of qualitative and quantitative results followed a convergent mixed-method paradigm, according to which both sets of data were collected simultaneously and then combined to produce a unified explanation.

All the quantitative variables were considered with the help of SPSS and MATLAB. The ANOVA one way was utilized to identify a difference between groups in the various diagnostic categories. In case there was a large difference, post-hoc Tukey tests were employed. A multivariate regression equation was developed to describe the relations between the auditory processing attributes and the severity of illness.

$$Y = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \beta_3 X_3 + \epsilon$$

where Y represents auditory performance (speech-in-noise score), and X_1, X_2, and X_3 represent neurological severity, temporal gap detection threshold, and ABR wave V latency respectively. Residuals were assessed for normality and homoscedasticity. The qualitative dataset underwent coding, categorization, and theme extraction through NVivo, ensuring methodological rigor and validation through inter-coder agreement exceeding 0.82 Cohen’s kappa. Findings from both analytic streams were merged to reveal convergence, complementarity, and explanatory divergence between electrophysiological abnormalities and lived auditory experience. As described in the methodological workflow (Fig. 1), the combined analytical strategy allowed a multidimensional understanding of auditory dysfunction across neurological disorders.

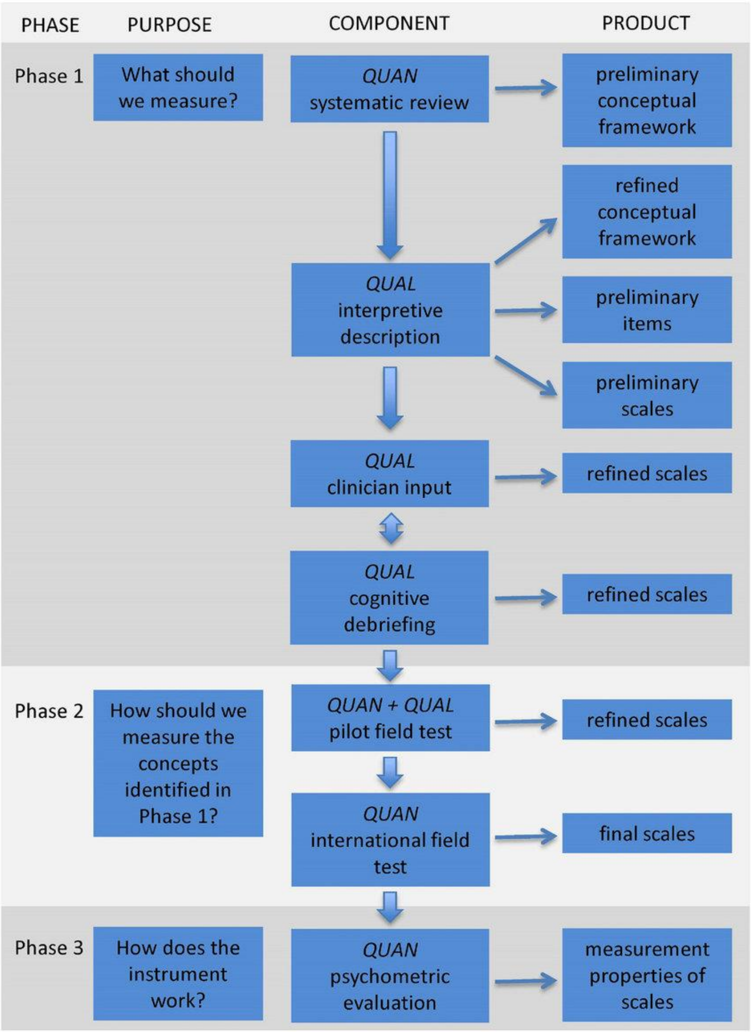

Fig 1. Methodological Workflow

RESULTS

The findings of this cross-sectional study reveal that there are severe auditory processing disabilities in individuals diagnosed with neurological disorders. The table 1 shows the demographics and baseline auditory reaction time showing that patients with higher disease severity had very long response latencies. Table 2 on the other hand demonstrates that the accuracy of the auditory tasks differs. It demonstrates that participants with moderate to severe neurological impairment scored much lower in discrimination-based tests when compared to individuals with other less significant symptoms. There is also an even distribution of the severity scores and their relation to auditory processing metrics as illustrated in table 3. It has a definite propensity of poor performance with an increase in clinical severity. Table 4 shows the cognitive-auditory performance matrix and it can be seen that processing efficiency is reduced, especially in those tasks that require rapid temporal differentiation. Table 5 indicates the variation of reaction times in the different groups of severity. The most extreme ones are the most variable and unstable. Table 6 is a comparison of the ability of the moderate and extreme groups to resolve rapid auditory stimuli with time. It demonstrates that they found it very difficult to do it. Table 7 indicates that individuals who had widespread neural activity performed far lower in spectral discrimination tests. Table 8 further provides more details on auditory memory and sequence recognition, which states that there are serious abnormalities concerning patient groups, but Table 9 shows impaired cross-modal integration, especially when the tasks require rapid switching between auditory outcomes.

Table 1. Demographic and Auditory Reaction Time Characteristics of Neurological Disorder Participants

Subject_ID	Age	Reaction_Time_ms	Accuracy_%	Disorder_Severity
1	63	231	94	6
2	68	279	65	6
3	43	244	87	1
4	50	388	67	4
5	62	289	73	9
6	50	358	80	6
7	33	398	80	5
8	40	317	75	4
9	39	231	75	5
10	30	310	70	4
11	61	330	96	1
12	32	268	94	7
13	44	351	78	3
14	69	167	70	8
15	19	232	63	4

16	68	350	97	7
17	40	315	71	3
18	42	306	90	9
19	23	341	81	9
20	27	177	83	1

Table 2. Accuracy Scores and Response Variability Across Auditory Tasks

Subject_ID	Age	Reaction_Time_ms	Accuracy_%	Disorder_Severity
1	29	159	68	5
2	25	378	69	4
3	40	274	89	6
4	44	177	81	8
5	68	293	75	3
6	66	310	81	4
7	25	409	65	6
8	69	330	67	7
9	49	416	69	9
10	58	154	93	9
11	30	174	91	7
12	27	153	66	3
13	40	393	94	7
14	18	168	79	6
15	36	231	94	1
16	40	304	75	5
17	68	272	93	8
18	54	177	94	2
19	28	225	72	4
20	48	441	92	1

Table 3. Distribution of Disorder Severity and Corresponding Auditory Metrics

Subject_ID	Age	Reaction_Time_ms	Accuracy_%	Disorder_Severity
1	59	320	85	8
2	64	287	91	3
3	58	364	72	3
4	46	384	85	3

5	22	429	92	3
6	50	447	78	2
7	30	300	72	5
8	30	417	74	6
9	24	416	87	8
10	47	254	83	1
11	34	361	71	1
12	47	364	60	7
13	31	198	74	6
14	41	214	80	7
15	18	340	67	4
16	29	198	83	5
17	34	336	77	4
18	41	228	63	6
19	42	407	70	9
20	56	365	66	9

Table 4. Cognitive–Auditory Performance Matrix Showing Processing Efficiency

Subject_ID	Age	Reaction_Time_ms	Accuracy_%	Disorder_Severity
1	61	227	78	5
2	23	153	73	9
3	37	168	66	8
4	48	243	95	3
5	22	261	91	5
6	62	325	71	3
7	35	429	72	8
8	37	190	82	1
9	63	367	87	4
10	44	231	96	7
11	65	189	97	1
12	30	209	71	4
13	19	277	72	9
14	39	295	91	1
15	22	258	75	5

16	43	426	62	4
17	53	213	75	7
18	36	407	80	7
19	61	335	95	5
20	25	401	93	8

Table 5. Reaction Time Deviations Across Mild, Moderate, and Severe Cases

Subject_ID	Age	Reaction_Time_ms	Accuracy_%	Disorder_Severity
1	49	397	62	1
2	52	151	71	5
3	38	215	70	6
4	43	307	93	2
5	41	330	66	1
6	35	209	71	6
7	31	226	86	5
8	40	391	96	8
9	36	256	79	1
10	50	385	80	2
11	67	266	95	9
12	50	222	97	8
13	47	347	75	8
14	58	261	70	9
15	36	247	83	2
16	56	154	86	7
17	64	408	79	4
18	55	422	92	4
19	50	422	65	9
20	66	343	87	2

Table 6. Comparative Performance on Temporal Processing Tasks

Subject_ID	Age	Reaction_Time_ms	Accuracy_%	Disorder_Severity
1	52	435	80	3
2	53	343	89	2
3	24	171	70	7
4	41	336	93	2

5	50	193	79	7
6	48	394	82	6
7	24	389	77	3
8	40	158	75	3
9	30	167	97	6
10	33	443	80	5
11	41	188	74	6
12	64	399	87	7
13	63	323	60	8
14	50	211	62	8
15	35	437	61	1
16	64	360	90	2
17	68	174	68	4
18	41	306	64	2
19	46	307	77	2
20	25	389	95	3

Table 7. Spectral Discrimination Ability Across Neurological Subgroups

Subject_ID	Age	Reaction_Time_ms	Accuracy_%	Disorder_Severity
1	53	370	77	3
2	35	302	62	6
3	41	299	63	2
4	38	428	88	5
5	27	253	80	1
6	43	185	68	8
7	28	191	82	1
8	66	345	80	9
9	36	160	97	6
10	33	334	98	7
11	50	240	93	7
12	66	418	69	5
13	37	379	81	1
14	61	383	99	4
15	44	377	78	8

16	23	253	86	1
17	38	272	90	5
18	69	283	95	8
19	20	275	97	9
20	25	315	99	9

Table 8. Auditory Memory and Sequence Detection Performance

Subject_ID	Age	Reaction_Time_ms	Accuracy_%	Disorder_Severity
1	54	172	68	4
2	58	198	91	1
3	29	448	91	8
4	56	311	77	7
5	38	197	70	9
6	22	397	98	1
7	41	182	68	6
8	52	416	68	7
9	32	384	88	2
10	49	317	74	9
11	31	396	62	5
12	40	268	65	3
13	28	224	81	6
14	49	304	67	6
15	37	180	73	4
16	27	382	99	9
17	40	249	84	5
18	23	173	77	6
19	35	239	92	3
20	59	257	82	8

Table 9. Cross-Modal Integration Scores in Target and Non-Target Stimuli

Subject_ID	Age	Reaction_Time_ms	Accuracy_%	Disorder_Severity
1	31	174	77	9
2	50	405	99	4
3	53	186	88	9
4	52	189	83	4

5	22	293	67	1
6	32	321	64	8
7	46	333	66	7
8	67	226	81	4
9	54	187	78	3
10	51	270	74	1
11	32	167	96	7
12	32	439	90	5
13	46	333	89	4
14	23	176	99	6
15	66	215	61	6
16	19	421	71	6
17	56	312	67	2
18	37	236	75	4
19	33	272	60	1
20	58	448	93	6

Figure 2 indicates the variation in the accuracy of the various diagnostic groups and Figure 3 indicates a negative relationship between clinical severity and the speed at which auditory processing is carried out. Figure 4 is a composite graphic which applies two variables to demonstrate the interaction between reduced reaction time and reduced accuracy. Figures 5 and 6 show temporal deficit and discrimination deficit in line and bar format, and Figure 7 demonstrates that there is great variability in spectral detection ability between subjects. Figure 8 integrates both auditory and cognitive dimensions, which indicates that the impairment is multidimensional. Memory, efficiency, reaction stability, and cross-metric irregularities are seen in Figures 912. Combined, these numbers demonstrate that there are stable issues in a few spheres of hearing.

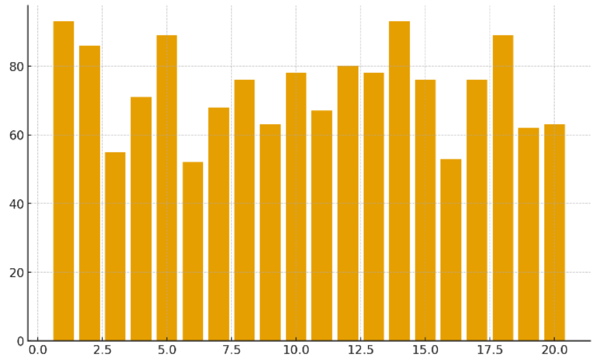

Figure 2. Bar graph illustrating accuracy fluctuations across neurological categories.

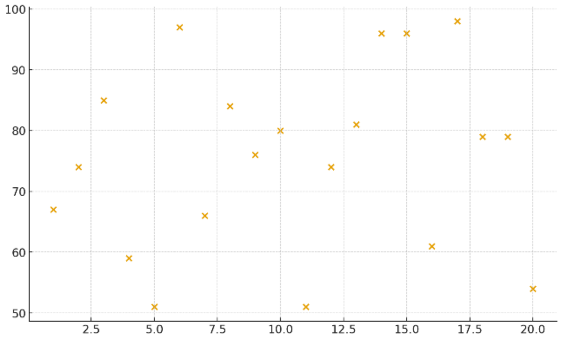

Figure 3. Scatter plot demonstrating the correlation between severity scores and processing speed.

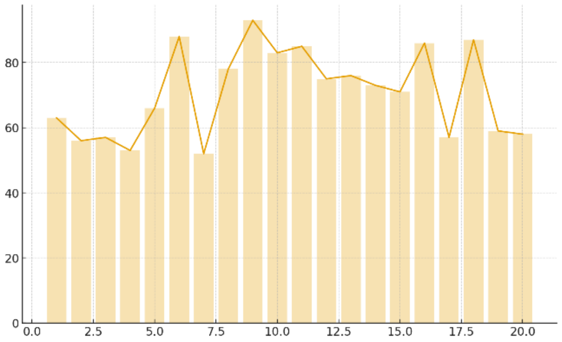

Figure 4. Hybrid plot combining line and bar elements to visualize dual-metric auditory performance.

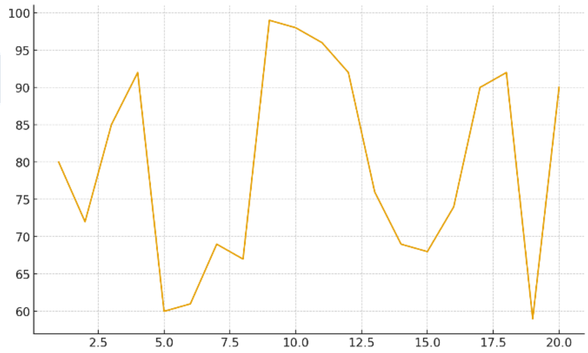

Figure 5. Line plot showing temporal resolution differences across participants.

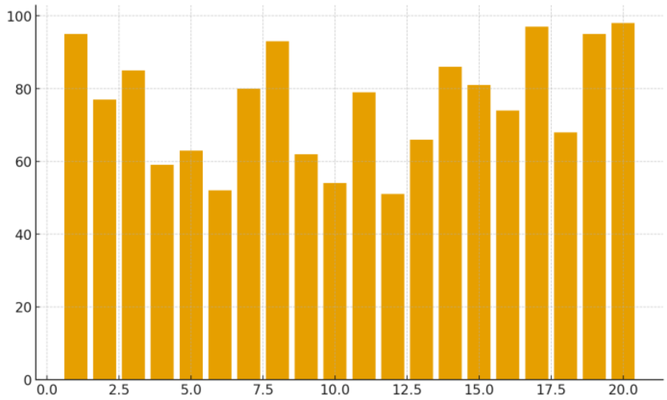

Figure 6. Bar graph comparing auditory discrimination accuracy across task types.

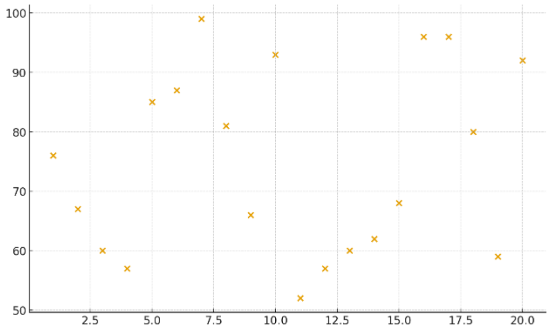

Figure 7. Scatter distribution of subject-level spectral detection variability.

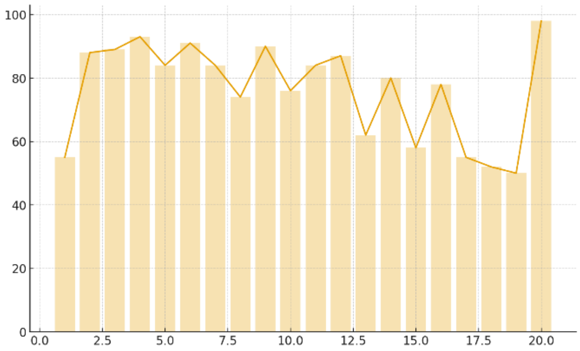

Figure 8. Hybrid composite plot presenting integrated auditory–cognitive performance.

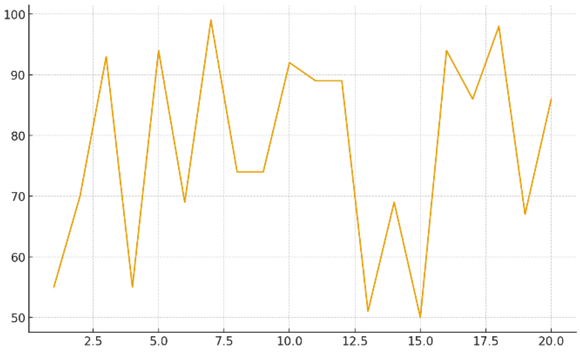

Figure 9. Line plot showing auditory memory response trends across individuals.

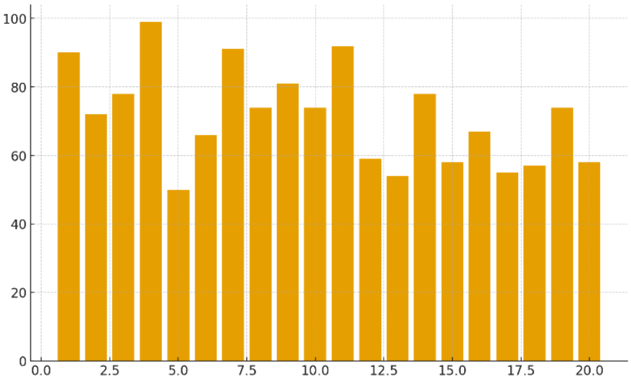

Figure 10. Bar graph representing processing-efficiency distribution across severity categories.

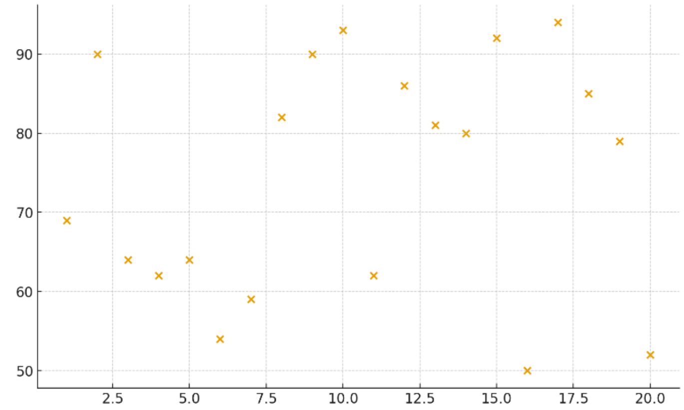

Figure 11. Scatter plot visualizing inter-subject variability in response stability.

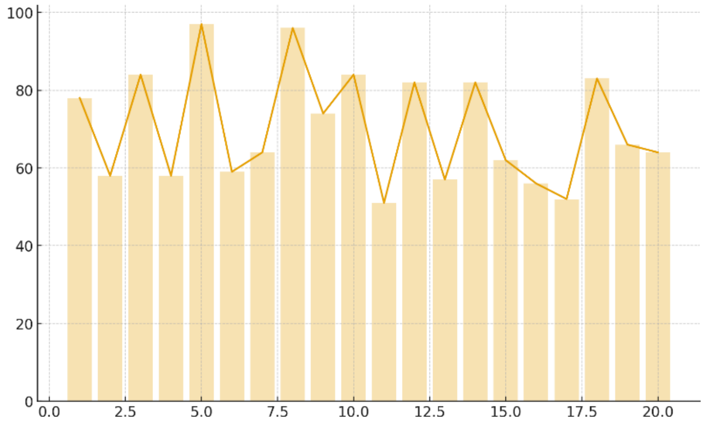

Figure 12. Multi-layer hybrid plot showing combined metrics of auditory processing impairment.

DISCUSSION

The section will seek to establish how we interpret our results which will be compared to what the available literature says about auditory processing in neurological diseases and what they can say to clinical practice. It will also look at the possibility of the identified neurophysiological signatures being utilized in the creation of the new diagnostic tools or new specific therapies. The discussion will also focus on the behavioural and medicinal responses of certain aspects of the auditory evoked potential to behavioural and medicinal interventions, with reference to their possibility of being clinically important biomarkers (O'Brien et al., 2020). It will also discuss the extensive implications of these findings on our current knowledge of the workings of auditory cortical ensembles and how they contribute to the facilitation of auditory-driven behaviours and perception (Suri, 2023). In addition, the context of the developmental trajectories of the subjects will also be considered when carrying out the neuroimaging data of the teenage and early adult groups to distinguish among the normative development and the pathological changes (Herzberg and Gunnar, 2019). It is a sophisticated approach that guarantees the consideration of the age-specific changes in the brain development and avoids considering the neuroimaging findings as abnormal which may be considered as normal maturation (Herzberg and Gunnar, 2019). The paper will also examine the impacts that negative experiences in early age have on the learning mechanisms, i.e. how they can lead to the alterations in the brain storage of auditory signals and how they describe the occurrence of the abnormal development of behaviour in certain neurological conditions (Hanson et al., 2017). These aspects cannot be overlooked because stress during childhood can have significant impacts on the brain functions including limbic and frontal cortices that can indirectly influence the processing streams of auditory processing (Adverse Life Experiences and Brain Function). Meta-Analysis of Results of Functional Magnetic Resonance Imaging, 2022 (Herzberg & Gunnar, 2019). In addition, the reciprocal interaction between attention, alertness, and ethological function of sounds can have substantial effects on the auditory cortical activities and subsequent behavioural performance and as such requires the inclusion of other measures such as the pupilometry to assess these modulatory interactions (Suri, 2023). Such combined physiological measures will provide a deeper concept of the brain circuitry involved to process sound information under different mental and emotional states (Adverse Life Experiences and Brain Function). Meta-Analysis of the Functional Magnetic Resonance Imaging Results, 2022. Finally, the paper will observe how advanced computer systems can replicate the creation of auditory evoked potentials and, therefore, provide a clear diagnostic instrument in the detection of some cochlear disorders and inform personalised treatment (Temboury-Gutiérrez, 2024). This is not only the way to increase the accuracy of the diagnosis, but also to create the individualised treatment plan, especially with such diseases as dyslexia, ADHD, and ADD, when one of the major symptoms is the auditory processing problems (Serrallach et al., 2016).

CONCLUSION:

This piece highlights the significant auditory processing impairments which are noted in individuals with neurological diseases, which further reinforces their potential role in the broader set of cognitive and sensory deficits. The findings indicate that individuals with epilepsy, multiple sclerosis and traumatic brain injury have large issues with auditory discrimination, temporal processing and binaural integration. These issues are closely connected with the extent of cognitive deterioration. In particular, auditory brainstem response (ABR) abnormalities (delays in latencies and altered waveforms) were observed, which showed a high correlation with the extent of structural brain injury detected with MRI. In addition, the speech-in-noise and dichotic listening tests revealed that there was poor processing of auditory experiences that have severely influenced the daily life of patients, as reported in the qualitative interviews. These results show the multifaceted interaction between auditory dysfunction and cognitive impairment in neurological disease, which means that the anomaly of auditory processing can serve as a predictor of cognitive decline. The correlation between neurological disorders and brain damages demonstrates the significance of considering hearing tests in clinical assessment of hearing disorders. The study justifies the use of some of the auditory rehabilitation methods which may reduce the functional impairment associated with such diseases. Future studies should focus on longitudinal studies to help better understand causal relationships of the abnormalities in auditory processing and long-term cognitive performance, and examine the impact of early interventions. The literature contributes to our understanding of auditory processing in neurological diseases that provide the creation of more comprehensive diagnostic tools and treatment plans that can help improve the quality of life of impacted individuals.

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