REVISTA CEFAC
SPEECH, LANGUAGE, HEARING SCIENCES AND EDUCATION JOURNAL
Rev. CEFAC. 2022;24(6):e5622 https://doi.org/10.1590/1982-0216/20222465622

Original articles

Frequency-Following Response and Auditory Middle Latency Response: an analysis of central auditory processing in young adults

Vitor Cantele Malavolta[1]
https://orcid.org/0000-0003-4171-1629
Milaine Dominici Sanfins[2]
https://orcid.org/0000-0002-3647-3999
Larine da Silva Soares[1]
https://orcid.org/0000-0001-8687-7759
Piotr Henryk Skarzynski[3,4,5]
https://orcid.org/0000-0002-4978-1915
Hélinton Goulart Moreira[6]
https://orcid.org/0000-0001-5212-7546
Vanessa de Oliveira Cristiano Nascimento[6]
https://orcid.org/0000-0003-1672-3847
Christine Grellmann Schumacher[6]
https://orcid.org/0000-0003-0732-6815
Arielly Freitas Moura[6]
https://orcid.org/0000-0002-0119-6725
Sandi Severo de Lima[6]
https://orcid.org/0000-0003-2864-7888
Aline Andressa Mundt[6]
https://orcid.org/0000-0001-7860-1445
Tainá Betti[1]
https://orcid.org/0000-0002-7930-2997
Michele Vargas Garcia[7]
https://orcid.org/0000-0003-3779-349X

[1] Universidade Federal de Santa Maria - UFSM, Programa de Pós-graduação em Distúrbios da Comunicação Humana, Santa Maria, Rio Grande do Sul, Brasil.
[2] Centro de Eletrofisiologia e Neuroaudiologia Avançada, São Paulo, Brasil.
[3] Instituto de Fisiologia e Patologia da Audição, Warsaw, Polônia.
[4] Departamento de Insuficiência Cardíaca e Reabilitação Cardíaca, Warsaw, Polônia.
[5] Instituto de Órgãos Sensoriais, Warsaw, Polônia.
[6] Universidade Federal de Santa Maria – UFSM, Departamento de Fonoaudiologia, Santa Maria, Rio Grande do Sul, Brasil.
[7] Universidade Federal de Santa Maria - UFSM, Departamento de Fonoaudiologia e Programa de Pós-graduação em Distúrbios da Comunicação Humana, Santa Maria, Rio Grande do Sul, Brasil.

Conflict of interests: Nonexistent

CC BY

Received on: August 28, 2022
Accepted on: September 21, 2022

Correspondence address:
Vitor Cantele Malavolta
Avenida Roraima, nº 1000, Prédio 26, Cidade Universitária, Camobi
CEP: 97105-900 - Santa Maria, Rio Grande do Sul, Brasil.
E-mail: vitorcmalavolta@gmail.com

ABSTRACT

Purpose: to compare the latency and amplitude of the Frequency-Following Response and the Auditory Middle Latency Response in typical individuals and those with altered auditory abilities, as well as to investigate the sensitivity and specificity of both assessments in relation to central auditory processing.

Methods: 32 individuals of both sexes were distributed into Group 1 (without altered auditory abilities) and Group 2 (with altered auditory abilities). The groups were divided according to behavioral tests of central auditory processing. Individuals in both groups underwent auditory evoked potentials. Student's t-test was used for analysis, considering a 5% significance.

Results: in Group 2, V and A had higher latency and lower amplitude and slope. Group 2 also had lower Na and Pa amplitudes in waves A1C3 and A2C3. The Frequency-Following Response showed 93% sensitivity and specificity, while the Auditory Middle Latency Response showed 87% sensitivity and 93% specificity.

Conclusion: the individuals presented with altered hearing abilities showed higher latency and lower response amplitude in the Frequency Following Response and Auditory Middle Latency Response compared to typical individuals. The Frequency-Following Response showed a better balance of sensitivity and specificity.

Keywords: Auditory Perception; Auditory Evoked Potentials; Adult; Hearing

INTRODUCTION

Central Auditory Processing (CAP) refers to the effectiveness with which the nervous system uses sound information[1]. Some individuals have a deficit in this neurobiological mechanism, affecting auditory perception, and it may impact other domains, such as attention, memory, and learning[2]. In adults, changes in auditory information processing tend to cause problems in work performance, also impacting mental health[3].

The assessment of CAP involves behavioral measures of auditory abilities, as well as the investigation of cognitive and language domains[4]. In this context, electrophysiological tests of hearing also contribute to this assessment, elucidating the structure-function relationships in the central auditory system[5,6]. Among these tests, it is possible to highlight the *Frequency-Following Response (FFR)* and the Auditory Middle Latency Response (AMLR), both of which are already studied in relation to the CAP, elucidating neurobiological changes of the central auditory nervous system[5-8].

The FFR is an assessment triggered by a verbal stimulus that reveals auditory neurophysiological processes in the brainstem, with responses recorded from multiple subcortical and cortical sources[9,10]. Although the FFR is not yet clinically available, there is evidence that the examination can be an effective tool in the assessment of CAP[9,11-14] and, therefore, help to investigate and elucidate aspects related to the condition.

The AMLR was also studied against the CAP, considered by some authors as a very important assessment due to its generating sites[15,16]. Nevertheless, there have already been records that demonstrated some inconsistency in this assessment compared to other CAP tests[6], making its applicability contested by some professionals.

Although there is no gold standard, it is known that an adequate assessment of the CAP depends on the application and interpretation of sensitive and specific tests[16]. Thus, parameters such as sensitivity and specificity of assessments become important. The previous literature has already studied these parameters for FFR and AMLR[17,18]. However, no studies were found describing which electrophysiological tests present the best performance in terms of sensitivity and specificity for assessing CAP in the young adult population.

Given the above, the present study aimed at comparing the parameters of latency and amplitude of FFR and AMLR in typical young adults with changes in auditory abilities, as well as investigating the sensitivity and specificity of both assessments against CAP in this population.

METHODS

This study has an analytical and observational character, and its data collection was conducted in 2019 in an Audiology service of a school clinic.

The study was approved by the Research Ethics Committee of the Federal University of Santa Maria, Brazil, under number 23081.019037/2017-19. All standards and guidelines for research with human beings complied with Resolution 466/12 of the National Health Council of Brazil. All individuals were informed about the research, and those who agreed to participate signed a Free and Informed Consent Form and the Confidentiality Form.

In total, 64 individuals were assessed. However, 32 were excluded because they did not meet the eligibility criteria. The convenience sample comprised 32 young adults, 20 females, and 12 males. All of them presented right-hand preference. The mean age of the individuals was 22.6 years (18 to 34 years), and that of education was 14.9 years. All were speakers of Brazilian Portuguese.

In the present study, the individuals were divided into two groups. Group 1 (G1) consisted of 16 individuals, 10 females and 6 males, with a mean age of 22.7 years. All members of G1 presented normality in CAP screening. Group 2 (G2), in turn, was composed of 16 individuals, also, 10 females and 6 males. The mean age of G2 was 22.6 years and all members of this group showed changes in CAP screening.

For both groups (G1 and G2), the individuals needed to present the following inclusion criteria: normal visual inspection of the external acoustic meatus bilaterally; air conduction thresholds up to 25 dBHL in octaves from 250 to 8,000 Hz[19]; normal functioning of the middle ear bilaterally, with type A tympanometric curves in both ears, presenting pressure values between -100daPa and +200daPa and compliance between 0.3 and 1.3mm; contralateral acoustic reflex present in both ears at frequencies of 500, 1,000,

2,000, and 4,000Hz[20,21]; Brainstem Auditory Evoked Responses (BAER) with the presence of waves I (1.66 ms), III (3.87 ms), and V (5.68 ms), as well as normal interpeak intervals I-III (2.21 ms), III-V (1.81 ms), and IV (4.02 ms), according to the Webster standardization (2017)[22].

For CAP screening and consequent separation of G1 and G2 groups, the following assessments were performed:

a. For G1: result above 95% in the Dichotic Digit Test (DDT) for both ears and also a result below 9.5ms in the Random Gap Detection Test (RGDT)[23,24].
b. For G2: result less than 95% in the Dichotic Digit Test (DDT) for both ears and also a result greater than 9.5ms in the Random Gap Detection Test (RGDT)[23,24].

The exclusion criteria of both groups were: neurological and/or psychiatric disorder, syndrome of genetic origin, degenerative disease, otological disease, tinnitus or dizziness, continuous exposure to noise, continuous use of medication, or chemical dependence. Furthermore, participants could not be submitted to any complementary therapy during the research period or take periodic music classes.

All subjects underwent the following procedures: audiological assessment, behavioral CAP tests, and electrophysiological hearing assessment.

Audiological Assessment

Audiological anamnesis: composed of questions related to the hearing and general health of the individual. The procedure was performed to meet the inclusion and exclusion criteria of the study;

- *Visual inspection of the external acoustic meatus:* to investigate the presence of physical obstructions in the external acoustic meatus;
- *Threshold Tonal Audiometry[25]:* performed in an audiometric cabin in the Interacoustics® AD629 equipment with annual acoustic measurement. Headphones TDH-39 were used. To measure air conduction thresholds, individuals were instructed to raise their hands if they heard the stimuli, even at low intensity. Bone conduction thresholds were not investigated because this study included only individuals without hearing loss. According to the individual's report, the examination was started in the best ear. The frequency initially tested was 1,000Hz, followed by frequencies of 2,000, 3,000, 4,000, 6,000, 8,000, 500, and 250Hz. The initial intensity presented was 50dB. As a normality criterion, individuals needed to have air conduction thresholds of up to 25dBHL for all tested octaves[19];
- *Acoustic Immittance Measurements[26,27]:* performed with the Interacoustics® AZ26 equipment, using a 226Hz test tone. The tympanometric responses of both ears were investigated, as well as the contralateral acoustic reflexes at 500, 1,000, 2,000, and 4,000 Hz. Individuals were instructed to remain seated and avoid swallowing during the procedure. For tympanometry, the normality standard for pressure was between -100 and +200daPa, and for compliance was between 0.3 and 1.3mmhos. In the acoustic reflex, the responses between 65 and 95 dB were considered within the normal range for all frequencies tested[20,21,25].

The Dichotic Digit Test (DDT) and the Random Gap Detection Test (RGDT) were selected for this assessment, considering the performance of both in previous studies and the importance of the abilities assessed by the tests for discrimination and speech understanding[6,28-32]. Although there is no gold standard, due to the heterogeneity of conditions involving CAP[16], both tests were chosen following the diagnostic criteria established by the *American Academy of Audiology (AAA)[16]* and the *American Speech Language Learning Association (ASHA)[1]*: at least two altered behavioral tests, considering two standard deviations.

Dichotic Digit Test (DDT)[33]*:* the test consists of four lists of 20 items, which present four disyllabic stimuli (for the Portuguese language), the numbers being four, five, seven, eight, and nine. The presentation of this test was performed in both ears, with an intensity of 50dB, and the individual was instructed to repeat the four numbers heard[33]. In the present study, only the binaural integration step was applied. As a normality criterion, individuals should present results ≥ 95% for both ears[33].

Random Gap Detection Test (RGDT)[34]: the test consists of the presentation of pure tones, which present small silent intervals, randomly varying between zero and 40ms. These stimuli are presented separately at four different frequencies (500, 1,000, 2,000, and 4,000 Hz). The individual needed to hear the test, presented at 50 dB, and indicate how many stimuli they perceived (one or two). The range detection threshold was established as the gap where the individual perceived two stimuli, not just one. The final result was the mean of the detection threshold in the four frequencies tested[34]. To be classified as normal, individuals had to present responses ≤ 9.51ms[13]. The test was applied binaurally.

The electrophysiological assessment of hearing was performed with the SmartEP equipment of "*Intelligent Hearing Systems*®", which presents annual acoustic measurements. Individuals were placed in a reclining chair in a room without electrical interference or environmental noise. Initially, the individual's skin was cleaned

using abrasive paste at the specific points of electrode placement for each examination, using the 10-20 electroencephalography system as a reference. For all electrophysiological tests, the electrode impedance was less than 3 kΩ, and the inter-electrode impedance was less than 2 kΩ. The transducers were ER-3A type.

Brainstem Auditory Evoked Responses (BAER)[22]*:* this test was performed to verify the neural integrity of the auditory pathway and was used as an inclusion criterion. The ground electrode was positioned on the forehead (Fpz), below the active electrode (Fz); the reference electrodes were placed on the left (A1) and right (A2) lobes. The stimulus was a click of 100*μ*s, in rarefied polarity and intensity of 80dB. In total, there were 2,048 stimuli delivered at a rate of 27.7/s, a gain of 100k, and a band-pass filter of 100-3,000Hz. The BAER was considered normal when the latency values of waves I, III, and V and their interpeak intervals I-III, III-V, and I-V were within the normative values. The parameters and the normality pattern used were those suggested by Webster (2017)[22], considering two standard deviations[22]. The acquisition was monaural, considering the repeatability and morphology for marking the waves. During the procedure, the individual remained in natural sleep.

"Frequency-Following Response" (FFR)[35]*:* the electrodes were in the same position as the BAER. Only the right ear was tested, and the stimulus was the syllable /da/ of 40ms duration. This syllable comprises a transient portion (/d/) and a sustained portion (/a/). The literature indicates that the FFR trace can be subdivided into three parts: onset (V and A), FFR (represented by components D, E eleven F), and offset (represented by component O)[36]. In this study, only the onset and the slope were analyzed. It was decided to analyze the latencies and amplitudes of V and A, as well as the value of the slope, considering the relationship of these components with the CAP and the results of a previous study[37]. The stimulus intensity was 80dB, alternating polarity, at a rate of 10.9/s, and the band-pass filter was 100-3,000Hz. There were 6,000 stimuli, and two waves were acquired, each with 3,000 stimuli. Finally, adding the waves was performed, generating a third waveform of 6,000 stimuli, in which the components were marked if there was repeatability. During the procedure, the subjects remained alert but without movement. For the test to be considered altered, at least one of the components needed to analyze (latency or amplitude of V and A, and the slope) was outside the normality standard stipulated. The reference values used were those described in the study by Song et al. (2011)[38] for the latency of V (6.65±0.27) and A (7.62±0.35), the amplitude of V (0.13±0.05) and A (- 0.20±0.06) and for slope (-0.35±0.11). Two standard deviations were used.

Auditory Middle Latency Response (AMLR)[39]*:* the electrodes were positioned at points Fpz, A1, C3, A2, and C4. Both ears were examined monaurally. The stimulus was a click of 100*μ*s, rarefied polarity, and an intensity of 70dB. On average, 1,000 stimuli were obtained, generating two waves per ear, which were named according to the electrodes: A1C3 (left ear - left hemisphere), A1C4 (left ear - right hemisphere), A2C3 (right ear - left hemisphere), and A2C4 (right ear - right hemisphere). The stimulus rate was 9.8/s, a gain of 100k, and the pass-band filter was 20-1,500 Hz. The four components of the test (Na, Pa, Nb, and Pb) were marked for latency and amplitude in the four waves generated. The amplitude was marked considering the zero point. The reference values for latency were those proposed by Hall (2007)[15]: Na (16-30ms), Pa (30-45ms), Nb (46-56ms), and Pb (55-65ms). Components were only marked if there was repeatability. The ear effect was studied for the analysis of auditory processing since, according to the literature, this aspect performs better in assessing the CAP[40]. The relative difference of the Na-Pa amplitude (peak to peak) of the right and left ears was calculated to determine the ear effect. The following formula was used: |(left ear in C3 + left ear in C4) / 2 | - |(right ear in C3 + right ear in C4) / 2|[8]. The cutoff value used in this study was 50%. Therefore, to be considered normal, individuals needed to present a result below 50%.

Initially, the data were tested for normality using the Shapiro-Wilk test and, based on this result, the other statistical tests were selected. The homogeneity of sex and age between G1 and G2 was analyzed using the chi-square test (sex) and Student's t-test (age). Student's t-test was used to analyze the comparison between variables. All results were analyzed using a significance level of 5%. Thus, $p<0.05$ was considered statistically significant.

For the sensitivity and specificity analysis of FFR and AMLR, the values were analyzed according to Chart 1.

Chart 1. Sensitivity and specificity of the Frequency-Following Response and the Auditory Middle Latency Response

FFR or AMLR	CAP BEHAVIORAL TEST		
	Altered	Normal	Total
Altered	A	b	a+b
Normal	c	d	c+d
Total	a+c	b+d	N
Sensitivity: (s)	a/a+c		
Specificity: (e)	d/b+d		

Captions: FFR = Frequency-Following Response; AMLR = Auditory Middle Latency Response; CAP = central auditory processing; N = total number of individuals.

RESULTS

Study sample

Participants in this study were distributed in G1 and G2, with 16 individuals in each group. Both groups were homogeneous in terms of gender (p=0.160), age (p=0.861), and education (p=0.803).

Frequency-Following Response

The latency comparison of components V and A for G1 and G2 is presented in Table 1. The comparison of the amplitude for the same components, as well as the slope, is presented in Table 2. In Table 3, it was observed that G2 presented statistically significant higher latency values of components V and A. Table 2, in turn, revealed that G2 had lower values for the amplitude of components V and A and for the slope, which were also statistically significant.

Table 1. Latency analysis of components V and A for Group 1 and Group 2

Group	V				A			
	n	Mean	SD	p-value	N	Mean	SD	p-value
G1	16	6.316	0.366	0.031*	16	7.898	0.443	0.033*
G2	16	7.280	0.254		16	8.380	0.183	

Captions: n = number of records; V = component V of the FFR; A = component A of the FFR; G1 = Group 1 without change in the screening of Central Auditory Processing; G2 = Group 2 with change in the screening of Central Auditory Processing; SD = standard deviation.
* Statistically significant

Table 2. Analysis of the amplitude of components V and A and Slope for Group 1 and Group 2

Group	V				A				Slope			
	n	Mean	SD	p-value	n	Mean	SD	p-value	n	Mean	SD	p-value
G1	16	0.132	0.031	0.044*	16	0.187	0.040	0.034*	16	0.200	0.044	0.032*
G2	16	0.081	0.026		16	0.139	0.056		16	0.082	0.041	

Captions: n = number of records; V = component V of the FFR; A = component A of the FFR; G1 = Group 1 without change in the screening of Central Auditory Processing; G2 = Group 2 with change in the screening of Central Auditory Processing; SD = standard deviation.
* Statistically significant
Student's t-test

Figure 1 depicts the illustration of components V and A of FFR for an individual of G1 and an individual of G2. The tracings demonstrate the statistically significant differences observed.

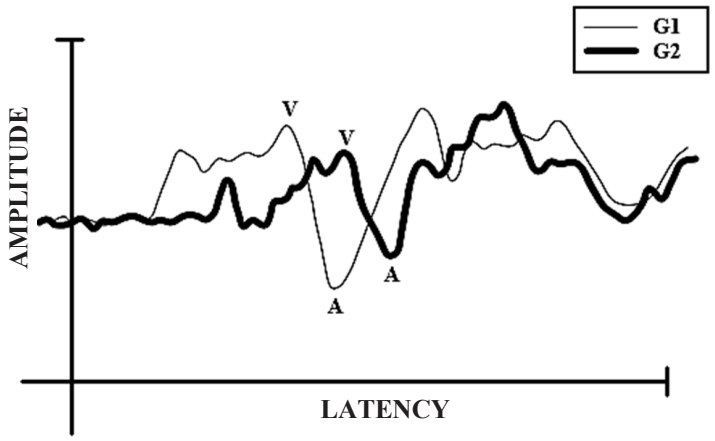


Illustration developed by the authors.

Figure 1. Illustration of Frequency-Following Response components V and A for Group 1 and Group 2

Auditory Middle Latency Response

AMLR was compared for the four components (Na, Pa, Nb, and Pb) of the four waves generated in this exam: A1C3, A1C4, A2C3, and A2C4. Table 3 shows the latency and amplitude of the components. It can be observed that G2 presented smaller amplitudes for the Na and Pa components of waves A1C3 and A2C3, being statistically significant.

Table 3. Analysis of the latency and amplitude of the components of the Auditory Middle Latency Response for all waves generated in Group 1 and Group 2

Component/Wave	Group	N	Latency			Amplitude		
			Mean	SD	p-value	Mean	SD	p-value
A1C3								
Na	G1	16	16.712	1.786	0.100	0.573	0.101	0.022*
	G2	16	18.000	1.360		0.342	0.102	
Pa	G1	16	29.331	0.883	0.248	0.662	0.143	0.023*
	G2	16	30.112	0.794		0.392	0.119	
Nb	G1	16	40.248	0.818	0.324	0.401	0.090	0.674
	G2	16	41.220	0.881		0.393	0.098	
Pb	G1	16	51.106	1.092	0.565	0.384	0.108	0.651
	G2	14	51.861	0.912		0.375	0.086	
A2C3								
Na	G1	16	16.374	1.462	0.309	0.612	0.080	0.041*
	G2	16	17.645	1.273		0.516	0.119	
Pa	G1	16	29.155	1.073	0.583	0.677	0.138	0.051*
	G2	16	29.939	1.184		0.580	0.079	
Nb	G1	16	40.170	0.761	0.613	0.400	0.082	0.596
	G2	16	40.780	0.871		0.389	0.073	
Pb	G1	16	50.762	1.091	0.362	0.384	0.081	0.494
	G2	14	51.401	1.164		0.341	0.071	

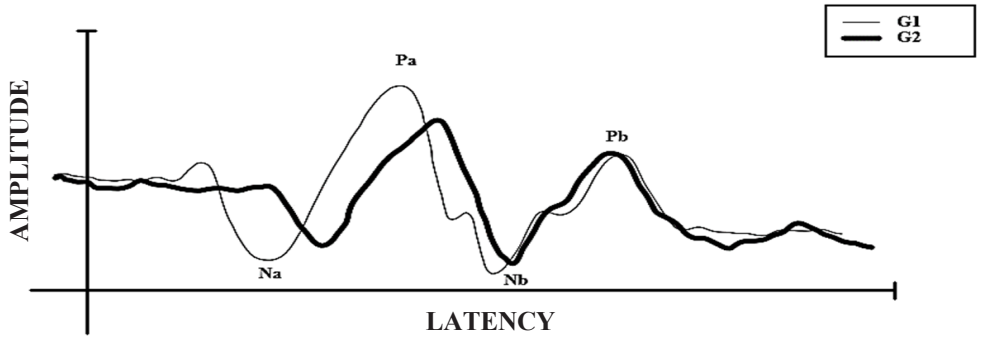
Component/Wave	Group	N	Latency			Amplitude		
			Mean	SD	p-value	Mean	SD	p-value
A1C4								
Na	G1	16	16.812	1.251	0.443	0.562	0.061	0.504
	G2	16	17.043	1.262		0.542	0.062	
Pa	G1	16	29.593	1.129	0.475	0.590	0.069	0.532
	G2	16	30.490	1.338		0.560	0.079	
Nb	G1	16	40.830	1.280	0.448	0.365	0.087	0.661
	G2	16	41.281	1.050		0.376	0.075	
Pb	G1	16	51.266	1.167	0.668	0.338	0.108	0.512
	G2	16	51.427	1.256		0.309	0.090	
A2C4								
Na	G1	16	16.493	1.470	0.441	0.571	0.082	0.650
	G2	16	17.032	1.209		0.564	0.089	
Pa	G1	16	29.296	1.141	0.405	0.586	0.100	0.426
	G2	16	30.376	1.231		0.536	0.097	
Nb	G1	16	40.779	0.873	0.399	0.390	0.077	0.664
	G2	16	41.092	0.986		0.380	0.063	
Pb	G1	16	51.130	1.134	0.102	0.350	0.076	0.591
	G2	16	52.033	1.324		0.327	0.075	

Captions: n = number of records; Na = AMLR component; Pa = AMLR component; Nb = AMLR component; Pb = AMLR component; G1 = Group 1 without change in Central Auditory Processing screening; A1C3 = electrode position; A2C3 = electrode position; A1C4 = electrode position; A2C4 = electrode position; G2 = Group 2 with change in Central Auditory Processing screening; SD = standard deviation.
* Statistically significant
Student's t-test

Figure 2 illustrates the A2C3 wave of AMLR for an individual of G1 and an individual of G2. The figure reflects the statistically significant results seen in Table 3.

Sensitivity and Specificity Analysis

Table 4 shows, respectively, the sensitivity and specificity analyses for FFR and AMLR with a cutoff value of 50%.



Auditory Middle Latency Response for Group 1 and Group 2
Illustration developed by the authors.

Figure 2. Illustration of the Na, Pa, Nb, and Pb components of the A2C3 wave of the Potential

Table 4. Sensitivity and specificity analysis of Frequency-Following Response and Auditory Middle Latency Response

	CAP BEHAVIORAL TESTS		
FFR	**Altered**	**Normal**	**Total**
Altered	15	1	16
Normal	1	15	16
Total	16	16	32
Sensitivity		93%	
Specificity		93%	
AMLR	**Altered**	**Normal**	**Total**
Altered	14	1	15
Normal	2	15	17
Total	16	16	32
Sensitivity		87%	
Specificity		93%	

Captions: CAP: Central Auditory Processing; FFR: Frequency-Following Response; AMLR: Auditory Middle Latency Response.

DISCUSSION

Studies investigating aspects of CAP in adults are scarce in the current literature, although it is known that the condition tends to impact the quality of life of these individuals[3]. Similarly, studies with FFR and AMLR compared to CAP in the adult population are not frequent, confirming the contribution of the present study.

Frequency-Following Response

Individuals with changes in CAP screening showed higher latency, the lower amplitude of components V and A of the FFR, and a lower slope value. These findings demonstrate the region's lower neural activity and the need for longer coding time for the /da/ stimulus in G2 individuals. The data corroborate previous studies, which investigated the potential in different populations[18,37].

The Onset (components V and A) reflects the coding of the rapid temporal changes resulting from consonants. The slope, in turn, indicates the response time of the generators[36,38]. Thus, it should be noted that individuals with altered auditory abilities presented a worse performance in coding the temporal aspects of the speech stimulus, as well as lower synchrony of the generators of components V and A. This factor may be closely associated with the difficulty in understanding the speech reported by these individuals, considering that speech processing depends on the temporal perception of the stimulus[41].

The V and A components of the FFR were observed in all tracings, indicating that the changes in the two screened auditory abilities did not significantly impact this aspect. A similar result was reported by Filippini and Schochat (2019)[4]. This finding does not allow us to make inferences about the underlying structural conditions because the FFR aims only to measure the functional aspects of the auditory pathway and does not provide exact indications about the generation sites[7].

Auditory Middle Latency Response

There was no statistically significant difference in AMLR latencies, indicating that the groups performed similarly. However, in terms of amplitude, the findings show that for waves A1C3 and A2C3, there were statistically significant differences for components Na and Pa. These findings for Na and Pa corroborate other studies, demonstrating that deficits in CAP generally reduce amplitudes, making them a sensitive indicator in these cases[42,43].

Great variability of amplitude and latency values among individuals without alteration of auditory abilities has not yet been observed, and latency values are quite similar to those of previous research, which used a capture protocol very similar to the one of the present study[44]. This finding becomes significant, considering that the variability of AMLR responses is one of the most questionable aspects of the applicability of the potential.

In a recent study, Musiek and Nagle (2018)[45] indicated that the AMLR components are likely to be generated in thalamic and cortical structures. Furthermore, they suggest that the Pa wave arises from regions such as the medial portion of the primary

auditory cortex. At the same time, the generation of the Na component presents contributions from the inferior colliculus. In this perspective, the results of this study suggest that individuals with altered auditory abilities presented alterations in neural synchrony in the regions mentioned above, evident only in waves A1C3 and A2C3. These findings corroborate Mattsson et al. (2019)[6], who concluded that the impairment of thalamic-cortical function could contribute to the difficulties of auditory discrimination in CAP.

Waves A1C3 and A2C3 result from the arrival of the acoustic stimulus in the left hemisphere, which contains an extension of the Wernicke area or associative auditory cortex. The Wernicke area is directed to the understanding of auditory information; therefore, the decoding failures evidenced by changes in Na and Pa in the present study may be degrading the acoustic signal and, consequently, causing difficulties in understanding[46].

In the study by Santos et al. (2015)[47], the authors pointed out that AMLR was correlated with several auditory abilities, such as auditory closure, discrimination, figure-ground, and temporal processing. This study highlights the effects of difficulties in decoding sound information, especially when speech is degraded. Also, it highlights the AMLR as an assessment capable of translating such difficulty.

The present study showed that the Pb component was absent in the A1C3 and A2C3 waves for two individuals in G2. The absence of the Pb component is generally observed in studies with infants and children[48,49], but it is not a frequent finding in adults. Aghamolaei et al. (2018)[50], studying the AMLR in adult and older individuals, confirmed the presence of the Pb component in this population. Nevertheless, the 2018 study did not include subjects with changes in CAP tests; thus, the results of the two studies may be consistent.

Sensitivity and Specificity

In the diagnostic analysis of FFR, sensitivity and specificity were both 93%. These results demonstrate the potential's adequate performance in identifying changes in CAP abilities. However, these results do not fully corroborate the results of Rocha-Muniz et al. (2014)[18], although both studies demonstrate that FFR performs well in the CAP assessment.

Rocha-Muniz et al. (2014)[18] studied the sensitivity, specificity, and accuracy for a sample of subjects aged 6-12 years. They used a ROC curve to generate latency cutoff values for all seven potential components (V, A, C, D, E, F, and O). For individuals with changes in CAP, wave A performed better, with 68% specificity, 80% sensitivity, and 74% accuracy. The difference in results may be due to several factors. In particular, although both studies investigated individuals who spoke Brazilian Portuguese, their age was different: the present study used a sample of young adults, while the other study investigated children. Also, different diagnostic methods were used.

For the cutoff criterion of 50% of the AMLR, there was a sensitivity and specificity of 87% and 93%, respectively. These values are higher than those observed by Schochat et al. (2004)[17] for the ear effect, also using a cutoff value of 50% (a sensitivity of 58.8% and a specificity of 88.9%).

The sensitivity and specificity values of AMLR and FFR were very similar. However, FFR used a speech stimulus, possibly explaining its better sensitivity. On the other hand, AMLR used a click stimulus, which, despite being effective for this potential, is less complex than the speech stimulus used for FFR. In this sense, the speech stimulus, precisely because it is more complex, becomes more sensitive to the synchrony and speed of neural impulses in processing auditory information, mainly because it contains linguistic information[4].

Limitations and future perspectives

Despite the registration impasses for the current clinical application of the FFR and the heterogeneity of the AMLR responses observed by clinicians, the contributions of both tests in the assessment of central auditory processing seem to be important and, therefore, measuring its sensitivity and specificity may be useful for audiologists and other professionals. Nevertheless, the sample size of the present study is not large enough to support the clinical findings. Therefore, the authors suggest further studies in larger samples, other populations, and other pathologies and objectively investigating the integrity of the central nervous system and cognitive and linguistic abilities.

CONCLUSION

Individuals with altered auditory abilities presented higher latency and lower response amplitude in FFR and AMLR as compared to typical individuals. FFR presented a better balance in sensitivity and specificity parameters compared to CAP, in young adults.

REFERENCES

1. American Speech-Language-Hearing Association (2005b). (Central) auditory processing disorders [Technical Report]. Available at: http://www.asha.org/docs/html/TR2005-00043.html. Accessed 2022 feb 18.
2. Moore DR. Auditory processing disorder. Ear Hear. 2018;39(4):617-20.
3. Obuchi C, Ogane S, Sato Y, Kaga K. Auditory symptoms and psychological characteristics in adults with auditory processing disorders. J Otol. 2017;12(3):132-7. doi: 10.1016/j.joto.2017.05.001.
4. Filippini R, Weihing J, Chermak GD, Musiek FE. Current issues in the diagnosis and treatment of CAPD in children. In: Geffner D, Ross-Swain D, editors. Auditory processing disorders: assessment, management, and treatment. 3rd ed. San Diego: Plural Publishing; 2019. p.3-36.
5. Schochat E, Rocha-Muniz CN, Filippini R. Understanding Auditory Processing Disorder through the FFR. In: Kraus N, Anderson S, White-Schwoch T, Fay RR, Popper AN, editors. The Frequency-Following Response. Cham: Springer; 2017. p.225-50.
6. Mattsson TS, Lind O, Follestad T, Grøndahl K, Wilson W, Nicholas Jet al. Electrophysiological characteristics in children with listening difficulties, with or without auditory processing disorder. Int J Audiol. 2019;58(11):704-16. doi: 10.1080/14992027.2019.1621396.
7. Skoe E, Kraus N. Auditory brainstem response to complex sounds: a tutorial. Ear Hear. 2010;31(3):302-24. doi: 10.1097/AUD.0b013e3181cdb272.
8. Weihing J, Schochat E, Musiek F. Ear and electrode effects reduce within- group variability in middle latency response amplitude measures. Int J Audiol. 2012;51(5):405-12. doi: 10.3109/14992027.2012.658970.
9. Kraus N, Anderson S, White-Schwoch T. The Frequency-Following Response: a window into human communication. In: Kraus N, Anderson S, White- Schwoch T, Fay RR, Popper AN, editors. The Frequency-Following Response: a window into human communication. Cham: Springer; 2017. p.1- 15.
10. Coffey EBJ, Nicol T, White-Schwoch T, Chandrasekaran B, Krizman J, Skoe E et al. Evolving perspectives on the sources of the frequency-following response. Nat Commun. 2019;10(1):5036.
11. Hornickel J, Kraus N. Unstable representation of sound: a biological marker of dyslexia. J Neurosci. 2013;33(8):3500-4. doi: 10.1523/JNEUROSCI.4205-12.2013.
12. Johnson K, Nicol T, Zecker S, Kraus N. Developmental plasticity in the human auditory brainstem. JNeurosci. 2008;28(15):4000-7. doi: 10.1523/JNEUROSCI.0012-08.2008.
13. Sanguebuche TR, Peixe BP, Bruno RS, Biaggio EPV, Garcia MV. Speech- evoked brainstem auditory responses and auditory processing skills: a correlation in adults with hearing loss. Int Arch Otorhinolaryngol. 2018;22(01):38-44. doi: 10.1055/s-0037-1603109.
14. Liu P, Zhu H, Chen M, Hong Q, Chi X. Electrophysiological screening for children with suspected auditory processing disorder: a systematic review. Front. Neurol. 2021;12:692840. doi: 10.3389/fneur.2021.692840.
15. Hall JW III. New Handbook of auditory evoked responses. Boston: Allyn & Bacon; 2007.
16. American Academy of Audiology. Clinical practice guidelines: diagnosis, treatment and management of children and adults with central auditory processing disorder. [homepage on the internet]. 2010 [accessed 2022 feb 20]. Available at: https://www.audiology.org/publications/guidelines-and-standards
17. Schochat E, Rabelo CM, Loreti RCA. Sensitividade e especificidade do potencial de média latência. Rev. Bras. Otorrinolaringol. 2004;70(3):353-8. doi: 10.1590/S0034-72992004000300011.
18. Rocha-Muniz CN, Befi-Lopes DM, Schochat E. Sensitivity, specificity and efficiency of speech-evoked ABR. Hear Res. 2014;317:15-22. doi: 10.1016/j.heares.2014.09.004.
19. Organização Mundial de Saúde - OMS [homepage on the internet]. 2014 [accessed 2020 oct 12]. Available at: http://www.who.int/pbd/deafness/hearing_impairment_grades/en/.
20. Maruthy S, Mannarukrishnaiah J. Effect of early onset otitis media on brainstem and cortical auditory processing. Behav Brain Funct. 2008;2(4):17. doi: 10.1186/1744-9081-4-17

21. Costa J, Valls-Solé J, Valldeoriola F, Pech C, Rumià J. Single subthalamic nucleus deep brain stimuli inhibit the blink reflex in Parkinson's disease patients. Brain. 2006;129(7):1758-67. doi: 10.1093/brain/awl143.
22. Webster R. The auditory brainstem response (ABR): a normative study using the Intelligent Hearing System's smart evoked potential system [thesis]. Towson, Maryland (USA): Towson University; 2017.
23. Santos FMC, Pereira LD. Escuta com dígitos. In: Pereira LD, Schochat E, editors. Processamento auditivo central: manual de avaliação. 1st edition. São Paulo: Lovise; 1997. p.147-50.
24. Sanguebuche TR, Peixe BP, Garcia MV. Behavioral tests in adults: reference values and comparison between groups presenting or not central auditory processing disorder. Rev. CEFAC. 2020;22(1):e13718. doi: 10.1590/1982- 0216/202022113718.
25. Humes LE, Bess FH. Audiology & communication disorders an overview. 4th edition. Wolters Kluwer Health/Lippincott Williams & Wilkins; 2008.
26. Jerger J. Clinical experience with impedance audiometry. Arch Otolaryngol. 1970;92(4):311-24. doi: 10.1001/archotol.1970.04310040005002
27. Jerger J, Jerger S, Mauldin L. Studies in impedance audiometry. Normal and sensorineural ears. Arch. Otolaringol. 1972;96(6):513-23. doi: 10.1001/archotol.1972.00770090791004.
28. Dias KZ, Jutras B, Acrani IO, Pereira LD. Random Gap Detection Test (RGDT) performance of individuals with central auditory processing disorders from 5 to 25 years of age. Int J Ped Otorhinolaryngol. 2012;76(2):174-8.doi: 10.1016/j.ijporl.2011.10.022.
29. Weihing J, Atcherson SR. Dichotic listening tests. In: Musiek FE, Chermak G, editors. Handbook of central auditory processing disorder. San Diego: Plural Puablishing; 2014. p.369-404.
30. Vellozo FF, Schwantes AL, Souza AEH, Peixe BP, Biaggio EPV, Martins QP et al. Temporal resolution in elderly. Rev. CEFAC. 2016;18(2):355-61. doi:10.1590/1982-0216201618219915.
31. Heeke P, Vermiglio AJ, Bulla E, Velappan K, Fang X. The relationship between random gap detection and hearing in noise test performances. J Am Acad Audiol. 2018;29(10):948-54. doi: 10.3766/jaaa.18005.
32. Sartori AATK, Delecrode CR, Cardoso AVC. (Central) auditory processing in schoolers in initial literacy grades. CoDAS. 2019;31(1):e20170237.doi: 10.1590/2317-1782/20182018237.
33. Pereira LD, Schochat E. Testes auditivos comportamentais para avaliação do processamento auditivo central. 2a edição. Barueri: Pró-Fono; 2011.
34. Keith RW. Standardization of the Time Compressed Sentence Test. Journal of Educational Audiology. 2002;10:15-20.
35. Sanfins MD, Garcia MV, Biaggio EPV, Skarzynski PH. The Frequency Following Response: evaluations in different age groups. In: Hatzopoulos S, editor. The human auditory system: basic features and updates on audiological diagnosis and therapy. 1st edition. IntechOpen; 2019.
36. Russo N, Nicol T, Musacchia G, Kraus N. Brainstem responses to speech syllables. Clin Neurophysiol. 2004;115(9):2021-30. doi: 10.1016/j.clinph.2004.04.003.
37. Kumar P, Singh NK. BioMARK as electrophysiological tool for assessing children at risk for (central) auditory processing disorders without reading deficits. Hear Res. 2015;324:54-8. doi: 10.1016/j.heares.2015.03.001.
38. Song JH, Nicol T, Kraus N. Test-retest reliability of the speech-evoked auditory brainstem response. Clinical Neurophysiology. 2011;122(2):343-55. doi: 10.1016/j.clinph.2010.07.009.
39. Hall III JW. Handbook of auditory evoked responses: principles, procedures & protocols. Pearson Education; 2015.
40. McPherson DL, Ballachanda BB, Kaf W. Middle and Long Latency Evoked Potentials. In: Roeser RJ, Valente M, Dunn HH, editors. Audiology: diagnosis. 2a edição. New York: Thieme; 2008. p.443-77.
41. Nakajima Y, Matsuda M, Ueda K, Remijn GB. Temporal resolution needed for auditory communication: measurement with mosaic speech. Front. Hum. Neurosci. 2018;12(149):1-8. doi: 10.3389/fnhum.2018.00149.
42. Romero ACL, Sorci BB, Frizzo ACF. Relationship between auditory evoked potentials and middle latency auditory processing disorder: cases study. Rev. CEFAC. 2013;15(2):478-84. doi: 10.1590/S1516-18462013005000002.

43. Schochat E, Musiek FE, Alonso R, Ogata J. Effect of auditory training on the middle latency response in children with (central) auditory processing disorder. Braz J Med Biol Res. 2010;43(8):777-85. doi: 10.1590/S0100- 879X2010007500069.
44. Pelaquim A. Potenciais de curta, média e longa latência em adultos no equipamento Smart-EP IHS®: normatização dos valores de latência e amplitude [Dissertation]. Londrina (PR): Universidade Estadual de Londrina; 2019.
45. Musiek F, Nagle S. The middle latency response: a review of findings in various central nervous system lesions. J Am Acad Audiol. 2018;29(9):855-67. doi: 10.3766/jaaa.16141.
46. Rouse MH. Neuroanatomy for speech-language pathology and audiology. 2ª edição. Burlington, Massachusetts: Jones & Bartlett Learning; 2019.
47. Santos TS, Mancini PC, Sancio LP, Castro AR, Labanca L, Resende LM. Findings in behavioral and electrophysiological assessment of auditory processing. Audiol., Commun. Res. 2015;20(3):225-32. doi: 10.1590/2317-6431-2015-1589.
48. Luo JJ, Khurana DS, Kothare SV. Brainstem auditory evoked potentials and middle latency auditory evoked potentials in young children. J ClinNeurosci. 2013;20(3):383-8. doi: 10.1016/j. jocn.2012.02.038.
49. Ozdamar O, Kraus N. Auditory middle-latency responses in humans. Audiology. 1983;22(1):34-49. doi: 10.3109/00206098309072768.
50. Aghamolaei M, Jafari Z, Grimm S, Zarnowiec K, Najafi-Koopaie M, Escera C. The effects of aging on early stages of the auditory deviance detection system. Clinical Neurophysiology. 2018;129(11):2252-58. doi: 10.1016/j.clinph.2018.08.006.