A Systematic Review of the Literature Between 2009 and 2019 to Identify and Evaluate Publications on the Effects of Age-Related Hearing Loss on Speech Processing

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Changes in central auditory processing due to aging in normal-hearing elderly patients, as well as age-related hearing loss, are often associated with difficulties in speech processing, especially in unfavorable acoustic environments. Speech processing depends on the perception of temporal and spectral features, and for this reason can be assessed by recordings of phase-locked neural activity when synchronized to transient and periodic sound stimuli frequency-following responses (FFRs).

An electronic search of the PubMed and Web of Science databases was carried out in July 2019. Studies that evaluated the effects of age-related hearing loss on components of FFRs were included. Studies that were not in English, studies performed on animals, studies with cochlear implant users, literature reviews, letters to the editor, and case studies were excluded.

Our search yielded 6 studies, each of which included 30 to 94 subjects aged between 18 and 80 years. Latency increases and significant amplitude reduction of the onset, offset, and sloop V/A components of FFRs were observed. Latency and amplitude impairment of the fundamental frequency, first formant, and high formants were related to peripheral sensorineural hearing loss in the elderly population.

Conclusions: Temporal changes in FFR tracing were related to the aging process. Hearing loss also impacts the envelope fine structure, producing poorer speech comprehension in noisy environments. More research is needed to understand aspects related to hearing loss and cognitive aspects common to the elderly.

Keywords: Aging • Auditory Perception • Brain Stem • Speech Perception

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Background

Speech perception in acoustically unfavorable environments, such as noisy or reverberant environments, is among the most complex tasks faced daily by individuals with normal hearing, representing challenges for young adults and the elderly [1-3]. Auditory thresholds are an important factor in speech perception in noise. In addition, the processing of temporal (duration and intensity) and spectral (tone and timbre) characteristics are essential for a successful understanding of the speaker’s voice [2,4]. In addition to the peripheral auditory system, structures of the central auditory system play an important role in this function [5,6].

Investigating the consequences of the impact of hearing loss in the aging process should be a priority, as this deficiency affects the communication process in an overwhelming way [4]. Hearing loss in the elderly is still underdiagnosed, and is often considered a stage of life, when in fact it is a health condition that should be treated quickly to ensure a better quality of life and well-being [7,8]. Many previous studies have used subjective measures to evaluate listening effort; however, the diversity of methods available today makes the application of subjective methods debatable [9]. The use of objective measures could help in this process.

Frequency-following responses (FFRs) are auditory evoked potentials in response to a speech stimulus. This objective and non-invasive method for the assessment of central auditory function allows the objective measurement of the neural representation in real time of important speech cues in the subcortical and cortical region of the auditory pathway [1]. FFRs are known to vary with age.

Therefore, a narrative review of the literature was conducted to identify and evaluate publications in the English language between 2009 and 2019 on the effects of age-related hearing loss on components of FFRs.

Material and Methods

Ethics Statement

The local ethics committee resolution 510/2016 provides for the waiver of submission to the ethics committee system for research carried out exclusively with scientific texts for scientific literature review, as is the case with this research.

Search Strategy

A narrative review was performed in July 2019 in the electronic databases PubMed and Web of Science. The elaboration of the search strategy aimed to concretize the research question. The selection of search terms was also realized by observing the terms that the relevant articles used as keywords. Search variables, including the search term “FFR”, were used in combination with controlling terms from MeSH including “aging”, “auditory evoked potentials”, “speech perception”, “time perception”, “auditory perception”, and “brain stem”. The combination of search terms was performed in triplets with the Boolean AND operator, as listed in Table 1.

Table 1. Description of the number of articles found according to descriptors, and the databases in which they were found.

| Descriptor Used                                                                 | Database | PubMed | Web of Science |
|--------------------------------------------------------------------------------|----------|--------|----------------|
| “Aging AND FFR AND speech evoked brainstem response” |           | 11     | 14             |
| “Aging AND FFR AND speech perception in noise” |           | 9      | 12             |
| “Aging AND FFR AND speech perception” |           | 19     | 22             |
| “Aging AND FFR AND temporal processing” |           | 16     | 11             |
| “Aging AND speech perception AND speech evoked brainstem response” |           | 24     | 27             |
| “Aging AND speech perception AND speech perception in noise” |           | 265    | 1026           |
| “Aging AND speech perception AND temporal processing” |           | 128    | 372           |
| “Aging AND speech perception in noise AND speech evoked brainstem response” |           | 12     | 25            |
| “Aging AND temporal processing AND speech evoked brainstem response” |           | 10     | 25             |
| “Aging AND temporal processing AND speech perception in noise” |           | 59     | 150           |
| Total number of articles                                                                 |           | 553    | 1684         |
Eligibility Criteria

The inclusion criteria were publications in English from July 2009-19 (10 years); controlled clinical trials; studies with elderly participants (individuals aged 60 years and over) according to the World Health Organization criteria [5]; and studies in which FFRs were performed using the syllable /da/ with a duration of 40 ms [10]. Exclusion criteria were experiments performed on animals, studies with cochlear implant users, literature reviews, letters to the editor, case-control studies, case studies, and studies that were not directly linked to the topic.

Selection Process and Data Collection Process

In an initial step, selection and evaluation of the articles was done by reading the titles and abstracts. Selected articles were then submitted to a full-text reading and only those that met the established inclusion and exclusion criteria were used for this review. Reference lists were not examined; references cited in study reports were included in the narrative review. There were no searches for cited references (backward and forward citation searching). Journals or conference proceedings were not included in the review.

Differences between the authors in their judgment were resolved through discussion. Information from the remaining full-text articles was collected in a spreadsheet including the variables analyzed: age, hearing status, stimuli presentation, and findings on FFRs.

Results

Study Selection

Among the 2237 initial articles identified, 6 articles were selected that met the criteria for methodological analysis [2,3,11-14]. Thirty-three studies were excluded from this review after reading the full text because they did not meet the previously established inclusion criteria. Some of these works made use of the syllable /da/, with a duration of 170 ms, as described in Anderson et al [1,13] and Fujihira and Shiraishi [15], or studies carried out with other types of verbal stimuli such as vowels (Figure 1).

Study Characteristics

FFR acquisition parameters (equipment, stimulated ear, stimulus type and duration, number of scans, polarity, fundamental frequency, and formants), in addition to the characteristics and results reported in the 6 selected articles – including sample, auditory evaluation, stimulus presentation, complementary evaluation, and results – are summarized in Tables 2 and 3.

Sample Characteristics

The number of study participants ranged from 30 [14] to 94 [11] subjects, aged between 18 and 80 years, with the presence of a control group in 5 of the 6 studies [2,3,11-14]. The exception was Clinard and Tremblay [2], who did not distinguish between the study group and the control group, instead comparing young, middle-aged, and elderly individuals without hearing loss, distributed into 7 groups per decade.
**Hearing Assessment and Complementary Assessments**

All participants in the 6 studies selected for this review underwent hearing assessment. Alterations in the pure tone auditory thresholds between the study groups (hearing loss) and the normal-hearing groups (controls) were seen in 3 of the studies [3,11,16]. In the other 3 studies, Ansari et al [5], Clinard and Trembley [2], and Vander et al [7], age was the only significant variable, since both groups had normal hearing.

Three of the 6 studies looked at wave V in addition to conducting pure tone audiometry. The presence of wave V, with latencies within the normal range, was the criterion for inclusion of participants, both in the control group and in the study group [12-14]. In 2 of the studies [3,11], cognitive tests and behavioral tests of speech comprehension in silence and in noise were used as complementary assessments. In 1 study, a self-assessment questionnaire was used [3].

**FFRs: Acquisition Parameters and Stimulus Presentation**

All studies obtained the FFRs using the verbal stimulus /da/, with alternating polarity and 40 ms duration [2,3,11-14]. The stimulus /da/ was presented, for the most part, at an intensity of 80 dB sound pressure level (SPL) [2,3,11,14]. Ansari and colleagues used the intensity of 65 dB SL [12] while Vander and colleagues [13] used 2 different intensities (82 and 62 dB SPL), and the lower stimulus level was recorded in a subgroup.

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**Table 2. FFR acquisition parameters of the included studies.**

| Article                  | Equipment                                | Software          | Stimulated ear | Stimuli | Duration (ms) | Number of sweeps |
|-------------------------|------------------------------------------|-------------------|----------------|---------|---------------|------------------|
| Jain et al 2019 [11]    | BioLogic-Navigator Pro                   | Matlab BioMARK    | RE/LE          | /da/    | 40            | 4000             |
| Heidari et al 2018 [3]  | BioLogic Navigator Pro                   | Matlab BioMARK    | RE             | /da/    | 40            | 2 blocks of 2000 |
| Ansari et al 2017 [12]  | Intelligent Hearing Systems              | SmartEP           | RE             | /da/    | 40            | 2 blocks of 2000 |
| Anderson et al. 2013    | BioLogic Navigator Pro System            | Neuroscan SynAmps2 BioLogic Navigator Pro | RE/LE | /da/    | 40            | 2 blocks of 3000 |
| Clinard and Tremblay    | Neuroscan SynAmps2                       | Matlab            | RE             | Tone burst /da/ | 500 | 2 blocks of 3000 |
| Vander et al 2011       | BioLogic Navigator Pro                   | Matlab BioMARK    | RE/LE          | /da/    | 40            | 2 blocks of 1500 |

| Article                  | Intensity | Polarity | Presentation rate (stimuli/s) | F0 (Hz) | F1 (Hz) | F2 (Hz) |
|-------------------------|-----------|----------|-------------------------------|---------|---------|---------|
| Jain et al 2019 [11]    | 80 dB SPL | Alternate| 10.1                          | 103-125 | 220-720 | 1700-1240 |
| Heidari et al 2018 [3]  | 80 dB SPL | Alternate| 10.9                          | 103-125 | 220-720 | 1700-1240 |
| Ansari et al 2017 [12]  | 65 dB HL  | Alternate| 11.1                          | 113-147 | 240-770 | 1670-1350 |
| Anderson et al. 2013    | 80 dB SPL | Alternate| 10.9                          | 103-125 | 220-720 | 1700-1240 |
| Clinard and Tremblay    | 80 dB SPL | Alternate| 10.9                          | 103-125 | 220-720 | 1700-1240 |
| Vander et al 2011       | 82 dB SPL | Alternate| 11.1                          | 103-121 | 454-719 | 721-1155  |

RE – right ear; LE – left ear; ms – milliseconds; SPL – sound pressure level; HL – hearing level; dB – decibels; Hz – hertz; F0 – fundamental frequency; F1 – first formant; F2 – second formant.
### Table 3. Characteristics of selected studies.

| Article | Sample | Audiological assessment | Stimuli presentation | Complementary assessment | Results |
|---------|--------|-------------------------|----------------------|--------------------------|---------|
| Jain et al 2019 [11] | SG: 40 ONH, 60-80 years, mean age 63±2.95 years | ONH: pure-tone thresholds <15 dB HL from 0.25-2 kHz and <30 dB HL from 4-8 kHz | BioLogic Navigator Pro | SIN test with sentences in Kannada | The older adults performed significantly more poorly than the younger adults on the quick speech perception in noise test and various cognitive measures |
| | CG: 52 YNH, 20-40 years, mean age 30±5.15 years | YNH: pure-tone thresholds <15 dB HL from 0.25-8 kHz | Quiet and noise condition (ipsilateral pink noise at +10 dB SNR) | Auditory digit sequencing | There was a significant deterioration in brainstem encoding of speech with aging |
| | Native speakers of Kannada | | | Spatial selective attention task | Fundamental frequency of the speech auditory brainstem response correlated with speech perception in noise |
| | Formal education ≥10 years | | | | |
| Heidari et al 2018 [3] | SC: 32 NH elderly, over 60 years, mean age: 68.9±6.3 years, 17 M | SG: pure tone average ≤25 dB HL in 0.5-4 kHz; thresholds of each of 4 frequencies ≤40 dB HL; maximum mean difference as 5 dB HL | BioLogic Navigator Pro | MMSE | The score of the SIN test was lower among the elderly people as compared with young people in signal-to-noise ratios of 0 and -10 based on Iranian version of the SSQ questionnaire (p<0.001) |
| | CG: 32 young NH subjects, 18-25 years, mean age: 21.43±1.74 years, 16 M. | CG: pure tone average <25 dB HL in 0.5-4 kHz | Quiet condition | SIN test | The range of F0 amplitude in the elderly people was also lower than that in young people (p<0.001), in speech ABR |
| | Persian native speakers | | | SSQ questionnaire | |
| | Right-handed | | | | |
| Ansari et al 2017 [12] | SG: 25 geriatric people with NH, 60-75 years, mean age 66.1±6.2 years | Pure tone thresholds ≤25 dB HL in 0.25-8 kHz | IHS SmartEP | | The older group had significantly smaller amplitudes and longer latencies for the onset and offset responses in noisy conditions |
| | CG: 25 young adults with NH, 18-25 years, mean age: 21.3±3.2 years | Normal middle-ear function | Quiet and noise conditions (ipsilateral Gaussian noise at +5 dB SNR) | | Stimulus-to-response times were longer and the spectral amplitude of the sustained portion of the stimulus was reduced |
| | Right-handed | Normal click-evoked ABR | | | The overall stimulus level caused significant shifts in latency across the entire speech-evoked auditory brainstem response in the older group |

*Note: ONH = Older Normal Hearing, YNH = Young Normal Hearing, MMSE = Mini-Mental State Examination, SSQ = Strittmatter Speech Understanding Questionnaire.*
### Table 3 continued. Characteristics of selected studies.

| Article                          | Sample                                | Audiological assessment | Stimuli presentation | Complementary assessment | Results                                                                                                                                 |
|---------------------------------|---------------------------------------|-------------------------|----------------------|--------------------------|------------------------------------------------------------------------------------------------------------------------------------------|
| Anderson et al 2013 [13]        | SG: 15 HI adults, ages 60-71 years, mean age: 64.07±3.39 years | SG: thresholds from 0.125-2 kHz ≤40 dB HL and from 3-8 kHz <70 dB HL PTA ≥30 dB HL and <45 dB HL | BioLogic Navigator Pro | CG: quiet and noise condition | In the HI group, there was a disruption in the balance of envelope-to-fine structure representation compared with the normal hearing group. This imbalance may underlie the difficulty experienced by individuals with sensorineural hearing loss when trying to understand speech in background noise. |
|                                 | CG: 15 NH adults, ages 61-68 years, mean 64.07±2.09 years | CG: ≤20 dB HL from 0.125-4 kHz, ≤40 dB HL at 6-8 KHz. PTA from 0.5-4 kHz ≤15 dB HL | SG: unamplified stimulus presented in quiet; amplified stimulus presented in quiet; unamplified stimulus presented in noise | Noise condition: ipsilateral, pink noise at +10 dB SNR |                                                                                                                                           |
|                                 |                                        | Normal click-evoked ABR | Quiet condition      |                          |                                                                                                                                           |
| Clinard and Tremblay 2013 [2]   | 34 adults aged 22-77 yrs., 30 M.      | NH sensitivity: thresholds ≤25 dB HL at 0.25-8 kHz | FFR elicited by 500 ms tone-burst stimuli (Neuroscan SynAmps2) | FFR elicited by consonant-vowel syllable (BioLogic Navigator Pro) | The neural representation of simple (tone) and complex (/da/) stimuli declines with advancing age. Tone-FFR phase coherence decreased as chronological age increased. Transient onset and offset response amplitudes were smaller, and offset responses were delayed with age. Sustained responses at the onset of vowel periodicity were prolonged in latency and smaller in amplitude as age increased. FFT amplitude of consonant-vowel FFR fundamental frequency did not significantly decline with increasing age. |
of subjects. The number of sweeps ranged between 2 blocks of 1500 [13], 2 blocks of 2000 [3,12], 2 blocks of 3000 [14], and 1 block of 4000 [11].

Monaural presentation of stimuli to the right ear (RE) occurred in 4 studies [2,3,12,13], while in 2 studies the presentation was to the RE and left ear (LE) separately [11,16]. Presentation rate was a parameter that differed among the selected articles; 3 of them [2,3,14] used a rate of 10.9 stimuli per second, while others [12,13] opted for a higher rate of 11.11 stimuli per second and only 1 article [11] used the rate of 10.1 stimuli per second.

Most of the FFR collections were performed using BioLogic-Navigator Pro equipment [2,3,11-13,14]. One study [12] performed the collections with the Intelligent Hearing System. Clinard and Trembley [2] used Neuroscan SynAmps2 for tone-burst collection and BioLogic-Navigator Pro for FFR collection.

FFR responses were assessed under conditions of silence or noise. Four articles explored both conditions [2,3,11,12] and 2 articles took the measurements only in the silence condition [13,14].

**FFR Analysis Parameters**

**Onset, Offset, and Transition Portion**

In 5 of the articles, analysis of the transient component of the FFRs was performed [2,3,11-14]. The latencies and amplitudes of waves V, A (onset), and O (offset) were measured, and showed statistically significant changes when the study and control groups were compared. The onset portion of the stimulus showed a reduction in amplitude of wave V in 2 cases [2,13]; an increase in the latency of waves V and A in 1 case [12]; and changes in both latency and amplitude in 2 cases [11,14].

As for the offset component, 5 studies reported a significant increase in latency [2,3,11-13] and in 3 of them there was a reduction in the amplitude of wave O [2,11,12]. A reduction in the slope of the VA complex was also reported in 1 of the studies. In 1 study, there were differences in the latency and amplitude of wave A when the RE and LE were compared [14], with the RE showing more changes.

Analysis of the C wave (transition component) was performed in 2 of the studies: 1 of them found a reduction in amplitude [12] while the other an increase in latency [2], the latter correlating the increase in latency with older age. Furthermore, the elderly in that study had hearing loss with a reduction in wave D amplitude. Turning to waves E and F, 1 paper did not see statistically significant alterations in these waves, which could be related to peripheral hearing loss [2]. On the other hand, another paper [14] found that a reduction in amplitude of these waves was correlated with peripheral hearing loss.

**Sustained Portion**

The sustained portion of the FFR was analyzed in terms of fundamental frequency (F0), first formant (F1), and higher
formants (HF). F0 was evaluated in all 6 articles. A reduction in the amplitude of F0 [3,12,14] was observed in conditions of silence only [3], noise only [13], and in both conditions [11]. An increase in latency associated with a reduction in F0 amplitude was described in 2 studies [11,13]. F1 and HF demonstrated an increase in latency and a reduction in amplitude of these components in 3 studies [11-13], and in 1 of them [12], the changes were observed only in the presence of noise. In another study [14], a reduction in amplitude was observed in the silent environment. In the work by Heidare et al [3], there were no significant differences between the control and study groups in terms of F1 and HF.

**Discussion**

The present study aimed to carry out a narrative review of the literature between 2009 and 2019 to identify and evaluate publications on the effects of age-related hearing loss on speech processing. The analysis of the studies showed that there are still few studies that make use of objective methods in the investigation of speech processing in elderly patients. Only 6 studies met the inclusion criteria for the present study. The data will be presented in a structured way to favor the reader’s understanding.

**Contestable Data**

**Sample**

Regarding the number of participants, there was great diversity between the different studies. One aspect that stands out is the age difference between individuals in the control group (usually young adult individuals) vs the study group (elderly individuals). Only 1 of the studies controlled for age. This difference between the control and study groups is a confounding factor that can give rise to misleading results. Except for the 2013 results of Andersons et al [14], the comparison performed was between the responses of young adults and those of elderly adults. The age difference between the groups may not be appropriate, since advancing age alone leads to an impairment in speech perception processes [17].

**Audibility**

Regarding the aspect of audibility, there is an important difference between the studies. In 50% of the studies, individuals in the control and study groups had pure tone thresholds within the normal range [2,12,13]. In contrast, in the other 50% of the studies, there were alterations in the auditory thresholds between the control and study groups [3,11,16]. Researchers have already found a significant impact on listening effort, mainly in speech recognition, communication, and language in cases of individuals with hearing loss [10]. Thus, the comparison of responses in individuals with different audibility conditions is a limiting factor.

**Cognitive Assessment**

Another point analyzed was performance on cognitive assessments, with a preliminary cognitive analysis being performed only in 2 [3,11] of the 6 studies. This was among the most worrying aspects, because there is a strong and clear association between hearing loss and impairments in cognitive processes. According to Loughrey et al [18], there are significant associations between hearing loss and cognitive abilities, such as: visuospatial ability, processing speed, semantic memory, executive function, global cognition, and episodic memory. Therefore, the application of assessments that analyze executive and cognitive functions are essential. The lack of this requirement can raise doubts in that the alterations found in the objective responses could be due to cognitive impairment or auditory impairment.

**Frequency-Following Response Assessment**

In view of the above considerations, from this point onwards, the responses on the FFR assessment will be discussed.

**Stimulus: Verbal Stimulus /da/**

All studies were performed using the verbal stimulus /da/ with alternating polarity and 40 ms duration [2,3,11-14]. For testing central auditory alterations in elderly patients, with or without hearing loss, FFRs using verbal stimuli have been widely studied. As described by Anderson and Kraus [4] and Kraus and Nicol [19], among other authors, the use of verbal stimuli allows the identification of temporal aspects (speech onset, offset, and transition between phonemes), as well as spectral aspects of the speech signal (pitch-F0 and timbre-harmonics) as they are being processed. The robust response patterns allow us to analyze processing of this information along the auditory pathway in terms of frequency and time. There seem to be good correlations between the responses and some complaints by the elderly population regarding speech comprehension.

The syllable /da/ is considered a universal syllable because it is present in most phonetic inventories [6,16,20]; it is made up of 2 distinct portions, a transient portion, and a sustained portion, each of which can be analyzed individually [16]. The syllable provides clear, robust, and replicable responses, providing insight into sound encoded in the auditory system. The advantages are that it maintains the original characteristics of the stimulus when electrophysiological responses are obtained [16,21], it provides a good correlation between intra- and inter-subject responses, and it gives stable test–retest responses [20].
The potentials evoked by complex stimuli such as speech are intensity-dependent suprasegmental tests. This means that FFR components are differently impacted by intensity variation, and so stepped increases in the stimulus intensity provide systematic changes in the latencies of the transient and sustained components [22,23]. Similar alterations have been observed with click auditory brainstem responses (ABR) and tone-burst-elicted FFR [16]. For this reason, parameterization of the stimuli and the responses is fundamental when comparing different studies. The FFR with verbal stimuli, especially the syllable /da/, has been widely used to precisely characterize how complex sounds are processed along the auditory pathway [6].

**Stimulus: Tone-Burst Stimulus**

In 1 of the analyzed studies [2], in addition to use of the verbal stimuli /da/, FFRs were also collected with a tone-burst of 500 ms at an intensity of 80 dB SPL. An FFR can also be performed with a tone-burst that broadly corresponds to the sustained portion of the FFR made with the syllable /da/ [24]. The objective here was to verify that there was agreement between the findings obtained with each of these stimuli, and whether these findings can be related to the aging process. So, the collection of potentials elicited by a tone-burst might be an efficient tool in identifying changes due to aging. Indeed, 1 paper found significant correlations between waves E and F in terms of phase coherence, suggesting there was worse neural synchrony and impaired frequency representation in older individuals [2].

**Number of Sweeps**

The number of sweeps varied, with 3000 [2,13,14], 2000 [3,12], and 4000 [11] sweeps used. The number of scans or stimuli presented varies widely in the literature [25]. Some suggest using 4000 to 6000 stimuli [26], but the highest number of waves can be discerned using 2 series of 3000 sweeps [26]. The latency of waves is not affected by the number of stimuli, although the number of waves visible can change in percentage terms. Waves V and C are the ones most likely to be compromised by fewer stimuli [27].

**Stimulus Presentation**

Monaural presentation of stimuli to the RE occurred in 4 studies [2,3,12,13], while in 2 studies the presentation was to the RE and LE separately [11,16]. When stimuli were presented to the RE and LE separately, the potentials were similar, although not identical. There is an advantage in the coding of verbal sounds when presented to the RE [16] because of contralateral projection to the left hemisphere [28], even in young individuals who have no hearing loss. In the transient portion of the FFR, an increase in latency and a reduction in the amplitude of wave A are observed when the LE and RE of the study group (the elderly) are compared, a change which was not observed in the control group (young adults). There was no difference in response between the LE and the RE when the sustained portion of the FFR was analyzed.

For adults, binaural presentation of a stimulus (RE and LE simultaneously) allows more robust waves to be visualized without altering the response time [16,25]. In only a single study [14] was the stimulus presented in the binaural condition, in which the intention was to observe differences in the elderly (with or without symmetrical peripheral hearing loss).

**Intensity Presentation**

With regard to intensity values, 80 dB SPL was used in 4 of the articles [2,3,11,14]; however, 1 of these used 65 dB hearing level [12]. In general, previous studies carried out with the FFR made use of 80 dB SPL [28,29]. One study carried out 2 intensities: 82 dB SPL and 62 dB SPL [13]. The change in intensity brought some new information as a strong correlation between auditory acuity and the latencies of waves A, E, and F. In addition, it was possible to confirm that in the group whose individuals had a higher degree of hearing loss, an increase in the values of latencies was observed.

**Condition Presentation**

FFR responses can be captured under 2 conditions, in silence or in noise. In 3 of the articles, both conditions were explored [11-13,], and in the other 3 [2,3,14], measurements were only made in silence. Nowadays, there is growing interest in comparing responses in silence vs noise, especially in individuals whose perception of speech sounds appears to be impaired, such as the elderly and children with dyslexia or scholastic difficulties [17,30].

**Equipment**

Five of the studies used BioLogic-Navigator equipment [2,3,11,13,14], while 1 of them used Intelligent Hearing System and Neuroscan SynAmps equipment, which corroborates with previous studies [29].

**FFR in the Elderly**

**Shape**

The FFR has 7 peaks, known as V, A, C, D, E, F, and O, with the first portion formed by the onset response and the last by the FFR. The onset portion is composed of waves V, A, and C, and the sustained portion of the FFR made with the syllable /da/ [24]. The FFR in the Elderly...
the vowel /a/. The FFR reflects the F0 and the transition of the formants to the harmonic structure of the consonant-vowel [6]. Latency and amplitude values of these peaks, as well as the VA and F0 slope, in normal-hearing young adults, have been extensively studied and characterized in the literature [31,32], allowing other groups to be characterized in terms of deviations from these reference values.

**Onset and Offset Portion**

In 5 of the articles, analysis of the onset portion of the FFRs was performed [2,3,11-14]. The onset portion of the stimulus showed a reduction in amplitude of wave V in 2 studies [2,13]; an increase in the latency of waves V and A in 1 study [12]; and changes in both latency and amplitude in 2 studies [11,14]. The onset component (waves V and A) and offset component (wave O) of the transient portion of the FFR show increased latencies and/or reduced amplitudes [2,3,11-13], a finding that may be directly related to aging of the auditory pathways. As for the transient portion of the FFR, no statistically significant differences due to age-related hearing loss have been identified in the transient and transition portions [14]. However, the VA slope has shown lower response amplitudes in elderly individuals [12]. The transient portion mainly represents the response to discrete changes in the stimulus. In speech perception, consonants are the part that bring meaning to words and their fast onset and decay demands a precise response from the auditory nervous system. Elderly people or people with learning disabilities often have deficits in the neural coding of speech sounds at the cortical and brainstem level, especially when background noise is introduced. The general findings are important, pointing out that both elderly people with and without hearing loss show the same decline in the perception of the transient portion, a characteristic that is not exacerbated by hearing loss.

In the offset portion, 5 of the studies reported a significant increase in latency [2-4,12,13] and in 3 of them, there was a reduction in the amplitude of wave O [2,11,12]. A reduction in the slope of the VA complex was also reported in 1 of the studies. In 1 study, there were differences in the latency and amplitude of wave A when the RE and LE were compared [14], with the RE showing more changes.

**Transition Portion**

The analysis of the C wave (transition component) was performed in 2 studies: 1 of them found a reduction in amplitude [12] while the other an increase in latency [2], the latter correlating with a reduction in wave D amplitude in the elderly who had hearing loss. Turning to waves E and F, 1 paper did not observe statistically significant alterations in these waves, which could be related to peripheral hearing loss [2]. On the other hand, another paper [14] found that a reduction in amplitude of these waves was correlated with peripheral hearing loss. The transition portion (C wave) of the FFR showed an increase in latency [2] and a reduction in amplitude [12]. However, in the literature, we saw that many researchers choose not to mark the C wave because it does not have a robust representation in the studied population [26,27].

**Sustained Portion**

The sustained portion of the FFR was analyzed in terms of fundamental frequency (F0), first formant (F1), and HF. F0 was evaluated in all articles, with a reduction in the amplitude of F0 [3,12,14] being observed in silence only [3], in the noise condition only [13], and in both conditions [11]. An increase in latency associated with a reduction in F0 amplitude was described in 2 studies [11,13]. F1 and HF demonstrated an increase in latency and a reduction in amplitude of these components in 3 studies [11-13], and in 1 of them [12], the changes were observed only in the presence of noise. In another study [14], a reduction in amplitude was observed only in the presence of noise. In the work by Heidare et al [3], there were no significant differences between the control and study groups in terms of F1 and HF.

The presence of peripheral hearing loss correlates with changes in the FFR, mainly with regard to the reduction in the response amplitude of F0, F1, and HF, both in silence and in the presence of noise [14]. Such findings may be related to alterations in the frequency components of the sound signal, given that hearing loss generates distortion in the speech envelope. Alterations in the peripheral auditory system can occur in several ways, varying in degree, type, and configuration. This change and its impact on the FFR were the subjects of interest in several studies in this review [3,11-13].

It was observed that the normal patterns established for the control group (young adults) differed from the patterns established for the study group (the elderly), especially at high frequencies, at which there was a statistically significant difference in thresholds [13]. Unfortunately, other articles [2,3,11,12] did not examine this aspect. A reduction in auditory perception does not involve just the periphery but also the brainstem and cortical regions where decoding and comprehension of the auditory messages occur [33].

There is a general deficit in response synchronization at generating sites (decreased response amplitudes) and in signal transmission speed (increased latency), and these reflect structural changes in the subcortical region of elderly individuals, which in turn affect the coding of speech stimuli and limit the effectiveness of information processing in the cortex.
The result is poor speech perception, especially in unfavorable acoustic situations [12].

The aging process seems to be a relevant factor in the characteristics of the FFR. A reduction in F0 amplitude was the most frequent finding when analyzing the sustained portion of the FFR. This reduction was more significant in the presence of competitive noise [3,11,12]. An increase in F0 latency has also been described, as well as a reduction in amplitude and increase in the latency of the F1 and HF. Studies suggest that aging can have an impact on suprathreshold auditory processes that cannot be identified by the clinical audiogram; this includes temporal coding which involves the synchronization of neural firing in the fine temporal structure or temporal envelope of sound [34].

**Speech Perception in Noise**

The perception of pitch and timbre are closely related to the identification of the F0, F1, and HF, so the reduction in amplitude of F0, F1, and HF, which were commonly cited in the studies analyzed in this review, may be closely related to speech comprehension difficulties, especially in the elderly population, in the presence of noise [3,4,35].

Some studies [10,36,37] have correlated the ability to understand speech perception in noise with adequate sound localization skills. These are directly linked to the temporal processing of acoustic information, as well as to the perception of characteristic frequencies that allows us to identify the pitch and timbre of a speaker.

The perception of pitch and timbre are closely related to the identification of the F0, F1, and HF, so the reduction in amplitude of F0, F1, and HF, which were commonly cited in the studies analyzed in this review, may be closely related to speech comprehension difficulties, especially in the elderly population in the presence of noise [4,3,35]. Alterations in amplitude values of waves A, E, and F may be more closely related to peripheral hearing loss [11], since such loss can impair neural phase locking and perception of the fundamental frequency and its formants. In this way, the speech perception becomes more impaired [38].

**Limitations of the Study**

The major limitation of the present study was that most of the studies analyzed did not carry out an analysis of the cognitive aspects of the evaluated individuals. It is important to consider that older age has been associated with increased gray matter atrophy and atrophy of global mass in the brain region related to auditory activation [39]. There is, therefore, a wide association between aging, hearing loss, and cognitive alterations.

It should be noted that the studies analyzed had many biases between them and, in addition, only 2 articles analyzed the cognitive conditions of the elderly individuals participating as subjects. Thus, in a new study, it could be interesting to carry out an analysis of the literature on the effects of age-related hearing loss on speech processing, while concomitantly analyzing cognition.

**Conclusions**

In general, the FFR is a useful assessment tool in the elderly population, whether or not the individuals suffer from hearing loss. This tool allows the experimenter to check for degradation in the neural representation of complex stimuli due to advancing age. Degradation will show up as a lower F0 amplitude and, in the offset portion, an increase in the latency over the entire auditory response. Hearing loss will also have an impact on the envelope fine structure, producing poorer speech comprehension in noisy environments.

**Declaration of Figures’ Authenticity**

All figures submitted have been created by the authors who confirm that the images are original with no duplication and have not been previously published in whole or in part.

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