

Research Report

Age-related changes in neural activity associated with concurrent vowel segregation

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Abstract

Older adults exhibit degraded speech comprehension in complex sound environments, which may be related to overall age-related declines in low-level sound segregation. This hypothesis was tested by measuring event-related potentials (ERPs) while listeners identified two different vowels presented simultaneously. Older adults were less accurate than young adults at identifying the two vowels, although both groups improved similarly with increasing fundamental frequency differences (Δf_0) between vowels. Reaction time data showed that older adults took more time to process stimuli, especially those with smaller Δf_0 . A negative ERP wave indexing the automatic registration of Δf_0 (the object-related negativity) was reduced in older adults. In contrast, young and older adults showed a similar pattern of neural activity indexing attentive processing of Δf_0 . The results suggest that aging affects the ability to automatically segregate speech sounds.

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1. Introduction

Aging impairs listeners' ability to identify speech, especially under adverse situations such as in the presence of background noise and acoustic variability [14,15,25,29,30]. Although this age-related change in perception has received considerable attention, there is no consensus about the mechanisms underlying speech perception problems in older individuals. Changes in hearing sensitivity [24], memory [25], attention [18], and speed of processing [28] have all been proposed to account for the difficulties older adults have in processing everyday speech.

Evidence from behavioral studies suggest that impairment in auditory scene analysis may also play an important role in the speech perception problems commonly observed

in older adults [3,16,17,22,27]. For example, older adults showed higher thresholds for detecting a mistuned harmonic apart from a complex sound compared to younger adults, even after statistically controlling for audiometric thresholds [3]. This indicates that age-related problems in detecting multiple objects as defined by inharmonicity do not depend solely on peripheral factors and must involve an age-related decline in central auditory functioning. Listeners who find it difficult to detect mistuning may assimilate one or more frequency components coming from secondary sound sources into the target signal. In this context, the mistuned harmonic might be analogous to the presence of a secondary voice related to another fundamental frequency. The inclusion of extraneous frequency components into the target signal could then lead to concomitant errors in perception. Related to this, older adults with hearing loss showed an impaired ability to identify concurrently presented vowel sounds [33], a task that requires parsing frequencies based on

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the fundamental frequency (f_0) of each vowel. It is unclear, however, whether this impairment arose from peripheral deficits or more central changes because the older participants had hearing loss. Furthermore, performance on behavioral tasks such as the one described above depends on many processes, including accurate peripheral extraction of frequency components from the complex vowel sounds [23], segregation of frequency components associated with two vowels, integration of frequency components to form two vowel representations, and comparison of the two representations with stored templates of the vowels. In addition, the double-vowel stimulus must be stored in memory long enough for all of these processes to occur. Thus, performance on this task relies on processing throughout the ascending auditory pathway in addition to cortical areas involved in attention and memory functions.

Recording of event-related potentials (ERPs) is a powerful technique for examining the effects of age on the neural correlates underlying speech separation and identification. ERPs reflect synchronous activity from large neuronal ensembles that are time-locked to sensory or cognitive processes. They are divided into automatic and controlled components. The former refers to brain waves that are stimulus-driven and occur irrespective of the listener's attentional state whereas the latter occurs only when participants actively process the stimuli. In conjunction with behavioral measures, ERPs can thus help identify the extent to which low-level and high-level factors contribute to age-related differences in sound processing [5]. In particular, the effects of age on concurrent sound segregation can be examined by comparing ERPs elicited by two concurrent vowels with either the same or different f_0 .

Previous research using harmonic series with a mistuned partial have identified a novel auditory cortical ERP at ~150 ms referred to as the object-related negativity (ORN), whose amplitude correlated with listeners' likelihood of reporting the presence of two simultaneous auditory objects [2,4]. The ORN is thought to index low-level sound segregation because it is present even for unattended stimuli [1,2,4]. The ORN may thus be viewed as indexing the automatic detection of the mistuned harmonic from a prediction based upon the fundamental frequency of the incoming stimulus. An independent laboratory has observed a similar ERP modulation during perceptual segregation of a narrow frequency band from background noise based on interaural timing information [19,20], suggesting that the ORN is not specific to mistuned stimuli.

A more speech-relevant task that is similarly amenable to ERP recording is concurrent vowel identification. In this task, identification rates are larger with increasing fundamental frequency separation (Δf_0) between the two vowels [7,8,11,12]. An auditory cortical component with similar latency, amplitude, and topographical distribution as the ORN appeared in the concurrent vowel task [6], and may thus provide a useful index of age-related changes in low-level speech segregation. This component likely reflects a

similar process as the ORN because they are both present during the segregation and formation of concurrent auditory objects with different f_0 and are both present even when participants ignored the stimuli. An additional response peaking ~250 ms was present in young adults when they actively performed the double-vowel task, but was absent when they ignored the sounds. Thus, this component may index more controlled processing such as the matching between the incoming signal and the stored vowel representations in working memory. These two responses thus reflect the automatic registration of Δf_0 and the influence of attention-dependent processes, respectively, related to concurrent vowel segregation and identification based on Δf_0 .

In the present study, young and older adults with normal hearing were presented with a mixture of two phonetically different vowels with the same or different f_0 and attempted to identify them during ERP recording. We tested the general hypothesis that performance in identifying both vowels would increase as a function of Δf_0 . We hypothesized that older adults would have more difficulty in identifying concurrent vowels, as assessed by identification rates and reaction times. Specifically, an interaction between age and Δf_0 with increasingly lower identification rates or longer reaction times at smaller Δf_0 would indicate age-related changes specific to vowel segregation processing. We further hypothesized that changes in processing as indexed by behavioral measures would be paralleled by ERP changes related to either bottom-up or top-down processing of concurrent vowels.

2. Materials and methods

2.1. Participants

Sixteen young adults (8 men and 8 women, age range = 19–34 years, mean age = 24.4 ± 4.6 years) and sixteen older adults (4 men and 12 women, age range = 61–76 years, mean age = 67.5 ± 5.3 years) participated after giving written informed consent according to the guidelines of the Baycrest Centre and the University of Toronto. All participants were compensated for their participation. They were all right-handed, spoke English as a first language, and had normal pure-tone thresholds measured in decibels (dB HL) for their age group at frequencies from 250 to 8000 Hz in both ears (see Table 1). Although our participants were screened for hearing loss, the older adults showed mild elevated hearing thresholds relative to young adults, especially in the high-frequency range. No differences between left and right ears occurred leading us to collapse threshold scores across this factor. A mixed-design analysis of variance (ANOVA) with age group (young and older) and frequency (250, 500, 1000, 2000, 4000, 8000) as factors yielded a main effect of age group, with older adults having higher thresholds than the young adults, $F(1,30) = 39.71$, $P < 0.001$. The interaction between age group and

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