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Effects of age and task difficulty on ERP responses to novel sounds presented during a speech-perception-in-noise test

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HIGHLIGHTS

- Amplitudes of Novelty P3 increased with increasing task demand in both age groups.
- Amplitudes of a late positive potential (LPP) increased only in older listeners.
- LPP could be a correlate of age-related sustained and more effortful processing.

ABSTRACT

Objective: Event-related potentials (ERPs) to task-irrelevant novel sounds have been shown to increase in amplitude with increasing task difficulty and might therefore reflect listening effort. Here we investigated whether this effect is similar in two groups of younger and older listeners with normal hearing.
Methods: Novel sounds were presented during a speech-perception-in noise test and task difficulty was adjusted decreasing the signal-to-noise ratio (SNR) relative to the individual 50% correct speech recognition SNR (easy +10 dB, medium +2 dB, hard 0 dB).
Results: Amplitudes of the Novelty P3 and a late positive potential (LPP) were significantly larger in younger compared to older participants. Novelty P3 amplitude increased with increasing task difficulty in both age groups, but the effect was more robust in younger listeners. By contrast, LPP amplitude increases were observed only in older listeners.
Conclusions: Novelty P3 and LPP were found to be differently affected by task difficulty in the two age groups indicating sustained and more effortful processing under challenging listening conditions in older listeners.
Significance: These results confirmed the potential use of novel sounds during an auditory task as an indirect measure of listening effort in younger and older listeners, but the different focus on Novelty P3 and LPP should be taken into account.

1. Introduction

While the treatment of hearing loss with hearing aids has considerably improved over the last decades due to the development of digital signal-processing and noise-reduction algorithms, there is increasing awareness that the impact of hearing loss and the outcome of hearing aid provision are not fully captured by routine audiometric assessment alone (Mackersie and Cones, 2011; McGarrigle et al., 2014). Pure-tone audiograms and speech audiometry provide hearing thresholds, percent correct speech recognition scores and signal-to-noise ratios (SNRs), but they do not provide information about the stress under which the listener produced this performance (Mackersie and Cones, 2011). In a recent study, Desjardins and Doherty (2014) used a dual-task paradigm to quantify the listening effort of hearing-aid users during a sentence-in-noise task with and without a noise-reduction algorithm of their device activated. While speech recognition scores did not change with activation of the noise-reduction algorithm, listening effort (as measured by the performance in a secondary visual-tracking task) decreased significantly in the more difficult condition. Thus, the dual task provided additional information supporting the efficiency of the noise-reduction algorithm, whereas speech audiometry failed to capture a change. However, a drawback of such dual-task paradigms, though widely studied as a

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potential assessment tool of listening effort (Anderson Gosselin and Gagne, 2010, 2011; Desjardins and Doherty, 2013; Fraser et al., 2010; Hornsby, 2013; Howard et al., 2010; Picou and Ricketts, 2014; Picou et al., 2013; Ronnberg et al., 2011; Sarampalis et al., 2009; Wu et al., 2014, 2013), is the interrelationship between the two tasks, because the addition of a secondary task may also change performance in the primary task. Furthermore, the way, how processing resources are allocated to the two simultaneous tasks, may vary considerably between subjects. Thus, there is a need for objective measures of listening effort to complement routine audiometric assessment.

Recently, there have been various approaches using psychophysiological measures such as pupillometry (Engelhardt et al., 2010; Kuchinsky et al., 2013; Zekveld et al., 2013, 2010, 2011; Zekveld and Kramer, 2014), eye movement tracking (Ben-David et al., 2011), galvanic skin response, electromyographic activity, heart rate variability (Mackersie and Cones, 2011; Mackersie et al., 2014), and electroencephalography (EEG) frequency bands (Obleser et al., 2012). Auditory event-related potentials (ERPs) could be another feasible psychophysiological method.

Task-irrelevant auditory stimuli presented during an auditory task have been shown to be sensitive to the difficulty of the task (Combs and Polich, 2006; Comerchero and Polich, 1999; Frank et al., 2012). Combs and Polich (2006) used three different types of distractors, a 4000-Hz tone, white noise and novel sounds in a three-stimulus oddball paradigm with an either easy (1000 Hz vs. 500 Hz) or hard (1000 Hz vs. 950 Hz) frequency discrimination task. The P3a amplitude in response to the task-irrelevant sound stimuli was largest for the white noise and novel sounds compared to the high-frequency tone, indicating that these distractors with their high salience were well suited to capture attention and to evoke an orienting response. Moreover, while the P3b response to the target stimuli decreased, the P3a amplitude increased in the difficult discrimination task. Thus, P3a amplitude change appeared to reflect indirectly the increased attentional demands of the task and increased effort of the listeners. In another study by Frank et al. (2012) the same white noise and novel sound distractors were used during a frequency discrimination task with three different degrees of difficulty (1000 Hz vs. 920/950/980 Hz). P3a did not differ in amplitude across difficulty levels, possibly due to the relatively small frequency changes of the target stimuli, but topographical distribution shifted from parietal in the easy condition to a more central/parietal distribution in the more difficult conditions.

In a recent study, we have used novel sounds during two types of experiments, a frequency discrimination task and a more realistic speech-perception-in-noise test, each with varying degrees of task difficulty (easy, medium, hard), to investigate their feasibility as a measure of listening effort (Bertoli and Bodmer, 2014). In both experiments, the Novelty P3 amplitude increased with increasing task difficulty. Another positive ERP component following the Novelty P3, which we had named LPP (late positive potential) was also analyzed. Although this component is visible in the responses to novel sounds in other studies, it has received little attention. LPP amplitudes increased continuously from the easy to the hard task in both experiments. Interestingly, participants with a hearing loss tended to have larger LPP but not Novelty P3 amplitudes, compared to the normal-hearing participants. Based on the similarity of the LPP in our study with visual and auditory LPPs from other areas of research, such as emotional facial expressions (e.g., Brown et al., 2012; Hajcak et al., 2010) and music perception (Brattico et al., 2010; Istok et al., 2013; Müller et al., 2010), we interpreted the LPP as a component modulated by the emotional rather than cognitive aspects of the task, possibly reflecting the arousal level and thus, the listening effort of the person. While both Novelty P3 and LPP were affected by changes in task difficulty, LPP appeared to be the more sensitive component for capturing listening effort.

Our first study was conducted with older adults aged between 60 and 86 years, because hearing loss and difficulties with speech perception in noise are more frequent among older persons (Anderson Gosselin and Gagne, 2011; Pichora-Fuller et al., 1995; Tun et al., 2009). In the current study, we aimed to investigate whether the same effects of task difficulty on the Novelty P3 and LPP could also be observed in younger listeners, in order to extend the application of novel sounds as a measure of listening effort to a larger age range. Although the effects of task difficulty on the responses to novel sounds have been shown for a group of young adults by Combs and Polich (2006) and for older adults in our prior study, the effects of age and task difficulty have not been addressed together thus far.

The results of the normal-hearing older participants from the prior study were reanalyzed and compared to those of a newly tested group of young normal-hearing participants. In this report, we focus on the speech-perception-in-noise test, because unlike the frequency discrimination task, it represents a more realistic test condition and simulates the difficulty of listening in the presence of background noise.

2. Methods

2.1. Participants

Eighteen older adults with normal hearing for their age (mean age = 70.0 years; range 62–78 years; twelve men) and 18 young normal-hearing adults (mean age = 23.6 years; range 20–30 years; nine men) participated. Older adults were recruited from the local Senior University, younger adults responded to an online advertisement of the study on the web-portal of the local University. The mean (±1 SD) pure-tone audiograms of the two groups are depicted in Fig. 1. Pure-tone air-conduction thresholds were ⩽20 dB HL from 0.25 to 3 kHz in both age groups. Pure-tone averages (PTA) at 0.5, 1, 2 and 4 kHz differed significantly between younger and older participants (right ear: 3.8 dB vs. 11.9 dB; $t = 5.5$; df = 34; $p < 0.001$; left ear: 5.0 dB vs. 12.2 dB; $t = 4.3$; df = 34; $p < 0.001$). All participants had a negative history of persistent tinnitus, head trauma, neurologic and psychiatric disorders. In addition, older participants passed a screening test for dementia using a German version of the neuropsychological assessment battery of the Consortium to Establish a Registry for Alzheimer's Disease (CERAD-Plus) with normative values adjusted for gender, age and education (Thalmann et al., 2000; Welsh et al., 1994). The study was approved by the local Ethics Committee of Basel

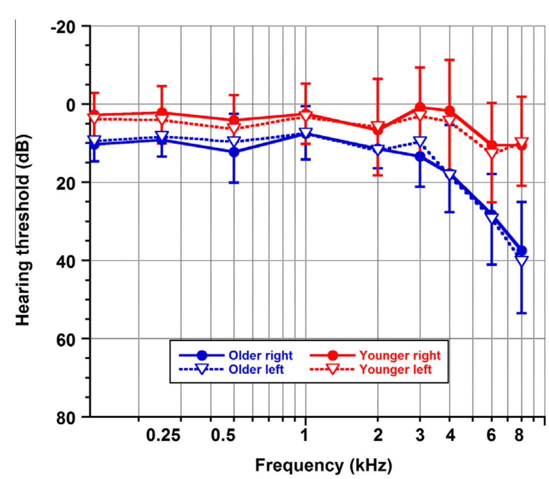

Fig. 1. Mean hearing thresholds (±1 standard deviation) of right and left ears for the younger and older listeners.