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Speech Auditory Brainstem Response through hearing aid stimulation

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ABSTRACT

Millions of people across the world are hearing impaired, and rely on hearing aids to improve their everyday life. Objective audiometry could optimize hearing aid fitting, and is of particular interest for non-communicative patients. Speech Auditory Brainstem Response (speech ABR), a fine electrophysiological marker of speech encoding, is presently seen as a promising candidate for implementing objective audiometry; yet, unlike lower-frequency auditory-evoked potentials (AEPs) such as cortical AEPs or auditory steady-state responses (ASSRs), aided-speech ABRs (i.e. speech ABRs through hearing aid stimulation) have almost never been recorded. This may be due to their high-frequency components requesting a high temporal precision of the stimulation. We assess here a new approach to record high-quality and artifact-free speech ABR while stimulating directly through hearing aids. In 4 normal-hearing adults, we recorded speech ABR evoked by a /ba/ syllable binaurally delivered through insert earphones for quality control or through hearing aids. To assess the presence of a potential stimulus artifact, recordings were also done in mute conditions with the exact same potential sources of stimulus artifacts as in the main runs. Hearing aid stimulation led to artifact-free speech ABR in each participant, with the same quality as when using insert earphones, as shown with signal-to-noise (SNR) measurements. Our new approach consisting in directly transmitting speech stimuli through hearing aids allowed for a perfect temporal precision mandatory in speech ABR recordings, and could thus constitute a decisive step in hearing impairment investigation and in hearing aid fitting improvement.

1. Introduction

Hearing is a central sense in our everyday life, since human communication mainly relies on speech. Across the world, millions of hearing-impaired patients would benefit from a hearing aid, and as this population is increasing, we need new solutions to handle the situation. Objective audiometry could be one of them, if it could be implemented with an efficient and objective measure that would give a lot of relevant information in a minimal recording time.

Speech Auditory Brainstem Response (speech ABR) is an electrophysiological marker of speech encoding, which provides precise spectro-temporal information on auditory processing at the brainstem level (Skoe and Kraus, 2010). Being seen as a direct window on what information enters the auditory central nervous system, speech ABR mimics so well its stimulus that when playing it back as a sound, the stimulus can be understood (Galbraith et al., 1995). As two recent articles suggested (Anderson and Kraus, 2013; Dajani et al., 2013), its intrinsic properties make it a good candidate to facilitate hearing aid selection, fitting, and evaluation of performance. Furthermore, using speech ABR as an objective audiometric tool would be of particular interest in non- or poorly-communicative hearing-impaired patients (e.g., young children, Down syndrome, dementia).

To record speech ABR, speech syllables are usually delivered by insert earphones whereby the sound is conveyed to the

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Abbreviations: Speech ABR, speech auditory brainstem response; AEP, auditory-evoked potential; ASSR, auditory steady-state response; SNR, signal-to-noise; F0, fundamental frequency; dB SPL, decibel sound pressure level; dB HL, decibel hearing level; EEG, electroencephalography; RMS, root mean square; DSS, denoising source sepan; ERP, event-related potential; FFR, frequency-following response

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participant's ears via plastic tubes, thus minimizing risks of stimulus artifact (Akhoun et al., 2008). However, such systems are somewhat limited in their intensity range. Stimulation through hearing aids would be far more ecological and powerful in the hearing-impaired, allowing the delivery of specific frequencies at very-high intensity (up to 130 dB SPL) and the assessment of particular settings for each hearing loss. However, it could fail to give proper speech ABR, because of stimulus artifact or inadequate precision of timing.

Previous attempts of using electrophysiological markers in hearing aid healthcare have been made, with Click ABR (Kiessling, 1983), Auditory Steady-State Response (ASSR; Picton et al., 1998) or cortical Auditory-Evoked Potentials (cAEPs; Billings et al., 2007), although none has led to a wide use in hearing aid healthcare. This might be due to their relatively low balance between relevance of information provided and recording time. In any case, what interests us in the present methodological paper is not relevance but feasibility: ASSR and cAEPs have already been recorded through hearing aid stimulation, but these activities are from lower frequencies than speech ABR, thus less demanding for a perfect hearing aid timing. Regarding ASSR, carrier frequencies can be as high as the higher frequencies present in speech stimuli, but the electrophysiological signal pertains to the low-frequency amplitude modulation and is thus less likely to be altered by a few-millisecond temporal jitter.

To the best of our knowledge, up to now, only one paper (Anderson and Kraus, 2013) reported preliminary speech ABR data in a single participant obtained with open-field stimulation amplified by hearing aids. Here, we assess more comprehensively the feasibility of using hearing aid stimulation to record artifact-free speech ABR. One major novelty here is that we chose to directly transmit the stimulus to hearing aids using a wireless connection, which allows (1) to avoid latency jitters caused by head movements and (2) to test mute conditions to properly control for the absence of stimulus artifact (see Methods). As obtaining speech ABR for individual participants is of particular interest for hearing aid benefit assessment, we also assessed the use of an advanced multi-channel-data processing method to improve signal-to-noise (SNR).

2. Material and methods

2.1. Participants

Four healthy adults (aged 22–25 years; 3 women) participated in the study. All were normal-hearing (with air conduction hearing thresholds measured below 20 dB HL between 250 and 8000 Hz with pure tone audiometry), native French speakers, and none had known language, psychiatric, or neurologic impairment. Each participant gave his/her written informed consent. All experimental procedures were approved by the “Comité de Protection des Personnes Lyon SUD-EST II” (#2008-017-2).

2.2. Stimulus

Speech stimulus was a 180-ms natural /ba/ syllable (Bellier et al., 2013), recorded from a French female voice. It was composed of a 45-ms voicing followed by a 135-ms vowel (Fig. 1). Fundamental frequency (F0) of the vowel/a/was slightly varying around 170 Hz, and the four first formants were respectively centered around 740, 1360, 2785 and 4310 Hz. The most energetic frequency during the vowel was F0.

2.3. Transducers

We recorded electrophysiological activity in response to the /ba/ stimulus in three runs using different transducers: insert earphones or hearing aids with two different settings (see below). Two additional runs were recorded with insert earphones and hearing aids but muted: transducers were in the same position as in normal runs and also played the /ba/ stimulus, but foam ear tips were filled with silicone and removed from ear canals, making the stimulus inaudible. The order of these five runs was randomized between participants.

Hearing aids were a pair of Siemens Motion 501 SX XCEL (Munich, Germany), and insert earphones were the Aearo E-A-RTONE 3A (Indianapolis, USA) – the most frequently used transducer in speech ABR studies. Both transducers were coupled with foam ear tips, to avoid leakage of low frequencies from ear canals. Two different settings were used for hearing aids, sharing all parameters but gains to obtain two different waveforms. Recordings of each transducer output were made using a G.R.A.S. 43AG ear simulator (Holte, Denmark), and are shown in Fig. 1 (average of 80 recorded stimuli). Stimuli were played directly through the hearing aids using the wireless transmission program, or through the insert earphones. Timing of stimulation through hearing aids and the wireless connection was highly reproducible (no jitter), but with a fixed delay of 62.2 ms (corrected in Fig. 1). For each transducer, sound level was measured with a 2cc coupler linked to the 43AG ear simulator and mounted on a Brüel & Kjær 2239A sound level meter (Nærum, Denmark), and sound card output level was adjusted to reach 80 dB SPL A-weighted.

2.4. Procedure

Participants sat in an armchair located in an electromagnetically-shielded soundproofed room, and watched a subtitled movie without soundtrack during the five runs. In each run, 3000 /ba/ syllables were binaurally delivered at a sound level of 80 dB SPL, with a rate of 2.78 per second, in alternating polarities (1500 each), using Presentation software (Neurobehavioral Systems; Berkeley, USA). Each run lasted 18 min, and was followed by a 5-minute break during which the transducers were changed.

2.5. Electrophysiological recordings and data processing

Speech ABRs were recorded using a 32-channel BrainAmp EEG system with ActiCAP active electrodes (Brain Products; Munich, Germany), at a sampling rate of 5000 Hz (Bellier et al., 2015). Reference was placed on the nose, and ground at AFz. Impedances were kept below 5 kΩ during all the procedure. Data were analyzed using Elan (Aguera et al., 2011) and MATLAB (The MathWorks; Natick, USA). For each run, raw data were first filtered with notch filters to remove the 50-Hz power line radiation artifact and its odd harmonics, then with an 80–1000-Hz Butterworth bandpass filter (fifth order) to isolate sub-cortical activity. Filtered data were epoched in 400-ms trials between −50 and 350 ms, and trials exceeding 100 μV of amplitude dynamics at any electrode were rejected. Accepted trials were averaged (1403 ± 50 out of 1500 trials per polarity; mean ± SD), and baseline correction was applied (−50 to 0 ms). Speech ABRs were obtained using a vertical montage by offline re-referencing the vertex to the average of mastoids (Cz−(M1 + M2)/2). We computed both envelope and spectral FFRs, respectively by averaging responses from opposite polarities or by averaging the response from one polarity and the negative of the response from the opposite polarity. Envelope FFR typically follows