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Research Paper

Human medial efferent activity elicited by dynamic versus static contralateral noises

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ABSTRACT

The medial olivocochlear reflex (MOCR) modifies cochlear amplifier function to improve encoding of signals in static noise, but conflicting results have been reported regarding how the MOCR responds to dynamic, temporally-complex noises. The current study utilized three MOCR elicitors with identical spectral content but different temporal properties: broadband noise, amplitude-modulated noise, and speech envelope-modulated noise. MOCR activity was assessed using contralateral inhibition of transient-evoked otoacoustic emissions in 27 normal-hearing young adults. Elicitors were presented contralaterally at two intensities of 50 and 60 dB SPL. Magnitude and growth of contralateral inhibition with increasing elicitor intensity were compared across the three elicitor types. Results revealed that contralateral inhibition was significantly larger at the elicitor intensity of 60 dB SPL than at 50 dB SPL, but there were no significant differences in the magnitude and growth of inhibition across the three elicitors, contrary to hypothesis. These results suggest that the MOCR responds similarly to both static and dynamic noise.

1. Introduction

The medial olivocochlear (MOC) efferent system modulates cochlear amplifier function through descending fibers that project from the brainstem to the outer hair cells (reviewed in Guinan, 2006). Afferent stimulation of the MOC triggers a reflex (MOC reflex, or MOCR) which improves auditory nerve encoding of transient sounds in background noise by reducing the neural response to the noise (Winslow and Sachs, 1987; Kawase et al., 1993). The MOCR appears to contribute to normal-hearing listeners' ability to understand speech in noisy situations (e.g., Giraud et al., 1997; Mertes et al., 2018). The MOCR is typically assessed non-invasively in humans using transient-evoked otoacoustic emissions (TEOAEs), which are measurable sounds generated in response to brief stimuli that are a byproduct of the cochlear amplification process (Kemp, 1978; Brownell, 1990). When measuring TEOAEs in one ear, presentation of contralateral sound activates the contralateral MOC pathway, decreasing cochlear amplifier gain and reducing TEOAE amplitude (Collet et al., 1990; Berlin et al., 1993). This process is referred to as contralateral inhibition, and larger inhibition is interpreted as a stronger MOCR (Backus and Guinan, 2007).

The MOCR is responsive to a variety of sounds, including pure tones, clicks, tone bursts, and noise (e.g., Veuillet et al., 1991; Berlin et al., 1993; Guinan et al., 2003). The magnitude of contralateral inhibition increases with increasing level and bandwidth of the contralateral stimulus, with static white noise yielding the largest inhibition (Maison et al., 2000; Velenovsky and Glattke, 2002; Guinan et al., 2003; Lilaonitkul and Guinan, 2009). Static white noise therefore has been used as the contralateral stimulus in nearly all studies of contralateral inhibition in humans. Despite the usefulness of using static white noise to study contralateral inhibition in laboratory settings, it is unclear how more dynamic, temporally-complex sounds activate the MOCR. If the MOCR responds differently to dynamic versus static noises, then measurements of contralateral inhibition using static white noise may not reflect the behavior of the MOCR in the presence of background noises that humans often encounter, such as multi-talker babble.

A small number of studies have examined contralateral inhibition using dynamic contralateral sounds, but results have been equivocal. One group found that amplitude-modulated (AM) sinusoids and AM broadband noise (BBN) yielded larger contralateral

Abbreviations: AM, amplitude-modulated; BBN, broadband noise; CAS, contralateral acoustic stimulation; EM, envelope-modulated; MEMR, middle-ear muscle reflex; MOC, medial olivocochlear; MOCR, medial olivocochlear reflex; OAE, otoacoustic emission; pSPL, peak sound pressure level; SSOAE, synchronized spontaneous otoacoustic emission; TEOAE, transient-evoked otoacoustic emission

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inhibition relative to unmodulated sinusoids and unmodulated BBN (Maison et al., 1997; 1999; 2001), consistent with the modulation transfer function measured in individual MOC neurons of the guinea pig (Gummer et al., 1988). However, Boothalingam et al. (2014) found a trend of reduced contralateral inhibition of otoacoustic emissions (OAEs) elicited with single-tone stimuli (stimulus frequency OAEs) when the tones were AM versus unmodulated. No significant differences were seen in contralateral inhibition when elicited by a babble noise relative to white noise (Timpe-Syverson and Decker, 1999; Papsin et al., 2014), but these studies did not report sufficient controls for middle-ear muscle reflex activation which could interfere with the interpretation of results (Goodman et al., 2013) and the click stimulus rate of 50/s may have elicited the ipsilateral MOCR (Boothalingam and Purcell, 2015). A recent paper examined the effect of a variety of contralateral noises on contralateral inhibition (Kalaiah et al., 2017). The noises included BBN, AM noise (4, 50, and 100 Hz modulation frequencies), multi-talker babble (two, four, and six talkers), and environmental (traffic and cafeteria) noises. Results showed that the multi-talker babble and traffic noises elicited significantly lower contralateral inhibition than BBN. The authors concluded that multi-talker babble noise is a less efficient activator of the MOCR than other noises, which could have implications for how the MOCR is activated in real-world listening situations. However, there were differences in the spectral content of the noises (see their Fig. 2), so it cannot be determined if the differences in MOCR activation were due to differences in the spectral and/or temporal content of the noises.

The primary purpose of the current study was to compare the magnitude of contralateral inhibition elicited by three contralateral noises that varied in their temporal characteristics while holding the spectral content the same. Static BBN and two dynamic noises (AM BBN and BBN modulated by the envelope of multi-talker babble) were utilized. It was hypothesized that BBN would elicit significantly larger contralateral inhibition than the dynamic noises because the lack of low-amplitude dips in the static noise would ensure sustained activation of the MOCR (Boothalingam et al., 2014). The growth of contralateral inhibition for the three noise elicitors was also explored to determine if the MOCR responds differentially across elicitor intensity level depending upon the temporal characteristics of the elicitor.

2. Material and methods

2.1. Participants

A total of 27 participants (20 females) participated. Participant ages ranged from 18 to 40 years [mean = 23.5 years, standard deviation = 5.9]. Screening procedures included a case history and audiologic screening. Eligible participants were required to have a self-reported negative history of the following: hearing difficulties, significant noise exposure within the past 6 months, tinnitus of a severe and/or bothersome nature, use of ototoxic medication, vertigo, and chronic middle ear pathology. Participants were also required to be right handed to avoid confounds of handedness effects on contralateral inhibition (Khalfa et al., 1998).

Audiologic inclusion criteria consisted of the following: an unremarkable otoscopic examination bilaterally, normal 226-Hz tympanograms bilaterally (tympanometric peak pressure between −100 and +50 daPa, static acoustic admittance between 0.2 and 1.8 mmho, and equivalent ear canal volume from 0.6 to 2.5 cc), pure-tone air-conduction thresholds ≤20 dB HL at octave frequencies from 250 to 8000 Hz bilaterally, and measurable TEOAEs in the right ear. The TEOAE screening measurement consisted of collecting 1250 sweeps in response to 40.96-μs clicks presented at 65 dB peak sound pressure level (pSPL) at a rate of 19.53/s using equipment described in Sec. 2.2. Mean TEOAE waveforms were bandpass filtered from 1000 to 2000 Hz. Participants passed the TEOAE screening if the time-domain signal-to-noise ratio (SNR) was >6 dB and the whole-waveform reproducibility (Kemp et al., 1990) was >70%.

The study protocol was approved by the Institutional Review Board of the University of Illinois at Urbana-Champaign. Written informed consent was obtained by all participants prior to their enrollment in the study. All participants received monetary compensation for their participation.

2.2. Equipment

Participants were seated in a comfortable recliner inside a 200 sq. ft. single-walled sound-treated booth with 8-in thick walls (Tracoustics, Inc., Austin, TX). To further reduce external noise from entering the sound booth, the experimenters were situated in a separate room with the door closed. The experimenters monitored participants during the experiment via a camcorder and intercom.

Audiometric screenings were conducted using an AudioStar Pro audiometer (Grason-Stadler, Inc., Eden Prarie, MN) and a Titan tympanometer (Interacoustics, Middelfart, Denmark). Contralateral inhibition testing was conducted using a WS-4 workstation [Tucker-Davis Technologies (TDT), Alachua, FL] and an RZ6 auditory processor (TDT) running custom software written in MATLAB (ver. R2017a, The Mathworks, Inc., Natick, MA) and RPvdsEx (TDT). Stimuli were routed from the RZ6 to two resistors (1/8 W, 22 Ω) that were placed in series with a pair of ER-2 insert earphones (Etymōtic Research, Elk Grove Village, IL). The acoustic tubing of the right insert earphone was connected to an ER-10B+ probe microphone system (Etymōtic Research) with the preamplifier gain set to +40 dB. The signal recorded by the microphone was routed to the input of the RZ6, sampled at 24414.06 Hz (the default sampling rate of the processor), and streamed to the workstation hard disk.

Offline analyses of TEOAE waveforms were performed using a combination of custom MATLAB code and the MATLAB Signal Processing Toolbox (ver. 11.1, The Mathworks, Inc.). Statistical analyses were conducted using SPSS Statistics (version 24.0.0.0, IBM Corp., Armonk, NY).

2.3. Contralateral inhibition measurement

Stimulus and recording parameters were adapted from those described in Mertes et al. (2018). Contralateral inhibition measurement consisted of obtaining TEOAEs with and without the three contralateral elicitors described in this section. TEOAEs were elicited using clicks generated by the RZ6 processor at the default sampling rate of 24414.06 Hz. Click stimuli were 40.96 μs in duration and were presented at a level of 65 dB pSPL and at a rate of 19.53/s. The stimulus level was selected to ensure robust elicitation of TEOAEs in all participants (Mertes et al., 2018), while the rate was selected to reduce potential elicitation of both the ipsilateral MOCR and the middle-ear muscle reflex (MEMR) by the click stimuli (Boothalingam and Purcell, 2015). The activation of either of these reflexes can confound the interpretation of the contralateral inhibition results and are thus desirable to avoid (Guinan et al., 2003; Boothalingam and Purcell, 2015).

Three noise stimuli served as contralateral elicitors of the MOCR (referred to hereafter as *elicitor types*): 1) broadband noise (*BBN*) consisting of Gaussian noise generated by the RZ6 processor with a nominal bandwidth of 0–12207 Hz; 2) amplitude-modulated (*AM*) BBN, consisting of the BBN from elicitor 1 that was amplitude-modulated at a rate of 100 Hz and at a modulation depth of 100%; 3) envelope-modulated (*EM*) BBN, consisting of the BBN from elicitor 1 that was modulated by the envelope of a four-talker