BRAIN RESEARCH 1586 (2014) 143–151

Available online at www.sciencedirect.com

ScienceDirect

www.elsevier.com/locate/brainres

Brain Research

Research Report

Mismatch negativity (MMN) objectively reflects timbre discrimination thresholds in normal-hearing listeners and cochlear implant users

Torsten Rahne[*], *Stefan K. Plontke*, *Luise Wagner*

Department of Otorhinolaryngology and Halle Hearing and Implant Center, Martin-Luther-University Halle-Wittenberg, Halle (Saale), Germany

ARTICLE INFO

Article history:
Accepted 16 August 2014
Available online 23 August 2014

Keywords:
Cochlear implant users
Mismatch negativity (MMN)
Just noticeable difference
Psychoacoustics
Timbre discrimination

ABSTRACT

Timbre perception is poor in cochlear implant (CI) users. Most behavioral studies assess timbre discrimination with real instrumental sounds differing in more than one timbre dimension. This study focuses on objective measures of individual discrimination of single timbre dimensions. A psychoacoustic and electrophysiological case-control study of timbre discrimination was conducted in 15 CI users and 15 normal-hearing (NH) listeners. Just noticeable differences (JNDs) for temporal envelope (TE) modulation differences and spectral distribution (S) differences of complex tones were measured in an adaptive three-alternatives forced-choice procedure. From individual JNDs, individual four tone pairs were computed: temporal envelope modulation/spectral distribution timbre discrimination, and above/below JND. With these tone pairs, four randomly arranged oddball paradigms were presented to derive mismatch negativity (MMN), which reflects the ability to automatically detect acoustic changes. JNDs could be derived for all NH listeners. Discrimination of spectral distribution differences and particularly temporal envelope modulation differences were more difficult for CI users. MMN was present in all NH listeners and CI users when the timbre difference was above the individual JND, but not when below JND. Thus, the timbre difference between 'deviant' and 'standard' tones reflected the individual threshold for automatic detection of timbre changes. We conclude that the timbre perception skills of NH listeners and CI users in particular can be assessed timbre dimension specifically with psychoacoustic measurements and MMN recordings. MMN occurrence reflects the individual JND for temporal envelope modulation and spectral distribution differences and can be used as a clinical tool to monitor auditory-verbal therapy after CI surgery.

*Correspondence to: Universitäts-HNO-Klinik, Ernst-Grube-Straße 40, 06120 Halle (Saale), Germany. Fax: +49 345 557 1859.
E-mail address: torsten.rahne@uk-halle.de (T. Rahne).

http://dx.doi.org/10.1016/j.brainres.2014.08.045

1. Introduction

In patients using a cochlear implant (CI), the cochlear nerve fibers are electrically stimulated to restore or enable sound perception. The incoming acoustic signal is pre-processed by the external audio processor portion of the CI. To reduce the data volume to the CI limits, temporal and spectral features of the signal are extracted and allocated to 12–22 electrodes spread along the cochlea. These coding algorithms allow for good speech perception (Santos et al., 2013; Stabej et al., 2012), but music and timbre perception remains poor (Fu et al., 2004, 2005; Heng et al., 2011; Massida et al., 2011), which becomes apparent on a cognitive level by reduced discrimination or recognition of melodies (Galvin et al., 2008; Gfeller, 2009; Gfeller et al., 2007; Mitani et al., 2007). Complex pitch perception is limited by the temporal resolution of the cochlear implant (Won et al., 2010). The number of electrodes limits the spectral resolution within the cochlea and thus affects (fundamental) pitch discrimination (Di Nardo et al., 2011; Limb and Roy, 2014).

Timbre perception and timbre discrimination are important factors for music perception. By definition, timbre comprises all psychoacoustic attributes of complex tones, which are not exclusively assigned to the perception of pitch, loudness, and subjective duration (American Standards Association, 1960; Sankiewicz and Budzynski, 2007). Thus, timbre itself is a multidimensional space where different dimensions contribute to the psychoacoustic perception. In normal-hearing (NH) listeners, recent work identified spectral distribution, spectral fluctuation, roughness, and attack as the dominating parameters of timbre (McAdams et al., 1995; Terasawa et al., 2005). Temporal envelope modulation was one important parameter characterizing the timbre difference of instruments (Emiroglu and Kollmeier, 2008). Other reports identified both temporal envelope modulation and spectral distribution as the most important parameters of timbre (Grey, 1977; Marozeau et al., 2003; Samson et al., 1997).

Pressnitzer et al. (2005) showed that spectral distribution also seems to be a dominating parameter of timbre discrimination in CI users. The discrimination of tones differing in their spectral distribution might be influenced by the applied coding strategies of the audio processor; e.g., the advanced combination encoders coding strategy selects stimulating electrodes by identifying frequency channels with maximum amplitudes. The roughness of tones might be allocated to the electrodes by channel-specific amplitude modulations as a function of the temporal envelope of the signal. Both attributes of timbre should thus be processed by the CI and CI users should be able to detect them. In recent studies, music perception was shown to improve if CI users have auditory-verbal training (Kelly et al., 2005; Sandmann et al., 2010; Sharma et al., 2002; Stabej et al., 2012). Since music perception is also a prerequisite for discriminating speech prosody (Mühlhaus and Barthel-Friedrich, 2008; van Zyl and Hanekom, 2013) and speakers (Cleary and Pisoni, 2002; Massida et al., 2011; Mühler et al., 2009), an improved timbre perception would also improve speech perception.

To evaluate the success of auditory-verbal training, subjective and objective methods are needed in clinical routine. Therefore, methods to objectively measure pure-tone thresholds and speech discrimination have been developed and are sometimes used in clinical routine. Current music perception tests rely on the identification and the discrimination of natural or synthetic sounds (Limb and Roy, 2014; Limb and Rubinstein, 2012; Nakata et al., 2005; Scorpecci et al., 2012; Stabej et al., 2012; Vongpaisal et al., 2006). However, a systematic measure of timbre perception can only be done if the underlying attributes are individually measured and no natural stimuli that differ in more than one timbre dimension are used. Therefore, a behavioral test using synthetic sounds was developed (Rahne et al., 2010a) and evaluated (Rahne et al., 2012). With this test, cross-faded ('morphed') tones were generated so as to change only the spectral distribution difference in certain steps by linear interpolation of spectral parameters. Thus, in contrast to previous studies that generated cross-faded continua of instrumental recordings (Emiroglu and Kollmeier, 2008; Heng et al., 2011; Tellman et al., 1995), these tones form a timbre continuum and differ only in their spectral distribution. In a behavioral forced-choice paradigm, the timbre difference was changed adaptively to measure the individual and timbre-dimension specific just noticeable difference (JND).

Shortly after CI implantation and the first fitting of the audio processor, the recipient's perception of pitch, loudness, and timbre improves. However, behaviorally measuring the progress of auditory-verbal training is hindered or not possible; e.g., with children and patients with mental disabilities. Thus, objective measures are also needed for these patients.

Event-related potentials (ERP) appear to be appropriate to objectively measure auditory perception skills in CI users (Bakhos et al., 2012; Friesen and Picton, 2010; Kraus et al., 1993; Santos et al., 2013). Particularly, the mismatch negativity (MMN) component of ERPs can be used to measure acoustic feature discrimination by reflecting the outcome of a pre-attentive change detection process (Näätänen et al., 1978, 2012; Ponton et al., 2000), and its elicitation does not require participants to actively detect the deviating sounds. Since recent studies report a correlation between MMN amplitudes and behavioral discrimination thresholds (Novitski et al., 2004; Stoody et al., 2011; Lopez-Valdes et al., 2013). MMN recordings could probably also used for objective measurements of behavioral discrimination skills.

MMN has been successfully recorded in CI patients (Kraus et al., 1993; Lonka et al., 2004; Ponton and Don, 1995; Rahne et al., 2010b; Torppa et al., 2012; Vavatzanidis et al., 2011; Zhang et al., 2011) even when a stimulation artefact occurred in the electroencephalogram (EEG) (Bakhos et al., 2012; Friesen and Picton, 2010). Music discrimination was studied in CI users previously by using complex sounds differing in more than one timbre dimension to elicit MMN (Roman et al., 2004, 2005; Sandmann et al., 2010; Timm et al., 2012). Thus, MMN amplitude might also reflect the automatic discrimination processing of single timbre dimensions in NH listeners and CI users.

We measured the MMN for spectral distribution and temporal envelope modulation cues and compared with the behavioral discrimination skills of NH listeners and CI users. Thereby, the individual JNDs are psychoacoustically measured. In an MMN paradigm, deviating stimuli are presented in a sequence of repeating standard stimuli. If a MMN could be elicited by differences between the standard and the deviant tones above the individual JND and not below, the MMN would be an objective method for measuring the