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Research paper

Simultaneous suppression of tone burst-evoked otoacoustic emissions – Effect of level and presentation paradigm

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Abstract

There is conflict in the literature over whether individual frequency components of a transient-evoked otoacoustic emission (TEOAE) are generated within relatively independent "channels" along the basilar membrane (BM), or whether each component may be generated by widespread areas of the BM. Two previous studies on TEOAE suppression are consistent with generation within *largely* independent channels, but with a degree of interaction between nearby channels. However, both these studies reported significant suppression only at high stimulus levels, at which the "nonlinear" presentation paradigm was used. The present study clarifies the separate influences of stimulus level and presentation paradigm on this type of suppression. TEOAEs were recorded using stimulus tone bursts at 1, 2 and 3 kHz and a complex stimulus consisting of a digital addition of the three tone bursts, over a range of stimulus levels and both "linear" and "nonlinear" presentation paradigms. Responses to the individual tone bursts were combined offline and compared with responses to the complex stimuli. Results clearly demonstrate that TEOAE suppression under these conditions is dependent upon stimulus level, and not upon presentation paradigm. It is further argued that the data support the "local" rather than "widespread" model of TEOAE generation, subject to nonlinear interactions between nearby generation channels.

Keywords: Transient-evoked otoacoustic emissions; Suppression; Tone bursts

1. Introduction

Transient-evoked otoacoustic emissions (TEOAEs) in response to click stimuli are typically recorded as complex, multi-frequency responses. The bulk of available data to date indicate the existence of relatively independent "generator channels", in that individual frequency components within the response are relatively unaffected by the presence of stimulus or response components at other frequencies (e.g., Kemp, 1978; Probst et al., 1986; Xu et al., 1994; Prieve et al., 1996; Tavartkiladze et al., 1997; Ueda, 1999). Further, a given response component is thought to be evoked by a stimulus component at the same frequency, and presumably at the corresponding tonotopic location along the basilar membrane (BM) (Kemp, 1978; Elberling et al., 1985; Norton and Neely, 1987). These concepts may be described as representing a one-to-one relationship between stimulus and response frequency components, in the generation of TEOAEs.

Recent suggestions for classification of otoacoustic emissions, based on understanding of their generation mechanisms rather than measurement techniques (e.g., Shera, 2004), also suggest that TEOAEs are generated by pre-existing "place-fixed" mechanical perturbations in

Abbreviations: BM, basilar membrane; OAE, otoacoustic emission; TEOAE, Transient-evoked otoacoustic emissions; I–O, Input–output; 2TS two-tone suppression

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cochlear mechanics. Such suggestions are consistent with the local, relatively independent generation of TEOAE frequency components as described above.

Some authors have, however, reported contrary findings that suggest other models of TEOAE generation. For example, Sutton (1985) and Withnell and Yates (1998) reported that the suppression of a TEOAE by a pure tone is not restricted to the frequency region of the pure tone. Withnell and Yates (1998) also observed *enhancement* of TEOAE responses at frequencies lower than the "suppressor" tone frequency. Avan et al. (1995, 1997) observed changes in low frequency components of the TEOAE following damage to the basal region of the BM. Carvalho et al. (2003) reported TEOAE phase data that suggested that a TEOAE "at frequency f cannot come from that place tuned to f". All of these findings suggest that the generators of individual TEOAE frequency components may in fact be distributed along the length of the BM. Most recently, Withnell and McKinley (2005) suggest that, at least in the guinea pig, relatively early TEOAE components are generated by a mechanism distributed along the BM, while relatively late components have local, "place-fixed" origins.

Other authors have obtained results that may be broadly consistent with the principle of local, independent generator channels, with, however, some interaction between such channels under certain conditions. Specifically, Xu et al. (1994) and Yoshikawa et al. (2000) found a degree of reduction or "suppression" of the response component at one frequency in the presence of a stimulus (and response) component that was 500–1000 Hz higher. Xu et al. (1994) found that the TEOAE in response to a 1 kHz tone burst was reduced in amplitude by the simultaneous presentation of a pair of tone bursts at 2 and 3 kHz. Similarly, Yoshikawa et al. (2000) reported varying levels of suppression of the response to a 1 kHz tone burst when simultaneously presenting a tone burst centred at either 1.5, 2 or 3 kHz. This suppression was greatest with the combination of 1 and 1.5 kHz tone bursts (i.e., smallest frequency separation).

One notable aspect of the findings of Xu et al. (1994) and Yoshikawa et al. (2000) was that the above suppression was only evident at high levels of stimulation – Xu et al. (1994) reported suppression at stimulus levels of 75 dB p.e. (peak equivalent) SPL, but not at 37 dB p.e. SPL and 59 dB p.e. SPL, and Yoshikawa et al. (2000) reported significant suppression at 70 dB p.e. SPL but not at 60 dB p.e. SPL. In both these studies, however, the responses at the highest stimulus level (which exhibited suppression) were also obtained using the "nonlinear" presentation paradigm often used in TEOAE measurements (Kemp et al., 1990). In contrast, responses at the lower stimulus levels (which did not exhibit suppression) were obtained using the more simple "linear" presentation paradigm.

The nonlinear presentation paradigm cancels out linearly scaling components in TEOAE recordings at two different stimulus levels, whilst partially preserving nonlinearly scaling components. The technique is of great practical value in removing the (linear) "ringing" of the stimulus click that would otherwise obscure the early (high-frequency) component of the TEOAE. TEOAE responses themselves typically exhibit a compressively nonlinear input–output (I–O) function, and are therefore not cancelled by the nonlinear paradigm. However, they are somewhat reduced in amplitude relative to recordings that do not implement the paradigm ("linear recordings"). Of more relevance to the present study, the nonlinear presentation paradigm also complicates the interpretation of the suppression data obtained by Xu et al. (1994) and Yoshikawa et al. (2000). For example, in the case of the stimuli presented in the nonlinear paradigm at a nominal level of 75 dB p.e. SPL, the amount of suppression is dependent upon three variables – suppression at a true stimulus level of 75 dB p.e. SPL, suppression at a true level of 85 dB p.e. SPL and the nonlinear relationship between responses at 75 and 85 dB p.e. SPL governed by the compressive nonlinearity of the TEOAE I–O function. Additionally, while the results were held to show that suppression increases with stimulus level, the data of Xu et al. (1994) indicate no significant suppression at either of the lower levels used, and a somewhat abrupt onset of suppression at the higher "nonlinear" level. Likewise Yoshikawa et al. (2000) describe suppression increasing with level, it is only at the higher "nonlinear" level that the suppression is shown to be significant. These data therefore raise the question as to whether the salient difference between stimuli that did or did not produce suppression was the presentation paradigm rather than the level of the stimulus.

The main aim of the present study was to determine whether the suppression of TEOAE responses as previously reported by Xu et al. (1994) and Yoshikawa et al. (2000) is entirely a function of stimulus level, or whether it is influenced by the presentation paradigm used. The secondary aim was to characterise any dependence of suppression upon stimulus level in greater detail than the previous work.

2. Materials and methods

2.1. Subjects

Subjects were fourteen normally hearing adults (10 female, 4 male), aged 21–28 years (median = 24.4 years). All subjects had audiometric thresholds of 15 dB HL or better from 0.25 to 8 kHz in the ear tested, and normal middle ear status as measured by otoscopic examination and tympanometry. TEOAEs in response to click stimuli were initially measured in both ears, and the ear with the larger TEOAE amplitude in each subject was selected for inclusion in the study. Eight right ears and six left ears were included.

2.2. Instrumentation and stimuli

Stimuli were generated and responses recorded using the Otodynamics ILO 88 system with software version 5.60. Two types of stimuli were generated using routines available in the ILO 88 software: (a) simple