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A Segmented Average Method to Increase the Reproducibility of Transient- Evoked Otoacoustic Emissions

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Abstract- **This study proposes a segmented average method that combines the derived nonlinear response (DNLR) method and the linear averaging method to increase the reproducibility of transient-evoked otoacoustic emissions (TEOAEs). Twenty normal ears were tested to evaluate the performance. For each ear, two types of TEOAE signals were obtained with the proposed method and with the DNLR method, respectively. Then the reproducibility of these two kinds of TEOAE signals was compared. Results showed that the average reproducibility of the TEOAE signals increased much with the proposed method.**

Keywords **- TEOAE, DNLR, reproducibility**

I.INTRODUCTION

Transient-evoked otoacoustic emissions (TEOAEs) are the evoked signals resulting from the cochlea in response to transient acoustic stimuli [1]. They are essentially present in all normal ears but usually absent or reduced in ears with mild hearing loss [1]. It is for this reason and for the short duration of the test time that the TEOAE test is now gaining momentum as a universal tool for the newborn hearing screening.

In the TEOAE test, noise contamination and stimulus artifact contamination are two critical factors that affect the accuracy of the pass/fail criterions. To reduce the noise contamination, a large number of evoked signals in response to transient acoustic stimuli were averaged to reduce the noise level, and the correlation (reproducibility) between two replicate averaged evoked signals was estimated to confirm the existence of true TEOAEs. To reduce the stimulus artifacts, which contaminate the first few milliseconds of the evoked signals, Kemp proposed a derived nonlinear response (DNLR) method [2] to extract the "true" TEOAE signal. It employs a train of evoked signals to effectively reduce the linear content of the stimulus artifacts. This train of evoked signals is the response to three transient acoustic stimuli with one polarity followed by the fourth one with opposite polarity and three-time amplitude.

Reproducibility is an important criterion in the identification of TEOAEs. The DNLR method successfully reduces the stimulus artifacts; however, the reproducibility obtained is lowered comparing to that using the classical synchronous averaging (linear averaging) method [3]. Some studies also showed that at greater latencies, the TEOAE signals recorded by the DNLR method exhibit no additional feature in comparison with those recorded by the linear averaging method, at all stimulus levels [3]. From the reasons above, the linear averaging method then becomes as the focus on designing a TEOAE recording protocol for many studies. In the linear protocol, it has been shown that the stimulus artifacts can be canceled by the combined use of a mid-level stimulus (68 dB p.e. SPL) and a time-window starting at 4 ms. However, the stimulus level and the time-window duration were with limited range in order to effectively cancel the artifacts. The limited range of stimulus level will restrict the feasibility to achieve higher reproducibility using higher stimulus level. The limited range of the time-window duration will remove the initial high frequency component of TEOAE signals. Therefore, this paper proposes a segmented average method combining the DNLR method and the linear averaging method to increase the reproducibility. In this procedure, the initial segment of each TEOAE signal was obtained by the DNLR method, and its later segment was obtained by the linear averaging method. The two kinds of TEOAE signals obtained by this method and by the DNLR method were compared to evaluate the performance.

II. MATERIALS AND METHODS

Our own acquisition system for the TEOAE signals was developed. This acquisition system included a personal computer (PC) equipped with Intel Pentium CPU, a Loughborough Sound Images' (LSI) PC/C32 control board and an Etymotic Research's ER-10C acoustic-electric transformation system. The TEOAE signals were recorded according to the procedure in previous study [4]. The all TEOAE signals for this study were collected from 20 normal ears of twelve adults, and they were measured within general laboratory without sound proof.

This study used the four-click-train stimuli to induce the four-click-train responses defined as $R_1(t)$ to $R_4(t)$. In the segmented average method, we obtained the subaveraged response $R_1(t)$ to $R_4(t)$ using the following procedure. In the segment of 2.5-8 ms, the subaveraged response was the average of $R_1(t)$ to $R_4(t)$ (DNLR); in the segment of 8-20 ms, the subaveraged response was only the average of $R_1(t)$ to $R_3(t)$. This procedure can be expressed as

$$Sub(t)=\begin{cases}[R_1(t)+R_2(t)+R_3(t)+R_4(t)]/2 & 2.5\le t<8ms\\ [R_1(t)+R_2(t)+R_3(t)]/3 & 8\le t\le 20ms\end{cases},$$

where $R_i(t)$ is the evoked signals in response to the three click stimuli with one polarity (i=1~3) and a click stimulus with opposite polarity (i=4). By the way, the subaveraged response of the same ear using the DNLR method was also obtained by the expression as

$$Sub(t) = [R_1(t) + R_2(t) + R_3(t) + R_4(t)]/2 \quad 2.5 \le t \le 20\,ms$$

For each ear, one pair of TEOAE signals was obtained with each method. Each TEOAE signal was the average of 260 subaveraged responses obtained by the corresponding method (the proposed method or the DNLR method). Then the reproducibility was estimated and compared. To clarify the terminology, the TEOAE signals obtained with the proposed method and the DNLR method will be referred to as merged TEOAE signal and DNLR TEOAE signal, respectively.

To observe the reproducibility change with time, each TEOAE signal was re-windowed, in the segment of 2.5-19.5 ms, by sixteen 2-ms-long windows with 1 ms overlapping. For each 2-ms segmental signal, the cross-correlation coefficient between the pair of TEOAE signals was estimated, and then obtained a measure of the correlation coefficient as a function of time.

III. Results

Fig. 1 shows the reproducibility for 20 TEOAE signals obtained by the two methods. It could be observed that the reproducibility was increased with the proposed method. Fig. 2 shows the mean 2-ms-long correlation coefficients of all 20 TEOAE signals as a function of time, for the DNLR TEOAE signals and the merged TEOAE signals, respectively. It could be observed that the mean values of the correlation increased after 8 ms, the time when the linear averaging method started to be used in the proposed method.

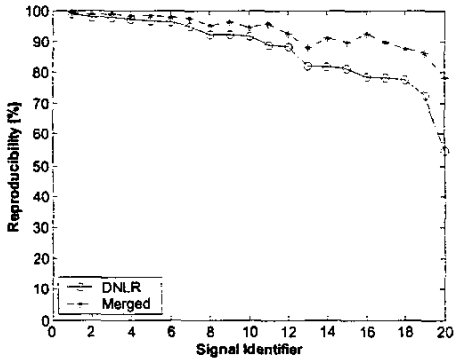

Fig. 1 Reproducibility of 20 TEOAE signals obtained with the proposed procedure (Merged) and with the DNLR method

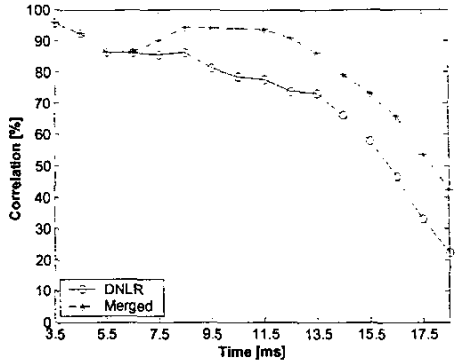

Fig. 2 Correlation values of the TEOAE signals in sixteen different time-windows.

IV. Discussion and Conclusion

This paper proposes a segmented average method to increase the reproducibility of TEOAE signals on the premise that the signal information is not lost and the test time is not increased. Results show that the reproducibility of 20 TEOAE signals did increase significantly with the proposed method.

Regarding the decision of separation time, when linear averaging method started to be used, it is very crucial to the proposed method. The earlier the separation time is, the higher reproducibility the merged signal will have. However, the higher reproducibility in the initial segment of the TEOAE signal is due to the stimulus artifacts. Because studies have shown that the TEOAE signals recorded using the DNLR method exhibit no additional feature in comparison with the signals recorded using the linear averaging method at latencies greater than 6 ms, at all stimulus levels [3], the separation time was set at 8 ms in this study. We believe that by combination of the DNLR method and the linear averaging method, not only the stimulus artifacts could be cancelled, but also the reproducibility can get much higher.

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