Behavioral and objective measures of the precedence effect

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The precedence effect (PE) refers to the dominance of directional information carried by a direct sound (lead) over the spatial information carried by sound reflections (lags) in sound localization. Many studies investigated the PE at different stages along the auditory pathway, but it is still unclear whether this perceptual phenomenon originates from peripheral or central processes. The present study aimed at investigating peripheral correlates of the PE by comparing psychoacoustical data to objective measures of lag-suppression.

The psychophysical data showed that the time range in which the PE operated (precedence window) was between 1 and 5 ms. Click-evoked otoacoustic emissions (CEOAEs) were recorded to investigate monaural lag-suppression at a peripheral stage of the auditory pathway, and showed lag-suppression within the precedence window. By using tympanic responses (ABRs) were used to investigate both monaural and binaural lag-suppression at the brainstem level. The ABRs to monaural stimulation reflected the peripheral lag-suppression, while the binaural ABRs did not show any additional contribution of binaural processes to the monaural lag-suppression.

The findings of this study demonstrate a monaural and peripheral component to lag-suppression, reflecting basilar membrane (BM) lead-lag impulse response interactions, in a time range from 1 to 4 ms.

Introduction

Consider a direct sound (lead) with a single reflection (lag). The lead-lag pair is represented in the free field setup, where the leading speaker is towards the right (positive ITD) and the lagging speaker is towards the left (negative ITD). The time ranges are defined for click stimuli.

Three perceptual phenomena occur within the precedence window:

- Fusion
- Lead-lag dominance
- Lag-suppression

Is the precedence effect a result of peripheral or central processes?

Aim of the study

To investigate the contribution of peripheral processing to the precedence effect by providing individual comparisons of objective and behavioral data.

Psychoacoustical experiments

Aim

- Define the three windows of perception
- Define the lateralization of the lead-lag pair for each window

Stimuli

- Design with ICIs of 0-8 ms and ITDs of 300 and 900 μs were presented using an interleaved technique. For each IC1 and ITD condition, 1800 replications of the following three stimuli were presented:
  - Single Click (SC)
  - Double Click (DC)
  - Double Click Inverted (DCI)

Results

- Several new hearing subjects performed the following three experiments:
  1. Fusion test: define the echo-threshold for monaural and binaural stimulation
  2. ITD-detection test: define the minimum interaural time difference (ITD) threshold
  3. ITD-lateralization test: specify the perception of the lead-lag pair as a function of the interaural interval (ICI)

Conclusions

- Mean echo-thresholds occur for IC1 of 4.3 ms (binaural stimulation).
- Similar thresholds for monaural and binaural stimulation.
- ITD-thresholds for an ICI between 1-5 ms indicate stronger lead-lag suppression than for IC1 = 4.3 ms.
- Lag-suppression at brainstem level

ABRs

Aim

- Compare ABRs to monaural and binaural stimulation to investigate whether binaural processes contribute to lag-suppression at brainstem level

Stimuli

- Devise with ICIs of 0-8 ms and ITDs of 300 and 900 μs were presented monaurally and binocularly. The ABRs were recorded using 4 scalp electrodes (M1, M2, Fz, Cz).

Results

- The ABRs recorded for subject KE for binaural stimulation (left: ITD=300 μs; right: ITD=500 μs). The waves V elicited by lead and lag are indicated by downward-pointing triangles.

Conclusions

- Lag-suppression at brainstem level

References

[6] Federica Bianchi, Sarah Verhulst, Torsten Dau (2009) Monaural ABRs and CEOAEs results. The ABRs to monaural stimulation (blue and red dashed curves in Fig. 9) followed the trends of the CEOAE results (blue and red solid curves). However, the two curves were not expected to be identical:

- CEOAEs reflect the amplitude reduction of the backscatter or forward traveling wave, which contains information of specific reflection sites along the basilar membrane (BM).
- ABRs reflect the neural activity elicited by the forward traveling traveling wave and should hypothetically reflect the synchronous activity of the whole basilar membrane.

Even though both CEOAEs and ABR results are expected to reflect monaural BM lead-lag interactions, the CEOAE only contains a subset of otoacoustic emissions and the ABRs are recorded at the brainstem level.

Monaural and binaural ABRs

- For ICI=0 ms, the lag-wave reduction obtained for monaural and binaural stimulation was not larger than the solution obtained for monaural stimulation.

These results suggest that binaural processes did not add any substantial contribution to monaural and peripheral suppression at the brainstem level, in agreement with [3].

Conclusion

The results show that BM lead-lag interactions reflect the main source of lag-suppression up to the brainstem. This suggests the existence of a direct and peripheral component to the linearly perceived PE.

Figures

- Figure 1: Three perceptual phenomena occur within the precedence window
- Figure 2: Results of the ITD detection tests for subject KE
- Figure 3: Monaural and peripheral lag-suppression (dB) for subject KE as a function of the IC1. The curved line shows the mean monaural lag-suppression, the solid curve the monaural left suppression
- Figure 4: Procedure to derive the suppressed response from the (left) ITD-CEA/IC1 component due to the leading click, while keeping the component due to the lagclick and the reentrant component due to the IC1.
- Figure 5: Mean echo-thresholds occurred for IC1 of 4.3 ms (binaural stimulation).
- Figure 6: Stimulus used in the ABR recordings and head schematic showing the position of the electrodes M1, M2 and Cz.
- Figure 7: ABRs for monaural stimulation (left: ITD=300 μs; right: ITD=500 μs). The waves V elicited by lead and lag are indicated by downward-pointing triangles.
- Figure 8: Reduction of the ABRs to monaural stimulation (left: ITD=300 μs; right: ITD=500 μs). The waves V elicited by lead and lag are indicated by downward-pointing triangles.