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Noise improves suprathreshold discrimination in cochlear-implant listeners

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Abstract

The present study aimed to examine the effect of noise on vowel-like suprathreshold discrimination in cochlear-implant listeners. The task was to detect an increment in level at the middle harmonic (400 Hz) in the background of a seven-harmonic complex from 100 to 700 Hz in 100-Hz steps. The task was performed in the absence (control) and presence of a white noise presented over a 20–35-dB range from inaudible to loud. The present result shows that discrimination of suprathreshold harmonic stimuli was significantly enhanced, particularly at the soft signal level, with suprathreshold noise. This result suggests that tuning of the noise level is required to optimize performance of different tasks in cochlear implants.

Key words: Noise; Stochastic resonance; Harmonic complex; Cochlear implant

1. Introduction

Stochastic resonance is a nonlinear phenomenon in which the addition of an appropriate amount of noise enhances detection of a signal (Wiesenfeld and Moss, 1995). Morse and Evans (1996) used frog's sciatic nerve as an electric stimulation model to demonstrate that noise could extract and enhance vowel formant information from the neural temporal discharge patterns. Morse and Evans's work has stimulated several subsequent studies attempting to demonstrate the role of stochastic resonance in human subjects, particularly those using the cochlear implant (CI). Zeng et al. (2000) showed a 2–6 dB improvement in detection threshold by the addition of noise in normal-hearing, CI, and auditory-brainstem-implant listeners. Chatterjee and Robert (2001) found that the addition of noise improved temporal modulations at soft but not loud levels in the CI listeners. In addition, Ward (2001) found that the addition of an optimal amount of noise significantly improved the detection of auditory and visual stimuli in normal-hearing listeners.

Although Morse and Evans's original work demonstrated formant enhancement, previous work mostly focused on the effect of noise on threshold-related phenomena. Because the most important listening tasks such as speech recognition are performed at the suprathreshold level, it is critical to investigate whether noise can improve suprathreshold discrimination. The present study aimed to examine how noise affects a vowel-like suprathreshold task in CI listeners.

2. Materials and methods

2.1. Subjects

Two Ineraid CI listeners participated in the present study. The two CI listeners were 40 and 70 years old, respectively. They had used their CIs for more than 10

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Abbreviations: CI, cochlear implant

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years. The subjects were compensated for their participation in this study. Local IRB approval and informed consent were obtained.

2.2. Stimuli

All stimuli were generated digitally (44.1 kHz sampling rate) using the Tucker-Davis Technologies System II equipment. A seven-harmonic stimulus with 100-Hz fundamental frequency was generated to resemble the stimulus used in Morse and Evans's study. The stimulus had 500 ms overall duration, including 10-ms cosine-squared ramps. The reference had all of the harmonics at the same level, whereas the signal had an increase in level at the 400-Hz middle harmonic. The reference stimulus was presented at a soft and a loud level according to the subjective loudness estimate from a scale of 0 to 10, with 0 corresponding to the threshold and 10 to the uncomfortable loudness level. The soft level corresponding to a loudness estimate of 1 was 2.5 μA for all harmonics in CI-1 and 1.8 μA in CI-2, while the loud level corresponding to a loudness estimate of 7 was 5.6 μA in both CI-1 and CI-2.

A Gaussian noise was presented continuously throughout the trials in all conditions except for the control. The threshold level for the noise was determined individually for each subject. The noise was then presented to the subject over a 20–35-dB range from inaudible to loud. We also observed that the noise had a dynamic range of 20 for CI-1 and 25 dB for CI-2, much greater than the 10-dB or less dynamic range for the present harmonic stimulus.

The signal and noise were mixed and presented to the most apical electrode in a monopolar mode via a voltage-to-current source that directly connected to the percutaneous interface in the Ineraid device (Eddington et al., 1978). Optical isolation and a foot-pedal switch that could terminate electric stimulation at any time were employed as safety measures.

2.3. Procedure

The subject sat in a soundproof booth and was instructed to identify the interval containing the signal. A three-interval-forced-choice adaptive procedure was used in all experiments. The signal level was reduced for two consecutive correct responses and was increased for each incorrect response. During each run, the step size was 2 dB for the first three reversals and 0.5 dB afterwards. To finish a run, either 12 reversals were reached or a total of 60 trials were completed. The threshold was determined by averaging all reversals except for the first three reversals using the large step size. The reported threshold was the average of three such runs.

3. Results

Fig. 1 shows the effect of noise on suprathreshold discrimination of harmonics presented at either a soft (top panel) or loud (bottom) level in the CI (dotted and dashed lines) subjects. The y-axis represents the threshold relative to that obtained in the no-noise control. The present result shows that noise enhanced discrimination of suprathreshold harmonic stimuli, particularly at the soft level. The 2–4-dB improvement with the soft level stimuli was significant for CI-1 at +12.5 to +17.5

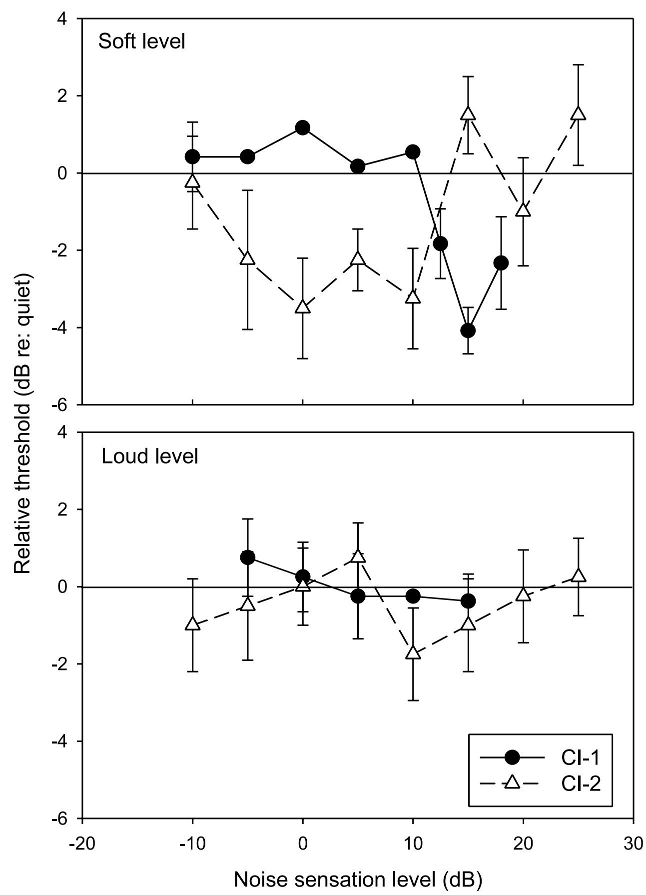

Fig. 1. Discrimination of level increment in a harmonic background as a function of the noise level (x-axis). The control stimulus was a seven-harmonic complex (from 100 to 700 Hz in 100-Hz steps) with equal amplitude. The signal had an increment at the middle harmonic (i.e., 400 Hz) that was required to produce 70.7% correct response. The y-axis represents the middle harmonic increment threshold in dB relative to the threshold in the absence of the noise. Error bars represent ± 1 S.D. (some error bars are masked by the symbols). The level for each harmonic was 2.5 and 1.8 μA for CI-1 and CI-2, respectively in the soft level condition (top panel) and 5.6 μA for both CI-1 and CI-2 in the loud level condition (bottom panel). The just-detectable increment at the middle harmonic in the absence of noise was 16.6 and 10.0 μA for CI-1 and CI-2, respectively, in the soft level condition and 9.2 and 11.6 μA for CI-1 and CI-2, respectively, in the loud level condition. This increment served as the basis for calculating the relative threshold shift in the presence of noise (y-axis).

dB noise sensation levels and for CI-2 at −5 to +10 dB (within-subject *t*-test, $P < 0.01$). The improvement was reduced to 0.5 dB for CI-1 (not significant) and to 2 dB for CI-2 at the 10-dB noise sensation level (significant, $P < 0.05$). Additionally, note that there was no or little (< 2 dB threshold elevation) masking effect over a noise range as large as 35 dB for this type of suprathreshold task. Finally, note that, except for the −5 dB condition for CI-2, the improvement occurred at 0 noise sensation level or above.

4. Discussion and summary

Because all harmonics were delivered to a single electrode and could not be resolved by the CI listener, the present task had to be performed based on either an overall loudness cue, or a complex waveform cue, or both, between the reference and the signal in the time domain. Independent of the cues used, the present study found that, consistent with Morse and Evans's (1996) model prediction, that an optimal level of noise improved discrimination between two harmonic stimuli in CI listeners. Comparing the present study with previous behavioral studies, three interesting observations can be made. First, the optimal noise level required to improve auditory perception appeared to be dependent on the task: a sub- or near-threshold noise was required to produce the improvement in a detection task (Zeng et al., 2000) while most likely a suprathreshold noise was required in a discrimination task (the present study). Second, the noise-induced enhancement appeared to be maximal with low signal levels but diminished with high signal levels. This observation is true for the present harmonic discrimination result and also for Chatterjee and Robert's (2001) modulation detection result. Hong et al. (2003) observed a similar level-dependent effect that a high-rate conditioner enhanced the electric dynamic range by greatly decreasing threshold but only moderately decreasing uncomfortable level. Third, there is a great deal of individual variability in both the present and previous studies. Taken together, these results suggest that noise-enhanced hearing depends on a number of factors including at least the noise level, the task, and the individual. Optimization of these factors presents a challenging task for using the noise to improve CI performance.

Acknowledgements

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References

Chatterjee, M., Robert, M.E., 2001. Noise enhances modulation sensitivity in cochlear implant listeners: stochastic resonance in a prosthetic sensory system. J. Assoc. Res. Otolaryngol. 2, 159–171.

Eddington, D.K., Dobelle, W.H., Brackmann, D.E., Mladevosky, M.G., Parkin, J.L., 1978. Auditory prosthesis research with multiple channel intracochlear stimulation in man. Ann. Otol. Rhinol. Laryngol. 87 (Suppl. 53), 1–39.

Hong, R.S., Rubinstein, J.T., Wehner, D., Horn, D., 2003. Dynamic range enhancement for cochlear implants. Otol. Neurotol. 24, 590–595.

Morse, R.P., Evans, E.F., 1996. Enhancement of vowel coding in cochlear implants by addition of noise. Nat. Med. 2, 928–932.

Ward, L., 2001. Noise can help as well as hinder seeing and hearing. APS Meeting, http://www.aps.org/meet/MAR01/baps/vpr/layn23-002.html.

Wiesenfeld, K., Moss, F., 1995. Stochastic resonance and the benefits of noise: from ice ages to crayfish and SQUIDs. Nature 373, 33–36.

Zeng, F.G., Fu, Q.J., Morse, R., 2000. Human hearing enhanced by noise. Brain Res. 869, 251–255.