Perception Of Increasing Or Decreasing Signal Intensity And Effects Of Compression By Hearing Aids

M.-J. Palardy, C. Giguère and C. De Segovia
Programme d'audiologie et d'orthophonie, Université d'Ottawa, 451 Smyth Road, Ottawa, Ontario K1H 8M5

1. INTRODUCTION

Signal-intensity changes provide important cues to evaluate the distance and motion of sound sources in the environment. In one study [1], signal intensity cues facilitated the perception of distance for both close and far sound sources. In another study [2], the listener's movement towards a sound source was also shown to help the evaluation of distance. For some people, like the blind, it is of utmost importance to perceive spatial sound information in order to gain independence in their mobility [3]. However, if an individual with a functional visual impairment also suffers from a hearing loss, his/her security might be threatened by the loss of some or all the essential spatial sound information. For example, when a car is moving closer, sound intensity increases, whereas when the car is moving away, sound intensity decreases.

Hearing aids are often equipped with non-linear noise reduction algorithms to increase the signal/noise ratio. Compression functions are also used to compensate for loudness recruitment. A typical compression hearing aid will amplify soft (or far) sounds and reduce loud (or closer) sounds. These strategies, useful for speech communication, may constitute a hazard for deaf-blind people [4]. For example, the increase in sound intensity of an approaching car may be lessened by hearing aid compression. This issue remains rather unexplored [5].

The purpose of this study was to determine whether compression algorithms in hearing aids make intensity changes more difficult to perceive than if no compression (linear aid) is used. The study also aims to determine whether the effect of a hearing aid on the perception of intensity changes can be predicted by the compression ratio. The signal was a car horn, which could increase or decrease in level, presented in silence or constant traffic noise.

2. METHOD

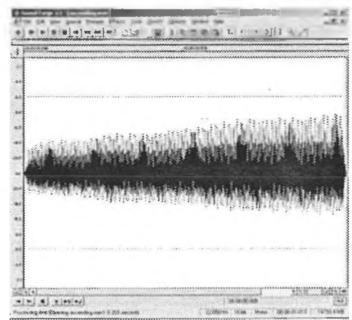
2.1 Subjects

Twenty subjects with normal hearing, aged 22 to 29 years, were recruited among students at the University of Ottawa. Selection was made according to the following criteria: a) air conduction hearing threshold $\leq$ 15 dBHL (*cf.* ANSI S3.6-1996) between 0.25 and 6 kHz bilaterally; b) normal tympanograms, and c) negative otologic history.

2.2 Materials

The car horn signal was extracted from a CD library of environmental sounds. It was a complex periodical signal of 1-sec duration and constant in intensity. The principal spectral components were at 700, 840 and 1045 Hz. Using this basic signal, a bank of increasing and descending car horn signals with different intensity changes were generated using MATLAB software. Figure 1 illustrates an increasing signal with a delta of 6 dB (difference in level between end and beginning of signal).

Figure 1: Car horn signal with increasing level (delta = 6 dB)



For listening conditions of the car horn in background noise, a 2-sec traffic noise recording was taken the CD library of environmental sounds. Using MATLAB, the bank of increasing and descending car horn signals was mixed with the constant traffic noise at a signal/noise ratio of + 6 dB.

The ascending and descending car horn signals, in silence and traffic noise, were then processed through a simulated hearing aid using MATLAB. The simulation was carried out for a "compression" hearing aid and a "linear" hearing aid. The simulated compression corresponded to an AGC-I hearing aid with a compression threshold of 45 dB SPL, a compression ratio of 3:1, and attack and release times of 3 ms and 100 ms respectively. A 1:1 ratio was used to reproduce the condition with linear amplification.

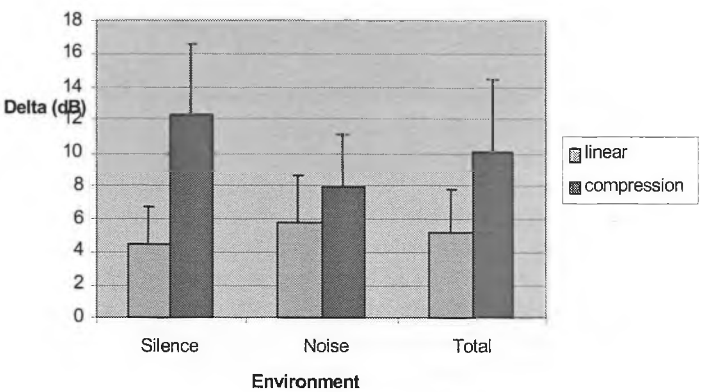
2.3 Procedure

All stimuli were presented at 65 dB SPL. For all subjects, the minimum detectable car horn signal-intensity change was measured using a forced-choice adaptive procedure for the two directions of signal change (increasing or decreasing), the two hearing aid simulations (compression or linear), and the two backgrounds (silence or traffic noise). In each experimental condition, the listeners received 20 stimuli. The first stimulus had a delta signal level change of 8 dB for conditions without compression and 16 dB with compression. Depending on whether or not the subject perceived the intensity change in the car horn, the next stimulus had a smaller or greater delta level change. The signal-intensity threshold was determined as the average delta level change (in dB) for the last 10 trials.

An adaptive A-B comparison procedure was also used to find the equivalence in the increasing (or decreasing) sensation between the two hearing aid conditions. The subjects received 20 pairs of stimuli. One of the stimulus was the car horn signal with hearing aid "compression" and its delta level change was always 15 dB. The second stimulus was the car horn signal with "linear" processing. The delta level change of the latter was varied adaptively from trial to trial to reach equivalence with the reference signal processed with compression. The starting delta was 5 dB. The ordering of the two stimuli was random from trial to trial. Subjects were tested in 4 experimental conditions (ascending in noise, ascending in silence, descending in noise and descending in silence). In each condition, the comparaison threshold was determined as the average delta level change (in dB) for the last 10 trials.

3. RESULTS AND DISCUSSION

Statistical analyses of the results revealed that there is a significant difference ($p < 0.05$) for the effect of hearing aid processing. Over all subjects and conditions, the average threshold in level change for the "linear" condition was of 5.1 dB, whereas for the condition "with compression", the threshold was of 10.1 dB. Thus, simulation of a hearing aid



with a compression ratio of 3:1 made intensity changes 1.98 times more difficult to perceive than with a simulated linear hearing aid. This is illustrated in Figure 2.

Figure 2: Significant results for various environmental background conditions (noise/silence), with or without compression

Crossed effects processing × background also displayed a significant difference (Figure 2). In silence, perception of ascending or descending car horn signals was more difficult in the compression (12.3 dB) condition than linear (4.5 dB) amplification by a factor of about 2.75. Thus, in silence, the effect of compression can be predicted by the hearing aid compression ratio (3:1 in the present study). This is because hearing aid compression is completely controlled by the signal in silence, and thus the car horn level increases or decreases are diminished according to the compression ratio. In noise (Figure 2), the level change threshold is also higher with compression (7.8 dB) than with linear (5.7 dB) amplification, but by a factor of only 1.37. This is because compression is now controlled by the whole sound (signal + noise), and the constant noise has the effect of linearizing the gain of the hearing aid (less gain changes as the signal increases or decreases).

Perceiving ascending or descending signals was easier in noise (6.8 dB) than in silence (8.4 dB). There was also a significant difference in the crossed effect background × direction of level change. In silence, perception is as easy in the ascending (8.6 dB) as the descending condition (8.2 dB), while in noise perception in ascending condition is much easier (5.2 dB) than in the descending condition (8.3 dB).

Statistical analyses carried out with the adaptive A-B comparison procedure revealed essentially the same results. In silence, the adverse effect of compression on the perception of signal level changes can be predicted by the compression ratio of the hearing aid.

4. CONCLUSIONS

The results confirm the hypothesis that signal compression in hearing aids make signal-intensity changes more difficult to perceive than linear amplification. However, the effect depends strongly on background noise. In silence, the effect of compression is most pronounced, and it can be predicted by the compression ratio of the hearing aid. In noise, the effect is less pronounced. It appears that the most difficult situation for perceiving signal-level changes with compression hearing aids is when the compression ratio is high and the signal/noise ratio is also high. In contrast, the adverse effects of compression are minimized when the compression ratio is low and the signal/noise ratio is also low, assuming constant noise. These results need to be confirmed with subjects with sensorineural hearing losses.

5. REFERENCES

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