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Speech intelligibility in noise with ear protectors

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Abstract. Speech perception was tested in high level noise under controlled laboratory conditions in noise-exposed workmen and normal subjects, with and without a hearing protector. The group was further divided by age and English fluency, the latter group being included because of the high proportion of non-fluent English speakers in the Canadian workforce. In normal-hearing subjects the highest discrimination scores were found without background noise, they were lower with white noise as a masker, and even lower with crowd noise as a masker; wearing of a protector had no effect on intelligibility. The results for non-fluent English speakers were parallel with these results, but the scores were lower in all test conditions. In the presence of a high frequency hearing loss speech discrimination was lower than in the normals in quiet and in noise. The addition of a hearing protector dropped their discrimination score even further. In a flat hearing loss, wearing of a protector also worsened the speech discrimination score. The results are discussed.

It is generally agreed that exposure to intense sound may result in a loss of hearing, either temporary or permanent[1]. In industrial settings ear defenders have been chosen as one method of hearing conservation which is both effective and inexpensive. The practicality of this solution depends on two considerations: first, the extent to which the defender selected reduces the noise transmitted to the cochlea (*i.e.*, the attenuation of the device over a wide range of frequencies); and secondly, the possible interference with perception of warning signals[2] and instructions on the job.

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ATTENUATION

Ear plugs are made of a wide variety of materials, from paper tissue to silicone, vinyl, sponge, plastic, glass wool, and rubber. They may be either formed by the user, factory formed, or custom molded. Measurements of the attenuation spectra of 45 common brands have been published recently by Tobias[3]. The

results indicated that, in general, the amount of attenuation increased with increase in frequency in the range of 250 to 4,000 Hz. Across defender types, attenuation scores varied from two to 25 dB at 250 Hz, and from 15 to 48 dB at 4,000 Hz. Within defenders, the difference in attenuation between these two frequencies varied from 0 dB (*i.e.*, a flat attenuation spectrum) to 30 dB. In the higher frequencies, from 8,000 to 18,000 Hz, attenuation values of 25 to 35 dB have been demonstrated[4] for selected types of rubber insert and polymer foam plugs and circumaural ear muffs.

Several reports in the literature comment on the effectiveness of ear defenders in reducing the incidence of noise-induced high frequency deafness for large numbers of workmen. In one study[5], 30,000 workmen were categorized according to level of noise exposure ranging from quiet surroundings to levels in excess of 90 dBA. Protectors were routinely worn in levels of 90 dBA or greater. A cross-sectional analysis of hearing thresholds for different age groups indicated that loss of hearing with age occurred at about the same rate for all exposure categories. Longitudinal studies, that is, the measurement of hearing thresholds in individual workmen over relatively long time periods have confirmed these findings[6].

SPEECH PERCEPTION

In listeners with normal hearing the wearing of ear defenders does not appear to interfere with speech intelligibility. Kryter[7] for example, asked a small group of college students to repeat monosyllables presented over a loudspeaker. Measurements were made for the open ear and with a defender in the ear canal. The level of noise varied from 65 to 105 dB SPL. The results showed that as signal-to-noise ratio was varied from –15 to 10 dB, intelligibility scores increased substantially from 0 to 80 per cent correct. The presence of an ear plug had no effect for noise less than 80 dBA and actually contributed to a gain of about 10 per cent in discrimination for higher levels.

The informal complaints of workmen that protectors prevent them from communicating adequately in a noisy work situation are in stark distinction to published reports of improved discrimination with ear protectors. Published data bear on this issue but do not answer the question directly. Coles and Rice[8], tested speech discrimination in normal hearing and in impaired subjects in quiet with and without an ear plug. Those subjects with severe high tone losses performed more poorly in both conditions. It has been argued[8,9] that in subjects with noise-induced deafness, the protector – with attenuation biased toward the higher frequencies – puts the level of speech below the already raised hearing thresholds in that range.

Study of the effect of noise on hearing, without consideration of protective devices[10], indicates that for signal-to-noise ratio of –8 subjects with hearing impairment perform more poorly than normal hearing subjects. Those with flat loss are more severely handicapped than those with increased thresholds in the high frequencies only. In quiet, with speech at about 40 dB SL, all three groups gave discrimination scores close to 90 per cent correct. The effect of combining the wearing of a muff and white noise background has been examined in subjects with high-tone loss by Lindeman[11]. The levels of speech and noise were 80 and 90 dBA respectively. The results indicated that a decrease in performance in the protected condition was significantly correlated with an increase in hearing loss. For slight impairment the muff produced some improvement in speech perception.

The present experiment is an extension of recent studies[12] of the effectiveness of ear protectors in industrial noise, for workers with pre-existing, noise-induced hearing loss. Specifically, we are attempting to assess changes

in speech perception that occur with variation in age, type of hearing loss, and the spectrum and relative level of the noise background. Of particular interest is the extent to which non-fluency with the spoken language provides an additional handicap for the hard-of-hearing. According to Statistics Canada[13], approximately 23 per cent of residents in Ontario in 1971 acquired English as a second language. For this group no data are available on the extent to which poor comprehension of instructions in English, apart from a hearing disability, interferes with communication in the industrial setting.

DESIGN AND METHODS

The experimental design provided for a comparison of three groups of subjects. Those with: i) normal hearing, defined by conventional audiometric tests (*i.e.*, puretone and speech thresholds); ii) bilateral high frequency loss (*i.e.*, 5-25 dB at 500 Hz with a slope in hearing loss of 35-65 dB between 500 and 4,000 Hz); and iii) bilateral flat loss (*i.e.*, 40-60 dB at 500 Hz and 50-70 dB at 4,000 Hz.

For each of these hearing types, two subgroups were examined: those fluent in English (*i.e.*, native language or acquired in primary school), and those not fluent (for whom English was acquired as a second language). Fluency was assessed using a three point rating scale:

0 – Fluent, English is native language or language of choice (acquired in primary school and used 90 per cent of the time).

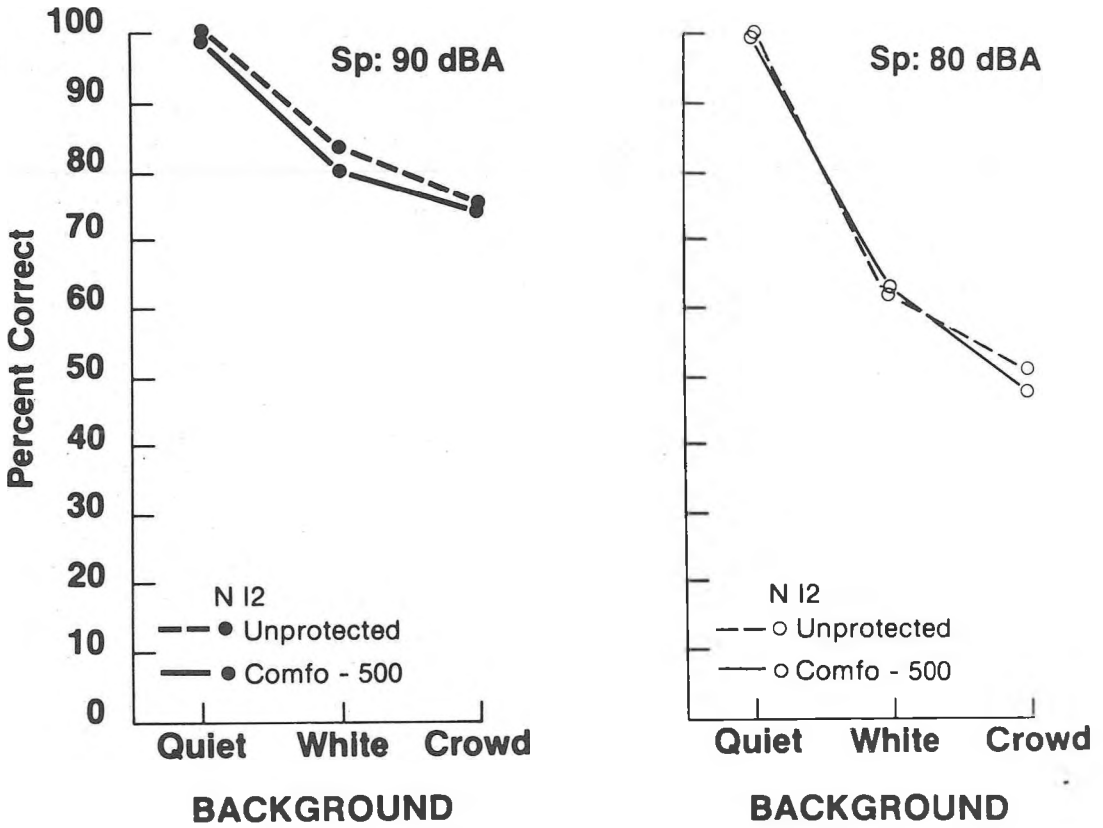

Fig. 1. Speech intelligibility in normal hearing, fluent subjects, aged 35 to 50 years.

1 – Non-fluent, *i.e.* English spoken ungrammatically, difficulty in finding appropriate words but able to converse and to understand instructions adequately.

2 – Non-fluent, *i.e.* one word English sentences or short phrases used, frequent gesturing and difficulty in understanding instructions.

Potential candidates for the study were rated independently by two audiologists and the attending otolaryngologist. Those with a rating of 2 were rejected from the study. Subjects with high-frequency loss, both fluent and non-fluent, were further subdivided into two age groups: 35-50 years and 51-65 years. Normal subjects ranged from 35-50 years of age. Subjects with flat loss were difficult to find and therefore were taken at any age between 35 and 65 years. In each of the eight subgroups 12 subjects were tested. Most subjects were patients referred to the Department of Otolaryngology for assessment of occupational hearing loss. Normal hearing subjects were volunteers from the hospital's housekeeping staff.

Subjects were tested individually while seated in an IAC booth. The ambient noise level of the booth met ANSI[14] standards. Speech stimuli were presented over a single 12 inch diameter conical loudspeaker (Madsen Electronics, Model FF73) placed free-standing on the floor at a distance of 80 inches directly in front of the subject. Noise was presented through two six-inch diameter conical speakers (Madsen Electronics, Model FF72) mounted on the side walls of the booth at a distance of 54 inches from the subject's ears and 11 inches above the head.

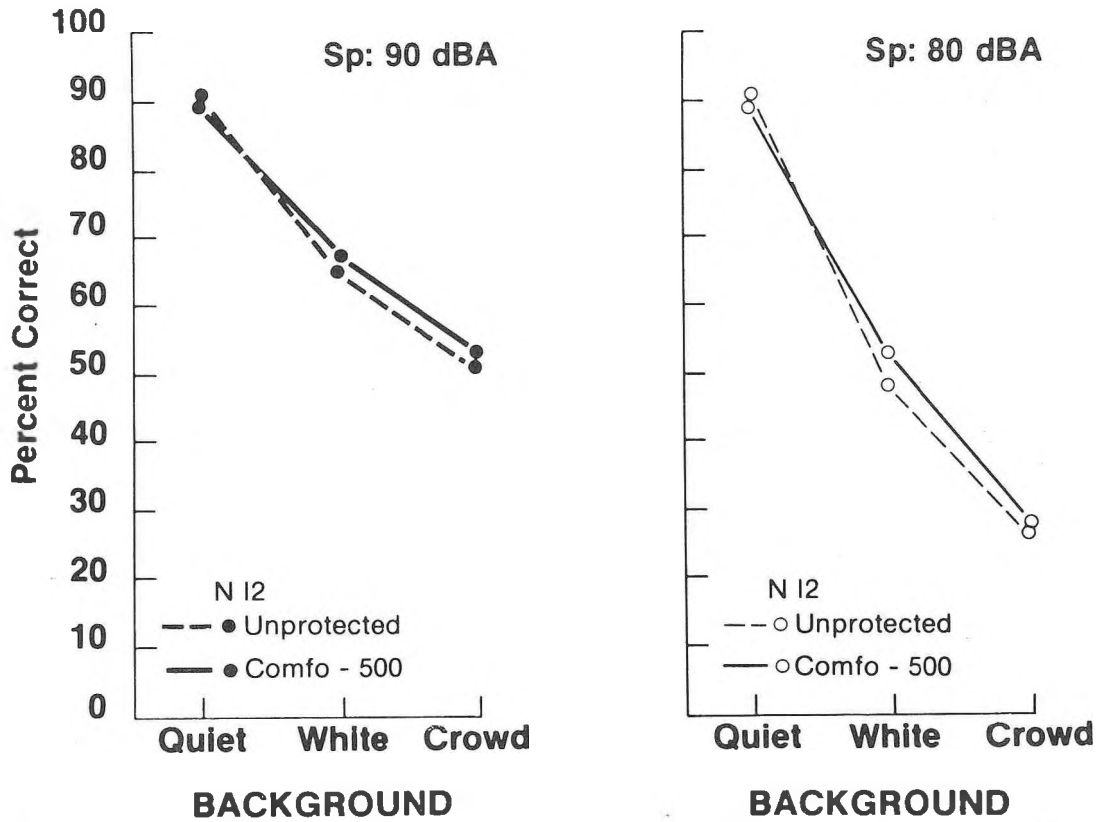

Fig. 2. Speech intelligibility in normal hearing, non-fluent subjects, aged 35 to 50 years.

Each subject was presented 12 lists of 25 monosyllabic words. The lists were constructed using the PAL-PB50 word lists and recorded on tape by a male speaker. The average discrimination threshold (level for reporting 75 per cent of the words correctly for five experienced listeners with normal hearing) ranged from 19 to 23 dBHL across the 12 lists.

Each list was presented under one of 12 listening conditions. We varied the background noise (quiet, white, or taped crowd noise), the amplitude of speech (80 or 90 dBA), and the presence of ear protection (Comfo-500 muff)*. The level of background noise when present was constant at 85 dBA. Across the 12 subjects in the group both the order of listening conditions and the lists used for each condition were randomized.

In addition to this procedure, thresholds for 1/3 octave narrow band noise were measured with the open ear and with the muff in place at each of 10 centre frequencies. The difference in each pair of measures gave the attenuation provided by the defender at each frequency.

Manufacturer: MSA

RESULTS

Preliminary results are presented in Figures 1-6 for six of the eight experimental subgroups. Testing of two groups: high frequency, non-fluent, 35-50 years; and flat loss, non-fluent, 35-65 years, were not completed at the time of analysis of results. In each figure the percentage of words correctly repeated is plotted against the noise back-

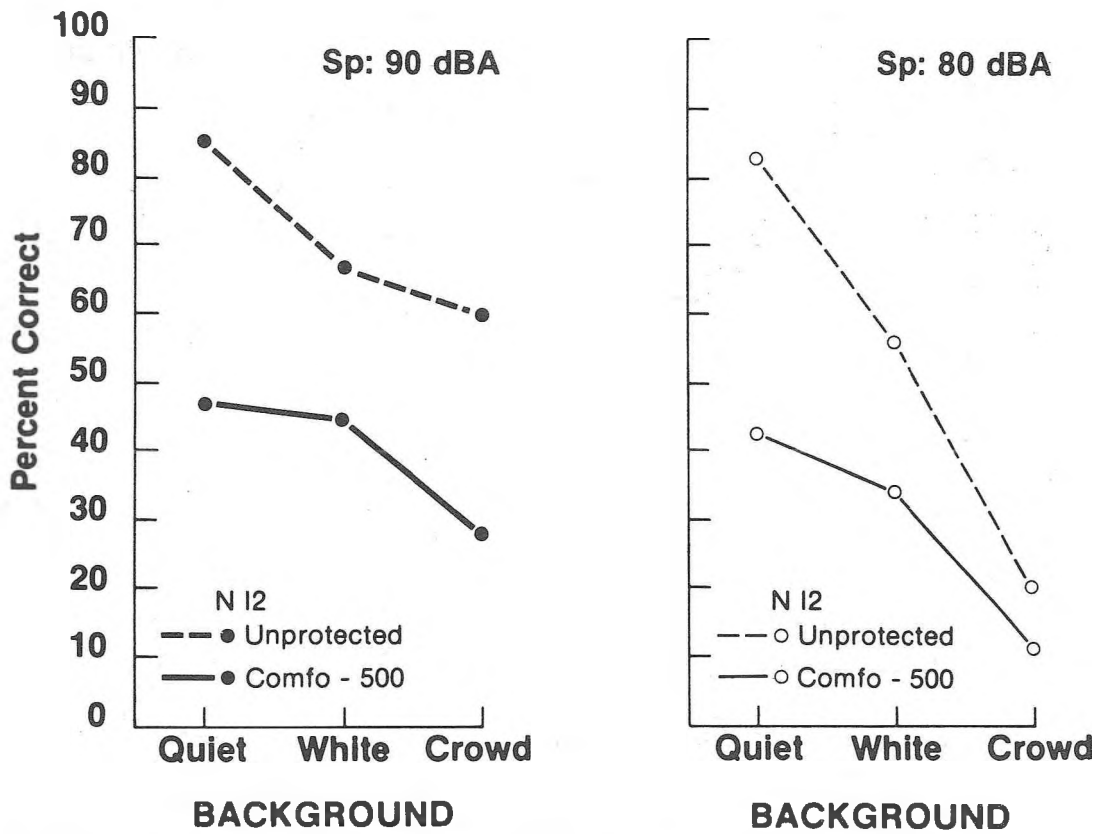

Fig 3. Speech intelligibility in fluent subjects with high frequency loss, aged 35 to 50 years.

ground. Each data point is the average result for the 12 subjects in the group. The dotted line shows the unprotected score and the solid line gives the score obtained with the muff worn. For the left panel in each figure the speech was presented at 90 dBA, and for the right at 80 dBA.

Attenuation

The attenuation data for the six groups are presented in Figure 7. Each data point is the average for the 12 subjects in the group. No systematic differences were observed between groups. The muff gave little attenuation, about 5-10 dB in the low frequencies. From about 1,000-4,000 Hz average attenuation scores of about 20-30 dB were observed. About 4,000 Hz attenuation scores began to decrease.

Within and Between Group Comparisons

1. Normal hearing (Figures 1 & 2)

Fluent: several results are evident from these data. A significantly greater score is achieved listening in quiet than in noise, and crowd noise provides a more effective masker than white noise. In either of the two noise backgrounds intelligibility decreases significantly with a 10 dB drop in the amplitude of speech. For any combination of background and speech level, the protector has no effect on intelligibility. Each of these effects was evaluated using paired comparison t-tests and found to be statistically significant beyond the .001 level.

Non-fluent: the results for non-fluent subjects are essentially the same as those for fluent subjects. Comparison across the two

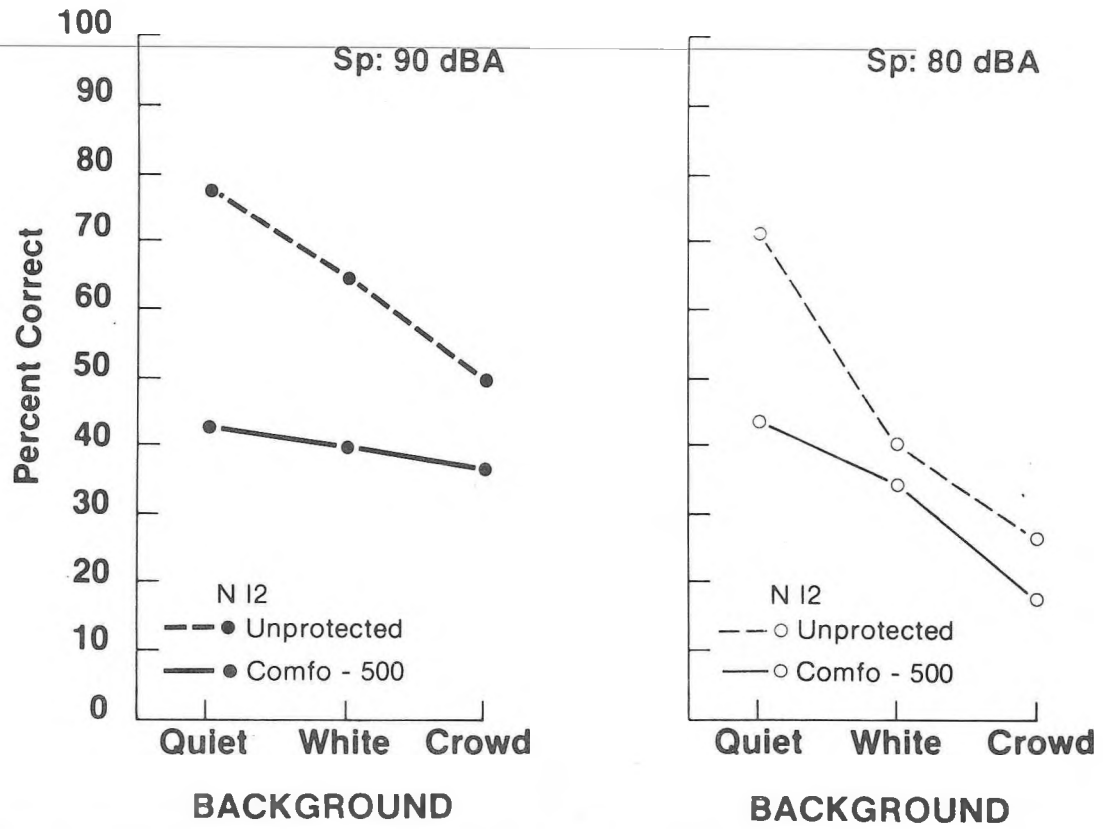

Fig. 4. Speech intelligibility in non-fluent subjects with high frequency loss, aged 51 to 65 years.

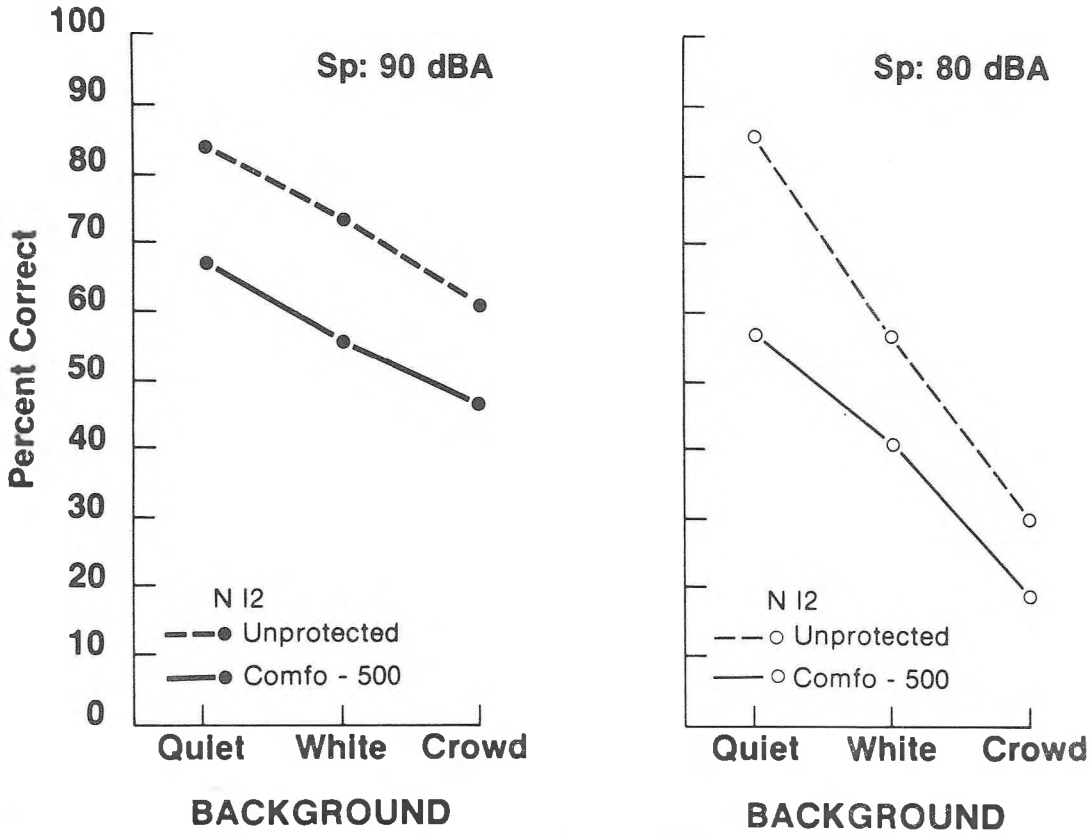

Fig. 5. Speech intelligibility in fluent subjects with high frequency loss, aged 51 to 65 years.

groups for each of the 12 conditions indicates that the scores for non-fluent subjects are significantly lower by about 15 per cent ($p < .01$).

2. *High frequency loss (Figures 3, 4, & 5)*

Fluent, 35-50 years: subjects with a high frequency loss show a different pattern of results from those with normal hearing. Again listening is easier in quiet than in noise and the percentage of words correctly repeated decreases with the lower amplitude of speech when presented in noise. In addition, these subjects show a substantial protector effect. In quiet there is a drop of about 40 per cent in speech discrimination when the muff is worn. In noise the difference between unprotected and protected values is smaller but still statistically significant ($p < .05$).

Non-fluent, 51-65 years: non-fluent subjects with a high frequency loss show a significant decrease in score for unprotected listening as the background changes from quiet to white to crowd noise ($p < .01$). When the muff is worn, background is an effective variable only for the lower amplitude of speech ($p < .005$). No differences are apparent at the higher speech-to-noise ratio.

If the results of this group are compared with fluent subjects matched for age and hearing loss, it is found that the non-fluency contributes a shift of 6-24 per cent across the various conditions. The effect is significant ($p < .005$) in only three instances: unprotected, low speech; quiet or white noise background; and protected, high speech, quiet background.

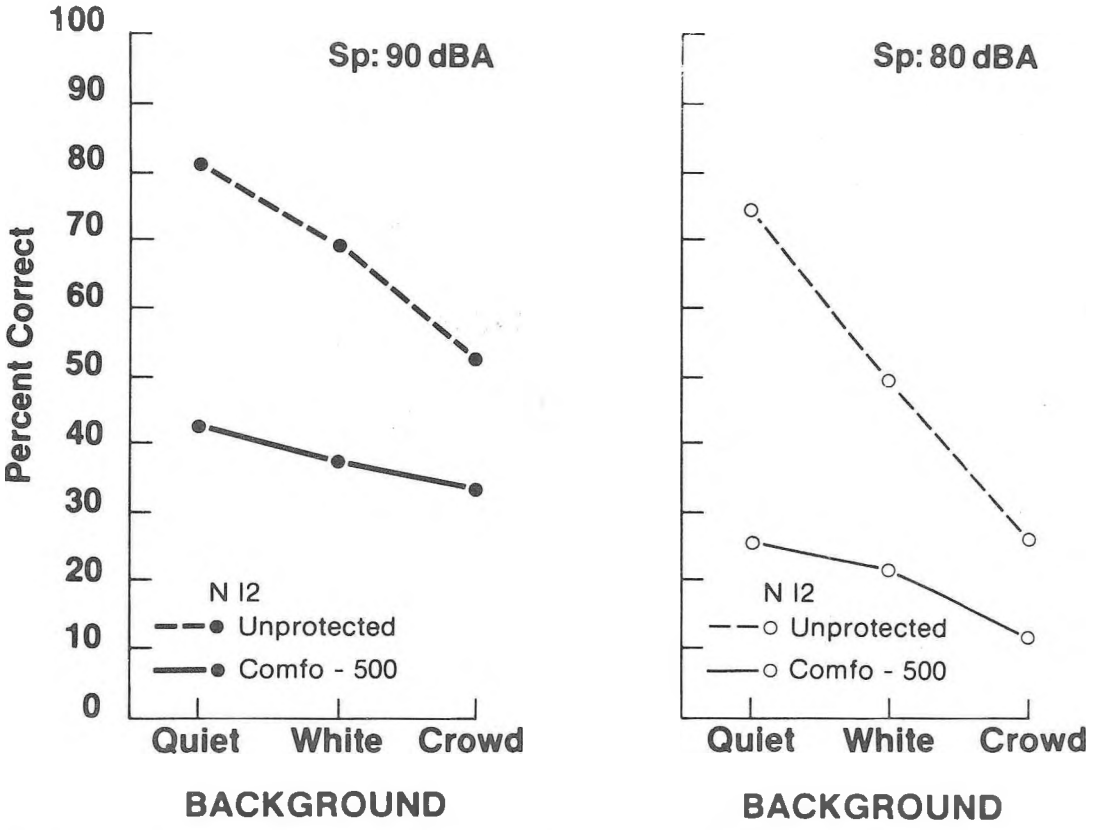

Fig. 6. Speech intelligibility in fluent subjects with flat loss, aged 35 to 65 years.

3. Flat loss (Figure 6)

Fluent, 35-65 years: the results for this group indicate that the protector used produced a significant decrement in speech perception for the six combinations of level of speech by background ($p < .001$). For each background by protector condition, scores decrease significantly with amplitude of speech ($p < .001$). With the muff, scores are similar for the three backgrounds at each signal amplitude.

Comparison of these subjects and those with high frequency loss, shows that for the protected conditions the flat loss results in a significantly poorer score in quiet and white noise, regardless of the signal amplitude ($p < .005$). Scores are similar in crowd noise. In the unprotected condition, the two groups differ only for listening in quiet at the lower level of speech ($p < .05$).

DISCUSSION AND CONCLUSIONS

Several conclusions may be drawn from the results presented. As might be expected, the attenuation provided by the Comfo-500 muff for noise presented free-field at threshold levels is essentially the same for all the experimental groups tested. On the contrary, intelligibility scores vary widely for listening with the open ear and muff, the difference depending on the particular combination of hearing configuration, fluency with the English language, level of speech, and noise background. Discrimination scores of subjects with normal hearing are unchanged by the wearing of an ear defender, but non-fluency,

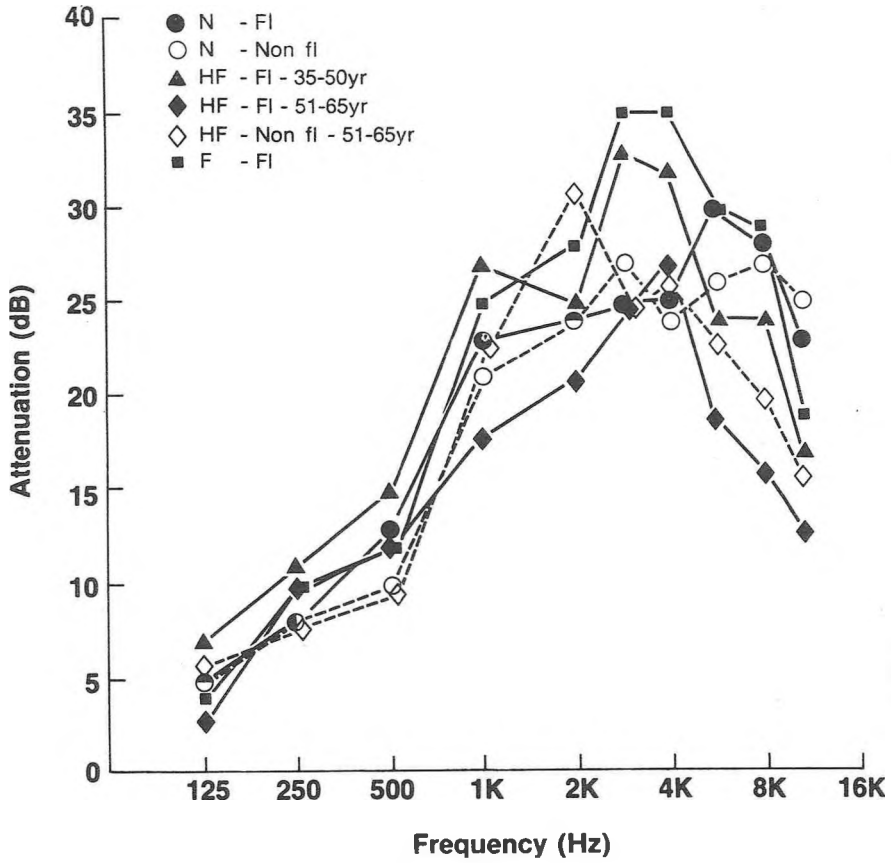

Fig. 7. Attenuation scores obtained with the Comfo-500 muff.

presence of a background noise, and lower speech-to-noise ratio all produce significant decrements in performance. Subjects with either high-tone or flat losses are substantially affected by the wearing of a muff. For a high-frequency loss, non-fluency does not appear to produce a clear and consistent decrement above that already produced by the hearing loss.

The practical consequences of these findings are substantial, particularly during the transitional phase from no hearing protection to full hearing conservation, which is currently taking place in so much of industry. There are substantial numbers of noise-exposed workers, whose hearing has already been damaged, who are now to wear personal protectors and in whom the ability to communicate may be significantly worsened by the devices. The question of linguistic ability has only been addressed marginally although, *de facto*, it is well known that to listen in a foreign language requires better listening conditions than in a language with which one is fluent. This series of experiments has shown that the non-fluent speaker is already at a greater communication disadvantage than the fluent, even before protectors are used, and strongly suggests the need for non-auditory means of communication in intense noise where language fluency cannot be guaranteed.

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Résumé. Nous avons mesuré la perception du langage dans des niveaux de bruit élevé, sous des conditions de laboratoire, chez des travailleurs exposés au bruit et chez des sujets normaux avec et sans protecteurs d'oreilles. Le groupe fut de plus sub-divisé selon l'âge et la connaissance de la langue anglaise à cause du grand nombre de travailleurs dont la langue première n'est pas anglais parmi la main-d'oeuvre canadienne. Chez les sujets normaux, nous avons trouvé les meilleurs taux de discrimination dans le silence et les moins élevés en présence de bruit blanc et encore moins élevés avec un bruit de foule; un protecteur ne modifie en rien ces résultats. Les résultats obtenus chez les groupes non-anglais furent parallèles mais inférieurs dans toutes les conditions. En présence d'une surdité affectant les hautes fréquences, la discrimination était inférieure à celle des sujets normaux dans le silence et dans le bruit. Le port d'un protecteur diminuait la discrimination encore plus. Les sujets atteints d'une surdité à courbe plate présentaient une déterioration de la discrimination en portant un protecteur.

REFERENCES

1. Henderson D, Hamernik RP, Dosanjh DS, Mills JH: *Effects of Noise on Hearing.* Raven Press, New York, 1976.
2. Wilkins PA, Martin AM: The effect of hearing protectors on the perception of warning signals — a general review. *Technical Report 98 Institute of Sound and Vibration Research,* University of Southampton, Southampton, England.
3. Tobias JV: Earplug rankings based on the protector-attenuation rating (P-AR), Report No. FAA-AM-75-11, 1975. Available from Federal Aviation Administration, Office of Aviation Medicine, Civil Aeromedical Institute, Oklahoma City, Oklahoma.
4. Townsend TH, Bess FH: High frequency attenuation characteristics of ear protectors. *J Occup Med 15:* 888-891, 1973.
5. Pell S: An evaluation of a hearing conservation program. *Am Ind Hyg Assoc J 33:* 60-70, 1972.
6. Gorztonyi RE Jr: The effectiveness of hearing protective devices. *J Occup Med 17:* 569-580, 1975.
7. Kryter KD: Effects of ear protective devices on the intelligibility of speech in noise. *J Acoust Soc Am 18:* 413-417, 1946.
8. Coles RRA, Rice CG: Earplugs and impaired hearing. *J Sound Vibr 3:* 521-523, 1965.
9. Martin AM, Howell K, Lower HC: Hearing protection and communication in noise. In *Disorders of Auditory Function II.* Stephens SDG, Ed, Academic Press, London, 1976.
10. Keith RW, Talis HP: The effects of white noise on PB scores of normal and hearing-impaired listeners. *Audiol 11:* 177-186, 1972.
11. Lindeman HE: Speech intelligibility and the use of hearing protectors. *Audiology 15:* 348-356, 1976.
12. Alberti PW, Riko K, Abel SM, Kristensen R: The effectiveness of hearing protectors in practice. *J Otolaryngol 8:* 354-359, 1979.
13. *Can Year Book, 1975.* An annual review of economic, social and political developments in Canada. Information Division, Statistics Canada.
14. Criteria for permissible ambient noise during audiometric testing. *ANSI S3.1-1977* (A revision of S3.1-1960), Standards Secretariat, Acoustical Society of America, New York.