RECOVERY OF THE ACOUSTIC REFLEX RESPONSE AS A FUNCTION OF NOISE EXPOSURE AND QUIET INTERVAL[1]

by

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ABSTRACT

In order to know if the acoustic reflex does protect the inner ear from temporary threshold shift caused by the exposure to a loud industrial noise, one need to know the reflex response decay during the noise exposure, as well as the amount of recovery allowed by quiet intervals. The influence of the duration of a broadband noise, on the recovery function of the acoustic reflex has been investigated. Four noise durations and four (or occasionally five) quiet intervals were selected. Results showed that the reflex recovery is an exponential function of the quiet interval that exists between two noise exposures; after a few seconds of rest, recovery proceeds fairly rapidly, even if the continuous noise exposure lasts 12 minutes. Results also indicated that for the 6 and 12 minute exposure durations, the reflex recovery is independent of the noise duration. For the shorter durations, that is those associated with a reflex decay of 20 and 40%, the results tend to indicate that the recovery is probably independent of the percentage of decay prevailing at the end of the noise exposure.

SOMMAIRE

Pour savoir si le réflexe acoustique peut protéger l'oreille interne contre un déplacement temporaire des seuils d'audition consécutif à une exposition à un bruit industriel intense, il faut être capable de prédire la dégradation de la réponse réflexe, tout comme l'ampleur de la récupération permise par des intervalles de silence. L'influence de la durée d'un bruit à large bande de fréquences, sur la fonction de récupération du réflexe acoustique a été étudiée. Quatre durées de bruit, et quatre (ou cinq suivant le cas) intervalles de silence ont été sélectionnés. Les résultats ont montré que la récupération du réflexe est une fonction exponentielle du temps de silence compris entre deux expositions au bruit; après quelques secondes de silence, la récupération s'effectue plutôt rapidement,

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même si l'exposition au bruit continu est de 12 minutes. Les résultats ont également indiqué que pour des durées d'exposition de 6 et 12 minutes, la récupération du réflexe est indépendante de la durée d'exposition. Pour les durées les plus courtes, c'est-à-dire celles associées à une dégradation du réflexe de 20 et 40%, les résultats indiquent que la récupération est probablement indépendante du pourcentage d'adaptation qui prévaut à la fin de l'exposition au bruit.

1 - INTRODUCTION

In humans, the acoustic reflex (AR) refers to the contraction of the stapedius muscle (one of the two middle ear muscles) following an exposure to a moderate or a high intensity acoustic signal. When the signal is a broadband noise, a L_{pA} of 72 dB is on average sufficient to activate a minimal contraction of this muscle (Hétu and Careau, 1977), and an increase in intensity induces a larger muscle contraction over a dynamic range of approximately 50 dB (Wilson, 1979). Therefore, a large number of industrial noises are loud enough to activate an important response of the AR.

It is known that the AR changes the mobility of the ossicular chain, causing among other things, an increase in the acoustic impedance at the eardrum, and therefore, an intensity decrease in sounds transmission to the inner ear (Møller, 1972). This attenuation is greater for frequencies lower than 1000 Hz, and in humans, amounts to 15-20 dB for a full contraction of the stapedius muscle. Moreover, the attenuation offered by the AR is proportional to the graded response of the AR (Borg, 1968; Zakrisson, 1975, 1979). Therefore, the AR protects the inner ear from loud sounds.

However, to know if the AR is capable of protecting the ear against temporary threshold shifts (and possibly againts permanent threshold shifts) caused by exposure to loud industrial noises, one has to consider not only the initial response of the reflex, but also its long term response to noises of various durations and temporal characteristics. Because of the numerous difficulties involved in monitoring the AR response of a worker at his job site, one has to rely on laboratory studies.

Industrial sound environments are characterized by noises of broad frequency bands. Therefore, laboratory studies carried on the AR activated by broadband noise should help to understand and predict the AR behaviour in real life situations. Such studies have shown that an exposure to a loud continuous noise produces a rapid decay of the AR within the first 4 or 5 minutes of exposure, followed by a slower decay, and finally by a stabilization of the response at a residual amplitude. The reduced response is reached after approximately 10 minutes of exposure, and its average amplitude is near 45 to 50% of the initial response (Hétu and Careau, 1977; Lalande and Hétu, 1979). Studies have also indicated that when subjects are exposed to intermittent noises of various periods or/and duty cycles, the presence of periodic quiet intervals prevents partially or totally the degradation of the AR (Hétu and Careau, 1977; Lutman and Martin, 1978; Wiley and Karlovich, 1978; Lalande and Hétu, 1979). The partial or complete recovery of the AR response found in these studies following quiet intervals, could be related to the ON-duration of the noise, at least for ON-durations that produce a decay of the AR but has never been investigated as such. Wiley and Karlovich (1978) have indeed shown that when the ON-duration of the intermittent noise is short enough to cause no response decay, the quiet interval necessary for a complete recovery of the excitability of the AR is independent of the ON-duration of the noise. But for ON-durations long enough to produce some adaptation of the reflex, the results of Lalande and Hétu (1979) have not allowed to determine if the time interval associated with a complete recovery of the excitability depends on the ON-duration of the noise, or rather on the amount of adaptation associated with a particular ON-duration. The aim of the present study was to determine if the quiet interval necessary for a full recovery of the excitability of the acoustic reflex (AR), that is the ON-response, depends mainly (a) on the duration of the signal, or rather (b) on the amount of reflex decay associated with a particular signal duration.

2 - METHODOLOGY

2.1 Subjects

The experiment was performed on 6 young female adults. They had normal hearing thresholds and normal middle ear function. Their acoustic reflex thresholds to pink noise was obtained at a L_{pA} of 90 dB or less, and their AR decay to that noise was known, as well as the noise duration associated with a residual steady state reflex response.

2.2 Experimental conditions

Each subjects was monaurally exposed to a continuous pink noise at a L_{pA} of 105 dB, as measured in a 6 cc coupler (Brüel et Kjaer, model 4152). The right and left ear were alternately stimulated. Decay and recovery of the AR was continuously monitored in the non-exposed ear, for various durations of noise exposure and quiet interval. An otoadmittance meter with a 220 Hz probe tone (Grason Stadler, model 1720 B), and a graphic X-Y recorder equipped with a time base (Grason Stadler, model 1701) were used to record the reflex.

The experimental noise exposures are summarized in Table 1. Four noise duration conditions were selected. Two conditions involved the minimal exposure time that induced respectively 20 and 40% reflex decay for each subject. The noise duration associated with these amounts of reflex adaptation was on the average 1,25 and 2 minutes. The other two conditions were 6 and 12 minute exposures. These two durations were associated respectively with the early and the late residual steady state reflex response, which both corresponded to the same amount of reflex adaptation. This adaptation was equal to or greater than 40% for all subjects.

Recovery of the reflex response was measured after quiet intervals of (a) 1, 5, 10, 30 and 50 seconds for the two first exposure conditions, and of (b) 5, 10, 30 and 50 seconds for the 6 and 12 minutes exposures. Monitoring of reflex activity was performed during two minutes following each quiet interval. But the present results refer only to ON-response recovery.

2.3 Quantification of decay and recovery

Figure 1 illustrates how the decay and recovery of the AR was achieved. The percentage of reflex decay (%D) was obtained by the following computation:

$$\% D = 100 - (B/A \, . \, 100)$$

EXPERIMENTAL CONDITIONS

reflex response under continuous exposure	noise duration - mn	quiet interval - sec
1. 20% reflex decay	≃ 1,25	1; 5; 10; 30; 50
2. 40% reflex decay	≃ 2	
3. early residual steady state reflex response	6	5; 10; 30; 50
4. late residual steady state reflex response	12	

Table 1. Values of the noise durations and quiet intervals selected for the 18 experimental conditions. The noise durations are associated either with a particular percentage of decay of the reflex response, or with the early and late residual steady state reflex response.

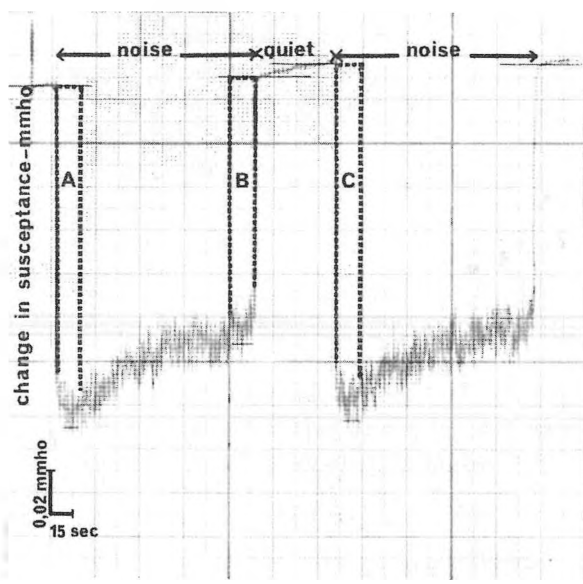

Figure 1. Recording of the acoustic reflex to a noise exposure condition, showing how the decay and the recovery of the acoustic reflex was computed.

where B is the median change in susceptance during the last 15 seconds of the initial noise exposure, and A is the median change in susceptance during the first 15 seconds of that exposure, herein defined as the initial ON-response.

The recovery of the ON-response was computed by two different methods. The first one was a measure of the amplitude of the second ON-response, relative to the initial ON-response, expressed in terms of percentage:

2nd ON-response - % = C/A . 100

where C is the median change in susceptance, of the ON-response following a quiet interval, herein defined as the second ON-response.

The second method took into account the amount of reflex decay at the beginning of the pause, therefore allowing a true measure of the recovery of the ON-response (% R). It was obtained by computing:

% R = C - B/A - B . 100

For both methods of calculation, a 100% value indicated a complete recovery of the amplitude of the initial ON-response. But the second method permitted to compare readily the recovery functions for the four exposure conditions.

2.4 Data analysis

The effect of the amount of reflex decay and of the duration of the noise, on the recovery of the AR at each quiet interval selected, were analysed using a Friedman two-way analysis of variance by ranks (Kirk, 1968). Significant effects were further analysed using the a posteriori test of Nemenyi (Kirk, 1968). Levels of confidence of 0,05 and 0,01 were adopted for all statistical analysis.

3. RESULTS AND DISCUSSION

Figure 2 shows that for very short quiet intervals, that is 1 and 5 seconds, the recovery values simply reflect the amount of response decay at the end of the exposure. When quiet intervals allowed partial or complete reflex recovery, that is for intervals of 10, 30 and 50 seconds, results show that the difference between the median recovery values for the four noise conditions is relatively small. In fact, there were no significant differences, except for the 10 seconds interval, for which there was a significant difference at the 0,05 level between the median value of the 20% condition compared to the 6 and 12 minutes conditions. The absence of significant differences could be explained by the small sample used in this study, as well as by the large intersubject variability associated with reflex recovery. However, these present results as a whole indicate that the time required for a complete or nearly complete reflex recovery is rather short, that is slightly less than one minute, for exposure durations ranging from several seconds to 12 minutes.

A better picture of the actual recovery process is obtained when the amount of reflex decay is taken into account in the computation of the reflex recovery. As shown in Figure 3, the recovery functions appear roughly similar for all exposure conditions. There were indeed no statistical significant differences across conditions except for the 5 seconds interval. In this case,

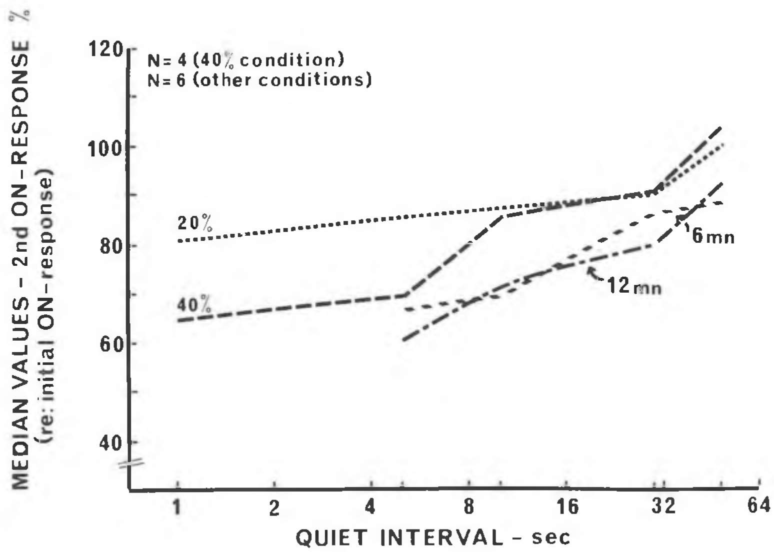

Figure 2. Median values of the second ON-response as a function of the quiet interval. The second ON-response is expressed as a percentage of the amplitude of the initial ON-response.

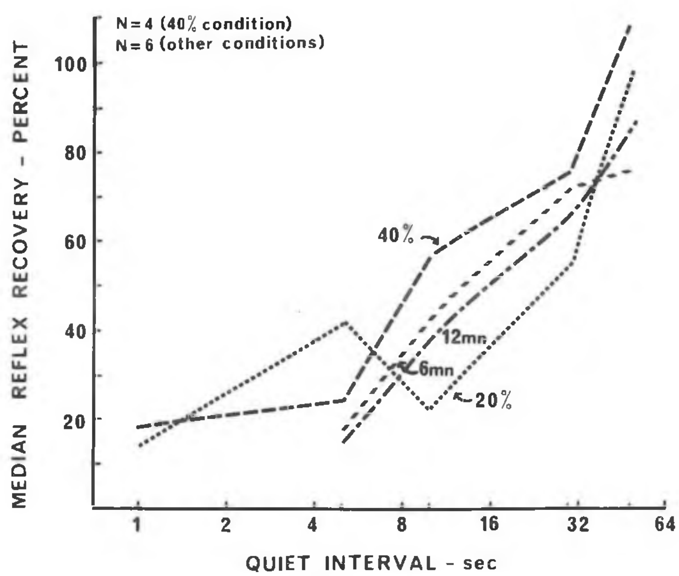

Figure 3. Median values of the percentage of recovery of the ON-response as a function of the quiet interval.

differences at the 0,05 level was found between the 20% condition compared to the 12 minutes condition. Because of this, one cannot consider that the recovery functions are perfectly identical for all conditions. Whether this difference is true or is due to the small sample used in this study, remains to be determined with a larger group of subjects. Moreover, inspection of individual data suggests that after a 50 seconds rest period, the full recovery was obtained more often when the durations of the exposure were shorter (1,25 and 2 minutes vs 6 and 12 minutes). Again, it remains to be verified with a larger group that a quiet interval of 50 seconds allows the same amount of reflex recovery for short and long noise exposures.

Nevertheless, the present results allow one to make the following two statements:

- First, recovery is an exponential function of time. After a few seconds of rest, recovery proceeds fairly rapidly even if the continuous exposure lasted several minutes. This rapid recovery of the reflex excitability has been previously reported by Borg and Ödman (1979). These authors found complete recovery in less than 10 seconds, instead of 50 seconds as obtained in this study. The spectrum and the intensity level of the stimulus are probably responsible for these differences.

- Secondly, for noise durations associated with a residual steady state response, the reflex recovery is independent of the exposure duration. A doubling of the exposure duration from 6 to 12 minutes, did not change indeed the recovery function of the ON-responses. For both durations, a recovery of 80% or more was obtained after a quiet interval slightly less than one minute. It is therefore a relatively short time compared to the exposure time to the noise. It should be mentioned however that, if the present results showed that the reflex recovery is independent of the exposure duration, this may not hold for much longer exposure durations, as suggested by the results obtained by Gerhardt et al. (1976) on chinchillas. It also may not be true for other patterns of noise exposures as suggested by Borg et al. (1979).

4. CONCLUSION

The present results indicate that for continuous exposures to a wide band noise of durations smaller than 12 minutes, the quiet interval necessary for a complete or nearly complete recovery of the excitability of the reflex response is rather short, that is, in the order of one minute. This implies that industrial noises characterized by the presence of periodic intermittency with (a) ON-durations equal to or smaller than 12 minutes, and (b) relative quiet intervals (levels lower than the acoustic reflex threshold for that noise, see Borg, 1980), probably allow the activation of the stapedius muscle at a nearly maximum contraction during the whole working day. Except for ON-durations smaller than a few seconds, for which no reflex decay takes place, the shorter is the ON-duration, the greater will be the protection offered by the reflex, since it is known that the decay of the AR to a continuous noise starts within the first 30 seconds of exposure (Lutman and Martin, 1978; Wiley and Karlovich, 1978; Wilson et al, 1978).

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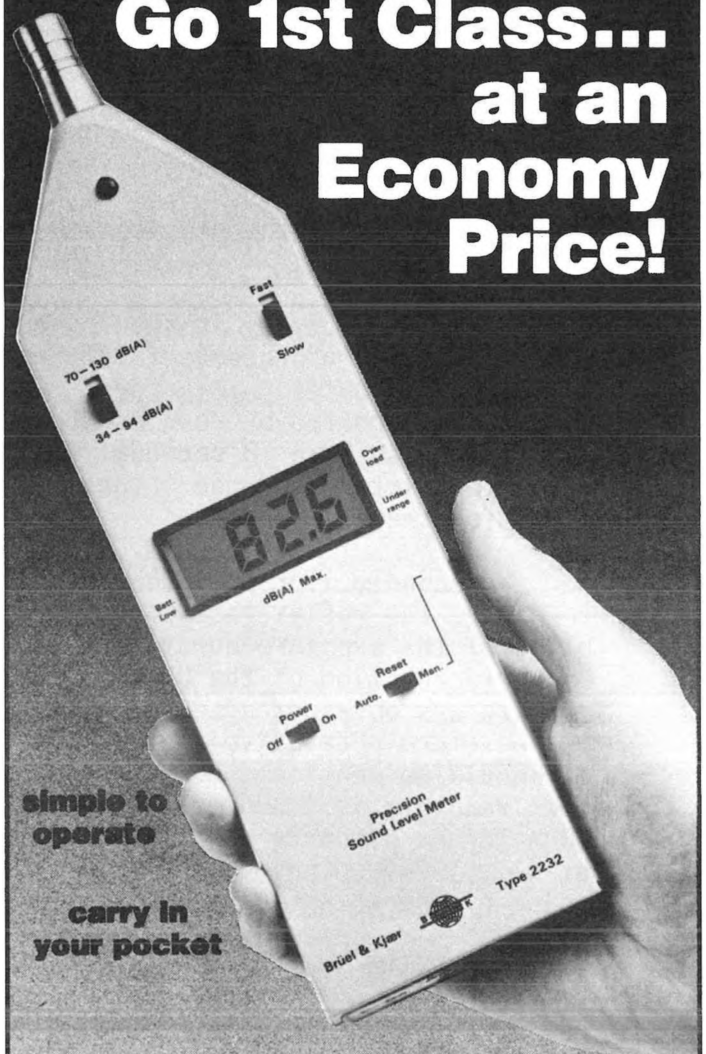

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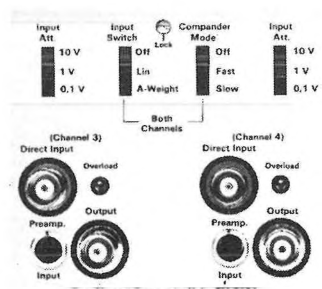

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TORONTO CHAPTER OF CAA MEETING REPORT

On January 11th, 1982, the Toronto Chapter of the C.A.A. devoted an evening meeting to Room Acoustics. Featured, were presentations by Michael Merritt of Engineered Sound Systems Limited and Aubrey Edwards of Ontario Hydro.

Michael Merritt thoroughly covered room acoustics and the Engineer's role in the design of sound reinforcement systems, going into the governing equations and, practical application (when the "correct answer" still doesn't apply). Mike also brought a P.A. System and microphones and demonstrated the effects of gain and multiple microphones on P.A. System feed back.

Aubrey Edwards detailed his research at Ontario Hydro into open office acoustics, and in particular the effectiveness of barriers, and ceiling, wall, floor and windown blind absorption using articulation index as the criterion. He then conducted a tour of the Hydro Place Offices, where his acoustic designs are in use.

Both presentations were very well received as evidenced by the many questions and comments.

The meeting was organized by John Swallow and Andy McKee. The next meeting will be held April 12, 1982 on the subject of Industrial Audiometry.

John C. Swallow
Barman Coulter Swallow Associates