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A LABORATORY STUDY OF PHYSIOLOGICAL STRESS IN HUMANS EXPOSED TO SIMULATED MILITARY AIRCRAFT FLYOVER NOISE

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1. INTRODUCTION

In recent years, there has been considerable public concern over whether environmental aircraft noise could lead to an increased risk of stress related illness. This paper describes the progress in a laboratory study to identify the biochemical markers of stress in humans arising from acute exposure to military aircraft flyover noise. Several studies performed on this type of noise, have indicated changes in the blood levels of biochemicals associated with stress [1,2]. Reproducible changes in these types of markers are needed to assist in evaluating the potential health effects.

Progress has been made in: (i)the exposure system and (ii)preliminary experiments on rats to identify biochemical markers of stress that would be suitable for examination in human subjects. This paper provides the characterization of the acoustical exposure system to be used for simulating military aircraft flyover noise in the human study. A prototype of the exposure system was described previously [3]. In addition, results are presented from a pilot study in rats on the blood concentrations of biochemical markers after acute exposure to broadband noise.

2. APPARATUS AND METHOD

Rat Study

This study examined cortisol, transferrin, haptoglobin and alpha tumour necrosis factor (αTNF) as potential markers of stress. Housing conditions were used to generate stress in the rat as a positive control. To be a useful measure of moderate physiological stress, the biochemical marker would have to discriminate between the different levels of stress found in the housing regimen and the additional stress impressed on the rat by an acute noise exposure. Sixteen female Lewis rats, age 35 days, were housed at 1, 2 or 4 per cage (1/C, 2/C, 4/C), corresponding to isolation, normal and crowded conditions.

White noise from 400 - 20000 Hz was used for the exposure. Sound pressure levels were measured in each cage with a 6 mm Brüel & Kjær 4135 microphone with nose cone. Over all the cages, the unweighted sound pressure level varied from 87 to 94 dB. In any cage, the 1/3 octave band spectrum of the sound pressure level differed from an ideal white noise spectrum with a standard deviation of ±3 dB.

The effects of housing or noise stress on the putative biochemical markers were evaluated by several statistical tests. These included a one-way analysis of variance, a Bartlett's test for homogeneity of variances, and finally, if a significant difference was detected, by a Tukey-Kramer multiple comparison test. Pair-wise comparisons were assessed using an unpaired t-test.

Acoustical Exposure for the Proposed Human Study

Exposures in the proposed human study are to take place under hemi-anechoic conditions in the anechoic chamber at the Canadian Radiation Protection Bureau (RPB). Volunteers will receive a set of brief exposures to the noise from simulated flyovers of low flying military aircraft. This will be created from a selection of single channel digital tape recordings of actual flyovers, carried out under a wide range of flight conditions [6]. For the work described here, a single flyover was chosen from this selection, to demonstrate the feasibility of the exposure system.

The main design goal of the exposure system was to create an accurately defined sound field which would appear to be emitted from an aircraft passing directly over the heads of the subjects [4,5]. In addition, it was intended that, with little change in the free-field exposure, the subject be able to sit, stand and move about over a limited area.

The exposure system is shown schematically in Figure 1. The loudspeaker arrays were positioned at angular positions, θ_i, on the arc of a 4 m radius circle, centred on a point 1.5 m above the floor of the hemi-anechoic chamber. The angular position of the aircraft during the flyover is shown as θ_e. The array at θ_1 was at an angle of 15° to the horizontal and the angular interval was 50° between adjacent arrays. At angles θ_1 and θ_4, each array consisted of two high efficiency JBL4892 speakers. At angles θ_2, and θ_3, each array consisted of four such speakers.

In order for the flyover noise to appear as realistic as possible, a 4 channel reproduction was used. This was done according to the following sequence. The digitized tape signal, sampled at 48 kHz was stored on an IBM PC compatible computer. This signal was processed to reduce tape noise and produce 4 channels, each weighted by an appropriate gain factor. The 4 channels were digitally re-sampled and played back at 24 kHz per channel via the analog outputs from two synchronized National Instruments DSP2200 signal processor boards. These outputs acted as input to Toa DACsys

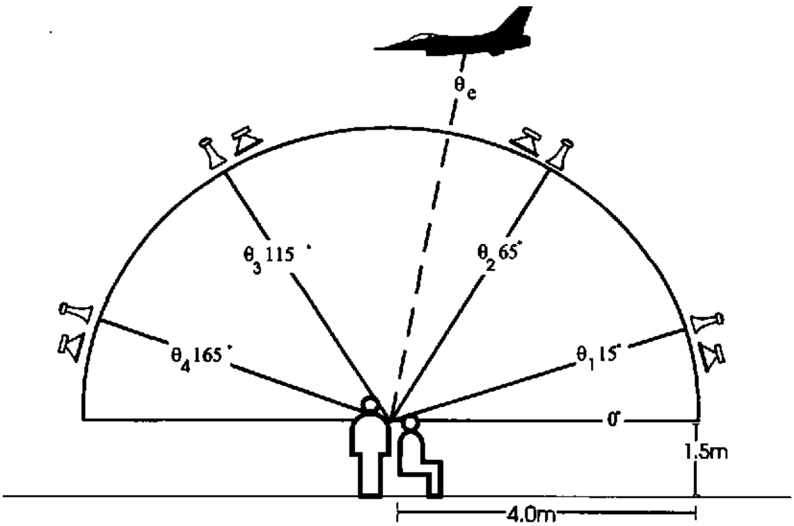

Figure 1: Schematic illustration of the flyover simulation showing the relative positions of the aircraft during the flyover, and the loudspeaker arrays. The θ_i are the angular positions of the loudspeakers and θ_e is the angular position of the aircraft. The human figures show approximately where the subjects will be.

DSP204 programmable digital crossovers. The crossovers shaped the spectrum of the flyover noise before playback through the loudspeakers.

Tape noise, before and after the flyover, was reduced to 45 dB A-weighted by a gating function smoothly fitted to the onset and decay rates of the flyover. This made it feasible to create a natural acoustic background for the flyover.

Figure 2 shows the gain factors for the 4 channels plotted as a function of time, t_r, where, t_r is defined as the time that a sound was received at the recording microphone, after being emitted by the aircraft at a time, t_e, and angular position, θ_e.

From Figure 1, the gain factors were derived as functions of θ_i and θ_e, assuming incoherent addition of the sound from adjacent arrays. They were then expressed as a function of time by solving for θ_e in terms of t_r. The time scale was fixed by assuming that the loudest sound to reach the microphone was emitted at time $t_e = t_0 = 0$, when θ_e was approximately 90 degrees. The nonlinear dependence of the gain factors on flight speed and altitude arose from the equation for t_r as a function of t_e, given by :

$$t_r = t_e + \frac{\sqrt{v^2(t_e - t_0)^2 + h^2}}{c}$$

where c was the speed of sound, h was the height of the aircraft above the recording microphone, and v was the speed of the aircraft.

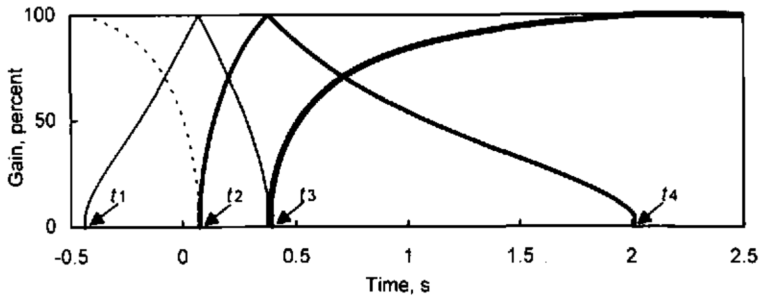

Figure 2: Gain factors for each of the four channels, plotted as a function of time, t_r (with t_0=0). The gain is expressed as a percentage of the original recorded level. - - - - - channel 1; ——— channel 2; ——— channel 3; ——— channel 4. Sounds emitted by the aircraft at angles θ_1, θ_2, θ_3, and θ_4 arrive at the microphone at times t_1, t_2, t_3, and t_4, respectively.

The gain factors satisfied two important criteria for a realistic simulation. First, they provided a smooth transition of the flyover noise from one loudspeaker array to the next. In addition, the gain factors accounted for the high speed and low altitude of the aircraft. Therefore, they were able to provide an apparent rate of change of aircraft angle on approach to the measurement microphone that was larger than the rate as the aircraft receded from this point. This was consistent with the high onset rate and asymmetry about the peak in the time history of the flyover noise.

Filtering through the DACsys was needed to correct the acoustical field in the exposure chamber to make it more like the original flyover. Correction was provided for: (I)the anechoic frequency response of the speakers, (ii)frequency dependent interference effects between the loudspeakers, including their image sources, and (iii)the variation of microphone directivity with angle.

The exposure system was characterized using a measurement system consisting of Brüel & Kjær equipment: (I)a type 4165 microphone, (ii)a type 2639 preamplifier and (iii)a type 2133 1/3 octave band real time analyser. The use of the same microphone as in the original recording helped to reduce microphone directivity and placement effects. The measurement system was calibrated using a Brüel & Kjær 4228 pistonphone at 250 Hz. To obtain the sound pressure level time history of the flyover, the analyser was set to exponential averaging with a time constant of 125 ms ("fast").

3. RESULTS

Rat Study

The changes in the blood levels of cortisol and alpha tumour necrosis factor (αTNF), for rats under moderate stress, gave some preliminary indications that these assays may be useful as measures of stress in future noise studies.

The variation of the blood level of cortisol with housing condition was consistent with that found in the literature [7], cortisol concentrations were lower in isolated rats than in rats housed under either crowded or normal conditions ($p<0.001$). In addition, acute noise exposure was associated with a decrease in cortisol levels ($p<0.0001$) in rats housed under crowded conditions. However, noise exposed rats housed at either 2/C or 1/C showed no significant change in cortisol levels compared to controls.

Alpha tumour necrosis factor (αTNF) is an acute phase response protein and, typically, it increases in response to stress. The concentration of αTNF (pg/mL), was not significantly affected by housing conditions or in rats exposed to noise at 2/C. However, for isolated rats, acute noise exposure did increase the concentration of αTNF ($p<0.01$). An increase was also observed for crowded rats exposed to noise, but it was non-significant at $p=0.08$.

Acoustical Exposure for the Proposed Human Study

The results described in this work were obtained from a recording of a Harrier GR5 aircraft flying 237 ft above ground level at a speed of 413 knots [6]. The onset rate and L_{Amax} for this recording were measured to be 22 dB/s and 115.3 dB, respectively. Figure 3, compares the A-weighted sound pressure level time histories of the actual and simulated flyovers, where the simulated flyover was measured at the centre of the loudspeaker arc shown in Figure 1. As can be seen, the agreement is good. The difference between the time histories did not exceed 3 dB.

The uniformity of the exposure with position was also obtained. The distribution of L_{Amax} values for the simulated flyover was determined from measurements at 33 different positions over a 2x2x0.6 m^3 volume about the centre of the loudspeaker arc of Figure 1. The L_{Amax} values show a reasonable degree of uniformity. They ranged from about 112 dB to 116 dB over the total measured volume and from about 114 to 116 dB over a 1x1x0.6 m^3 volume.

In summary, with loudspeakers at approximately 4 m from the microphone, the measured time history indicated that the exposure system was able to faithfully recreate the flyover noise. Furthermore, a reasonable degree of uniformity was obtained over a 2 m^3 volume.

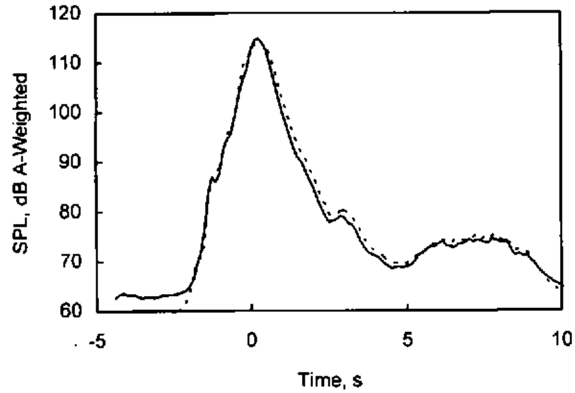

Figure 3: A-weighted sound pressure levels (obtained with "fast" exponentially weighted time averaging) for the actual (———) and simulated (- - - - -) flyovers.

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