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DIFFERENTIAL EFFECTS OF NOISE AND MUSIC SIGNALS ON THE BEHAVIOR OF CHILDREN

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A theory based on the model of how the auditory–brain system perceive primary sensations is used to explain the differential effects of noise and music signals on the sleep of babies and on the performance of mental tasks by children. In a previous study by Ando and Hattori, [1], it was found that sleeping babies (2–4 months old) whose mothers had begun living in a noisy area before conception or during the first five months of pregnancy did not react to daily aircraft noise but did react to music. In another previous study by Ando *et al.* [2], the percentage of the pupils in "V-type relaxation" state during an adding task in a quiet living area was much greater when pupils heard music than when they heard noise. These phenomena are explained here by the difference between the temporal factors extracted from the running autocorrelation function of the noise and music signals.

1. INTRODUCTION

Orthogonal factors extracted from the running auto-correlation function (ACF) of source signals can account for any subjective effects when the spatial factors extracted from the interaural cross-correlation function (IACF) are invariable. The theory of primary sensation [3] is used here in an attempt to explain differential responses to the environmental noise and music during the sleep of babies [1] and differential effects of the environmental noise and music on the performance of mental tasks [2, 4, 5].

2. EFFECTS OF ENVIRONMENTAL NOISE AND MUSIC ON THE SLEEP OF BABIES

In this section, the differential reactions to reproductions of aircraft noise and to music are described. These reactions are those evident in the plethysmogram (PLG) and electroencephalogram (EEG) records of 78 sleeping babies [1].

The subjects were classified into five groups according to length of time their mothers had lived in the noisy area near an international airport: group I: 33 babies whose mothers had come to the noisy area before conception; group II: 17 babies whose mothers come to the noisy area during the first five months of pregnancy; group III: 10 babies whose mothers come to the noisy area during the last four months of pregnancy; group IV: 10 babies whose mothers had come to the noisy area after giving birth to them; and group V: 8 babies whose mothers lived in a quiet area where there were no aircraft flying over either during the pregnancy or after birth.

Most of the babies were selected from living areas where other environmental noise, such as traffic, was weak.

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The experiment was performed in spring and autumn with comfortable climate conditions. PLG and EEG records were obtained during the natural sleep without the aid of a soporific of the babies in their own regular sleeping rooms (see Figure 1). The aircraft noise reproduced in the sleeping rooms was that of a typical jet plane. The order of exposure was 70, 80, and 90 dB(A), and the reactions of babies were observed and recorded. Then a peaceful music piece (just before the chorus of Beethoven's Symphony No. 9) was presented. Examples of the sound pleasure levels and the spectra at the peak levels measured by the available instruments are shown in Figures 2 and 3.

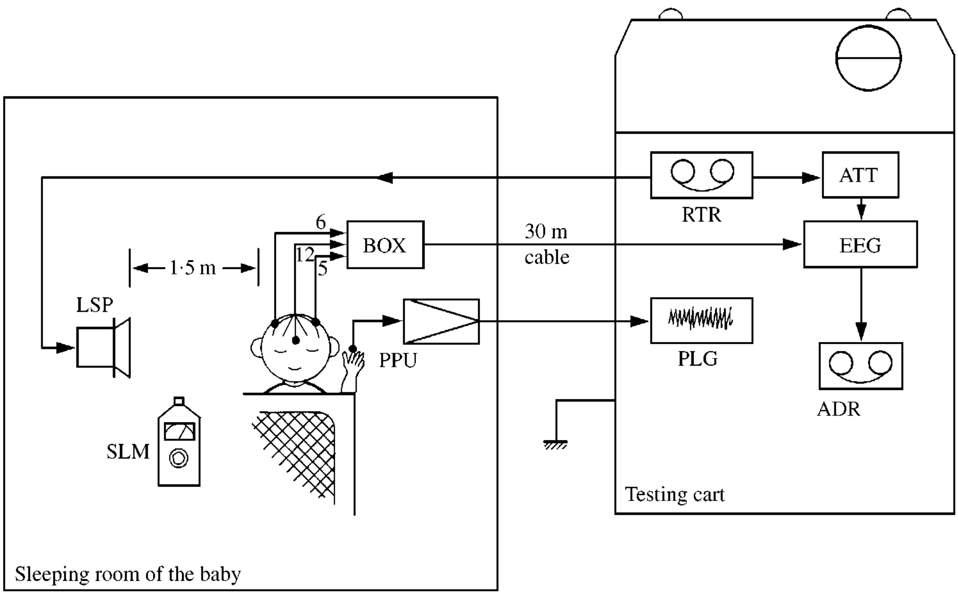


Figure 1. Equipment for recording plethysmogram (PLG) and the electroencephalogram (EEG) at a house where the subject regularly sleeps [1]. LSP: Loudspeaker reproducing sound stimuli. SLM: sound level meter. Box: electrodes connection box. PPU: optical pulse pick-up. EEG: electroencephalograph. PLG: plethysmograph (X–Y recorder). RTR: reproduction tape recorder. ATT: attenuator. ADR: analog data recorder (4ch).

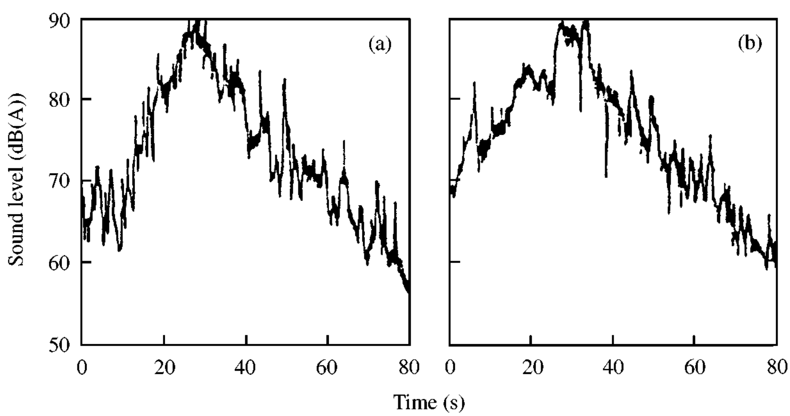


Figure 2. Sound pressure levels of stimuli as a function of time [1]. (a) Aircraft noise with a peak of 90 dB(A), 90N; (b) music piece before the chorus of Beethoven's Symphony No. 9 with a peak of 90 dB(A), 90M.

2.1. PLG REACTIONS

The PLG reaction levels observed in response to aircraft noise are listed in Table 1 for the babies who lived in the area where the outdoor WECPNL was below 94 in the outdoors, where the noise level was approximately obtained by

$$\text{WECPNL} \approx [\text{dB(A)}]_{averaged} - 3. \tag{1}$$

In most of the houses the sound transmission loss from outdoors to indoors was measured at about 10–20 dB throughout the frequency range. The data in this table show, for example, that in group I only 5 of 18 subjects showed PLG reactions to 70 and 80 dB(A) noise. Thus, the percent reactions at 70 and 80 dB(A) of babies in groups I and II are, respectively, only 28 and 30%. However, 100% of the babies in groups III, IV and V reacted to the noise. This difference between the reaction rates of babies in groups I and II and the reaction rates of those in groups III–V is significant at the 1% level ($p < 0{\cdot}01$).

The corresponding results for PLG reactions observed with respect to the music are listed in Table 2. In groups I and II, 15 subjects among 20 reacted to 70 and 80 dB(A) (75%). And

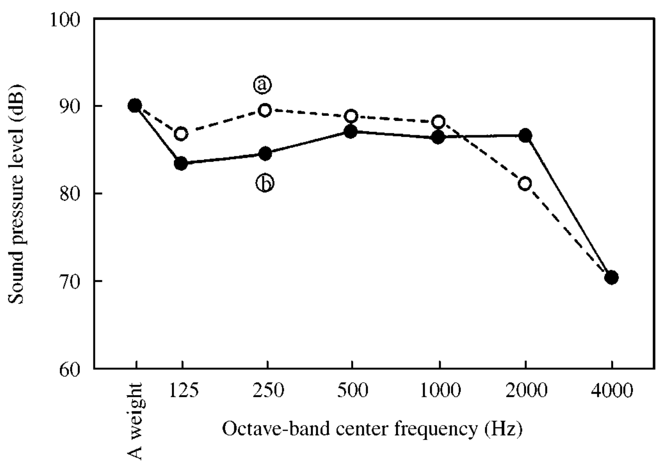


Figure 3. Spectra of sound stimuli at the peak levels: (a) aircraft noise; (b) music.

TABLE 1

PLG reactions in response to aircraft noise

Group	Number of subjects reacting 70N	80N	90N	No reaction 70–90N	Percent reacting 70–80N	Total
I	1	4	1	10(2)	28%	18
II	1	2	1	5(1)	30	10
III	4	4	0	0	100	8
IV	1	1	0	0	100	2
V	7	1	0	0	100	8

Note: Number in parentheses is the number of subjects who did not react to 70 and 80N. The test could not be done at 90N as the subjects were awakened by other factors. The total number of subjects was 46 (varied data) [1].

all the babies in groups III and V reacted to music. While many of the subjects in groups I and II did not react to the aircraft noise they did react to the music ($p < 0{\cdot}05$).

Particularly, in an area with a noise level over 95 WECPNL where the real aircraft noise often exceeded 95 dB(A), an abnormal PLG during the sleep of babies was often observed [1].

2.2. EEG REACTIONS

As mentioned previously, although babies from groups I and II showed little or no reaction to the aircraft noise on PLG, most of them reacted to music. To study such phenomena further, we also recorded the EEG of the babies in groups I and II. The electrodes were connected to the top of head (5, 6) and to the forehead (12) as shown in Figure 1.

The stages of sleep were classified as follows: stage W: awake. Amplitudes (peak to peak) below 50 μV and frequencies over 4 Hz; stage 1: amplitudes of 50–75 μV and frequencies of 3–4 Hz; stage 2: amplitudes of 75–150 μV and frequencies of 2–3 Hz; stage D: amplitude greater than 150 μV and most of the frequencies less than 2 Hz.

Examples of sleeping stage changes evidenced in EEG records are shown in Figure 4. In this figure, the subject 58 (group I) first showed stage D, and the stage was not changed by exposures to the 80-dB(A) aircraft noise reproduced (hereafter called as 80N), to the exposures to 90N + 95-dB(A) jet noise actually occurring during the examination (95NJ), 90N, or 70-dB(A) music reproduced (hereafter called 70M). The stage was changed,

TABLE 2

PLG reactions in response to music

Group	Number of subjects reacting 70M	80M	90M	No reaction 70–90M	Percent reacting 70–80M	Total
I	3	8	2	0	85%	13
II	2	2	1	1(1)	57	7
III	2	3	0	0	100	3
V	1	4	0	0	100	5

Note: The total number of subjects was 28 (varied data) [1].

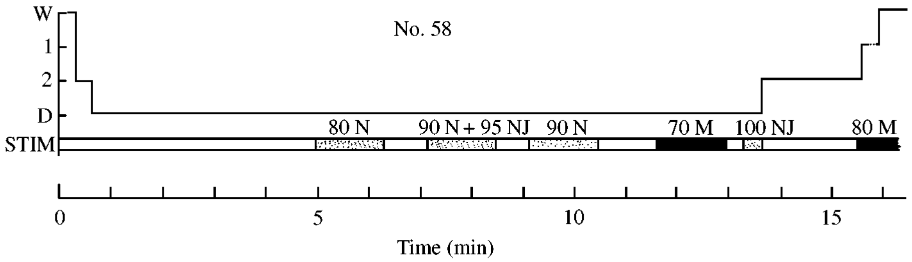


Figure 4. Sleeping-stage changes observed in the EEG of a subject (No. 58) from group I, during exposure to the noise (80N, 90N + 95NJ, 100NJ) and the music (70M, 80M).

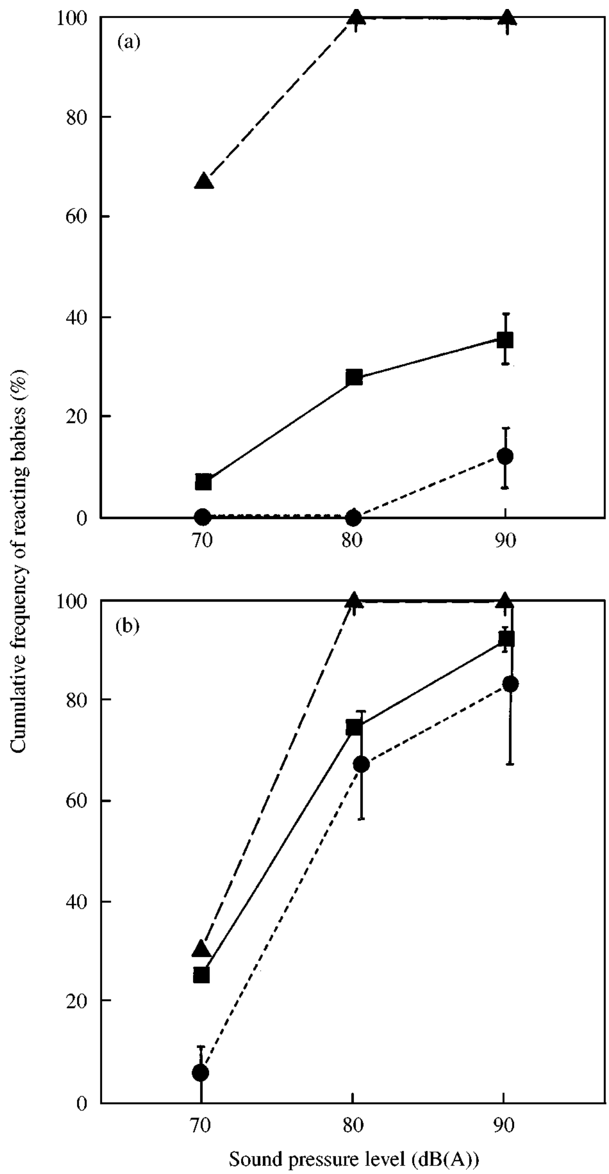


Figure 5. Percentage of the cumulative frequency of reactions to each stimulus sound level. I; Range of possible reactions; results of PLG are also shown in Table 1 and Table 2. (a) Results for aircraft noise stimuli: (■——■), reaction of babies on PLG in groups I and II (28 subjects); (▲- - -▲), reaction of babies on PLG in groups III–V (18 subjects); (●····●), reactions of babies on EEG in groups I and II (17 subjects). (b) Results to music stimuli: (■——■), reaction of babies on PLG in groups I and II (20 subjects); (▲- - -▲), reaction of babies on PLG in groups III–V (10 subjects); (●····●), reaction of babies on EEG in groups I and II (9 subjects).

however, into stage 2 by the actual noise of 100NJ, and stage 2 was changed into stage 1 by the exposure to 80M. Through this subject showed PLG reactions in response reacted to the exposure of (90N + 95NJ), no reaction to the same stimulus could be seen on the EEG. In general, the PLG reactions were much more sensitive than the EEG reactions [1].

Significant differential responses of the subjects in groups I and II to aircraft noise and to music were also observed in the EEG records (see Figure 5). For example, at the sound pressure level of 80 dB(A), no subjects reacted to the noise on EEG but more than 65% of them reacted to music.

3. EFFECTS OF ENVIRONMENTAL NOISE AND MUSIC STIMULI ON THE PERFORMANCE OF TWO MENTAL TASKS

In order to evaluate the differential effects of reproduced noise and music on two kinds of mental tasks namely, left and right hemispheric tasks as indicated in the upper parts of Figures 6 and 7 [2, 4, 5], we investigated children from noisy and quiet living areas (see Table 3). The tasks were carried out by children under conditions of no stimulus, noise stimulus, and music stimulus.

Tests were carried out in the classrooms (the reverberation time 0·5–0·9 s in the 500 Hz octave band) of two schools in each living area. The no-stimulus was tested in a normal classroom without the reproduced sound. The noise group was tested while being exposed to a jet plane noise of 95 ± 5 dB(A), peak. The music group was tested while listening to an excerpt of music from the fourth movement of Beethoven's Ninth Symphony (85 ± 5 dB(A), peak). As shown in Figure 2, the time pattern and spectrum of the music were similar to those of the jet noise. The sound stimulus was reproduced from two loudspeakers set in

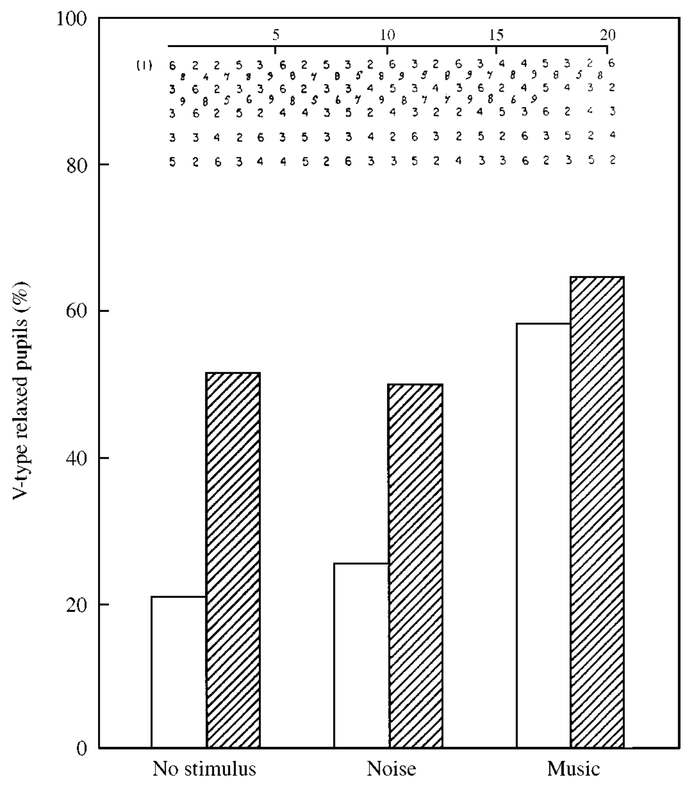


Figure 6. Proportion of V-type relaxed children during the adding task [4, 5]. Upper part indicates the task of one period in N (= 15). Unshaded bars show results for children from quite living areas; shaded bars show results for children from noisy living areas.

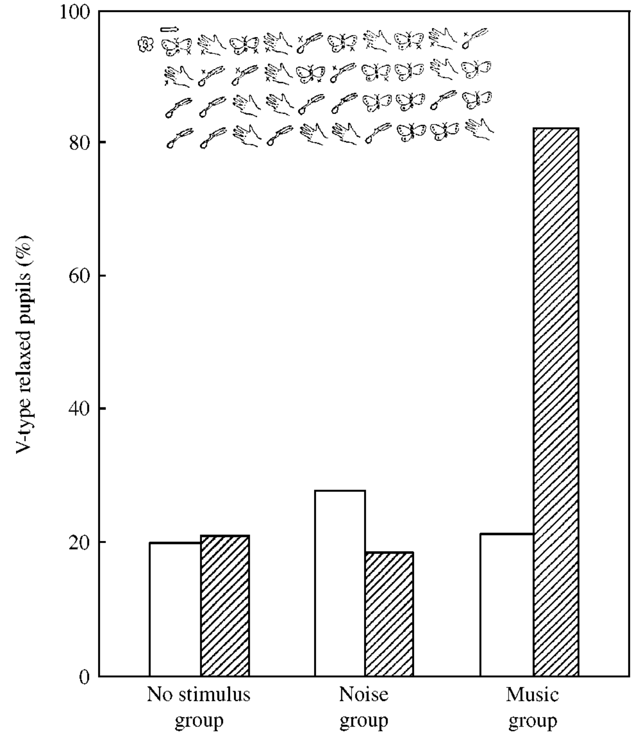


Figure 7. Proportion of V-type relaxed children during the search task [4, 5]. Upper part indicates the task of one period in N (= 10). Unshaded bars show results for children from quite living areas; shaded bars show results for children from noisy living areas.

TABLE 3

Number of subjects from both quiet and noisy living areas monitored while performing mental tasks

Task	Age (years)	Living area	No-stimulus group	Noise group	Music group	Total
Addition		Noisy	146	151	34	331
(left-hemisphere)	9–10	Quiet	120	123	36	279
Pattern search		Noisy	183	179	34	396
(right-hemisphere)	7–8	Quiet	123	119	38	280

Note: The total number of subjects was 1286 (varied data) [2].

front of the classroom, during every alternative period during the tasks given by

$$i = 2n, \tag{2}$$

where $n = 1, 2, \ldots, 7$ for the adding task, and $n = 1, 2, \ldots, 5$ for the search task. Examples of one period are shown in the upper part of Figure 6 (60 s/period) and Figure 7 (30 s/period).

Other test conditions and a part of the results have been published previously [2, 4].

The individual work produced in each period, called the "working curve", was drawn for all test results. The mean work performance is not discussed here because there were no significant differences between the different conditions. Of particular, importance in evaluating the tests results is the "V-type relaxation". This score is classified into two categories according to the occurrence of a sudden large fall in the working curve during each task. This assessed by $M_i < M - (\frac{3}{2})W$, $i = 1, 2, \ldots, N$, where M is the mean work performance and W is the average variation of the curve excluding an initial effect at the first period, $i = 1$. Such relaxation is thought to be caused by an abandonment of effort when mental functions are disturbed.

As shown in Figure 6, in a quiet area the percentage of relaxed children given the additional task ($N = 15$) was much greater in the music group than in either the no-stimulus group and the noise group ($p < 0{\cdot}01$). In a noisy area, however, the percentage of relaxed children was always greater than that in the quiet area, particularly in the no-stimulus group ($p < 0{\cdot}001$).

As shown in Figure 7 for pattern-search task ($N = 10$), the percentage of relaxed children in a quiet area was similar under all test conditions, except for a slight increase in the noise group. The only significant change between the subjects from different living areas was found in the music group ($p < 0{\cdot}001$).

The results of the mental tasks were not dependent on the sex, birth order, or birth weight of child, on whether or not the mother was a working mother, or suffered from toxicosis during her pregnancy, on the child's gestational age when the mother moved into the noisy area, or on child's feelings about aircraft noise [2].

4. DISCUSSION

4.1. ON THE SLEEP OF BABIES

Because the babies in groups I–III were equally exposed to aircraft noise postnatally, the difference in their reactivities to aircraft noise can be ascribed to a prenatal difference in the time of exposure to aircraft noise [1, 12]. This phenomenon may be explained as a "prenatal adaptation" of mothers or a habituation of babies to aircraft noise. On the other hand, the growth inhibition of the fetuses has been known by measuring the level of human placental lactogen in the serum of expectant mothers both subjected and not subjected to aircraft noise between 22 and 41 weeks of pregnancy [13].

A further remarkable finding in this study is that most of the subjects in groups I and II showed both EEG and PLG reactions to the music but not to the noise. To explain this selective ability of the babies, orthogonal factors extracted from the running ACF during first 25 s of the sound are plotted against time in Figure 8. Remarkable differences are found in the delay time of the first peak of ACF τ_1, corresponding to pitch [6–10], and in the effective duration τ_e, corresponding to similar repetitive features. The values of τ_e for noise vary smoothly between 4 and 10 ms, while those for music fluctuate sharply between 5 and 60 ms. The pitch of music changes with time, over a range of 750–3300 Hz, and that of noise changes over a much lower range 300–700 Hz. This suggests that music may stimulate the left hemisphere of babies that have not been habituated to the daily noise more than it does the right hemisphere. Therefore, such distinctive reactions of babies to noise and music may be related to the specialization of the cerebral hemispheres [3]. Meaningless noise changing the sound pressure level may simply stimulate the right hemisphere [14, 15]. Rapid changes in the values of τ_e and large changes in the values of τ_1 (about 3-fold), corresponding to the changes in the pitch of music over time, may stimulate the left hemisphere. It is considered, therefore,

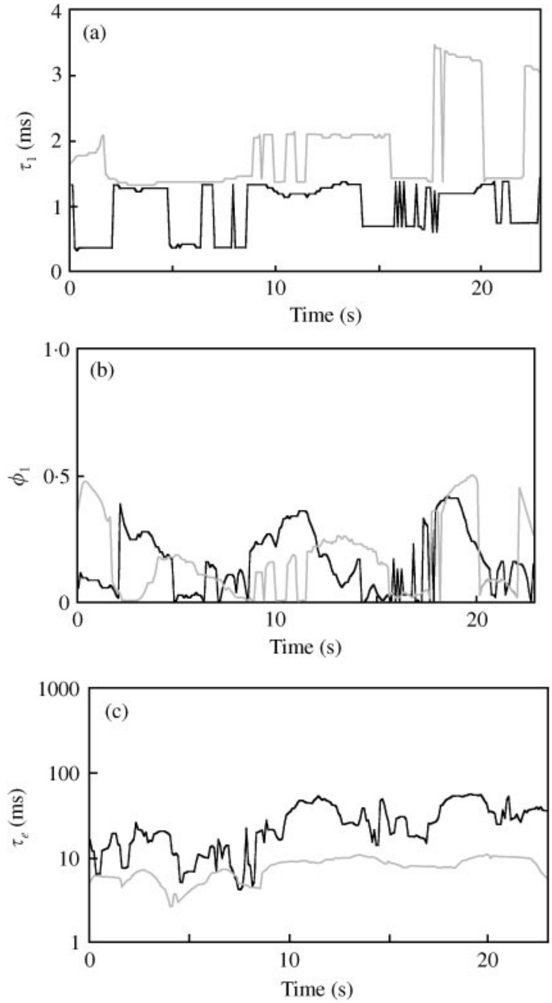


Figure 8. Three orthogonal factors extracted from the ACF of sound signals for the first 25 s of stimuli, analyzed by $2T = 2$ s and running interval of 100 ms. (a) Values of τ_1 corresponding to the pitch of the aircraft noise (——) and the music (——); (b) values of ϕ_1 corresponding to the strength of pitch of the aircraft noise (——) and the music (——); (c) Values of τ_e corresponding to the similar repetitive feature signals of the aircraft noise (——) and the music (——).

that babies from groups I and II reacted sensitively to music but not to noise during sleep (see Figure 9).

4.2. ON THE PERFORMANCE OF MENTAL TASKS

As shown in Figure 6, in the quiet area the percentage of V-type relaxed children given the additional task was much greater in the music group than in the no-stimulus and the noise group ($p < 0{\cdot}01$). In the noisy area, however, the percentage of relaxed children was always greater than that in the quiet area; particularly, in the no-stimulus group ($p < 0{\cdot}001$).

During the pattern search task as shown in Figure 7, in the noise group, the percentage of relaxed children given was similar under all test conditions, except for a slight increase. The

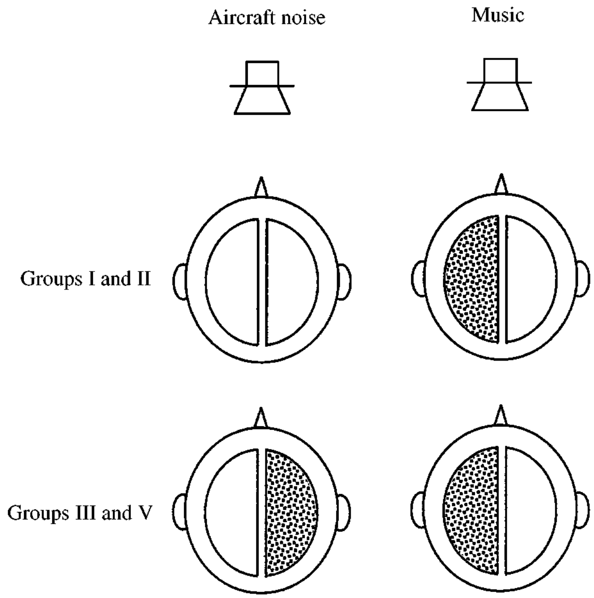


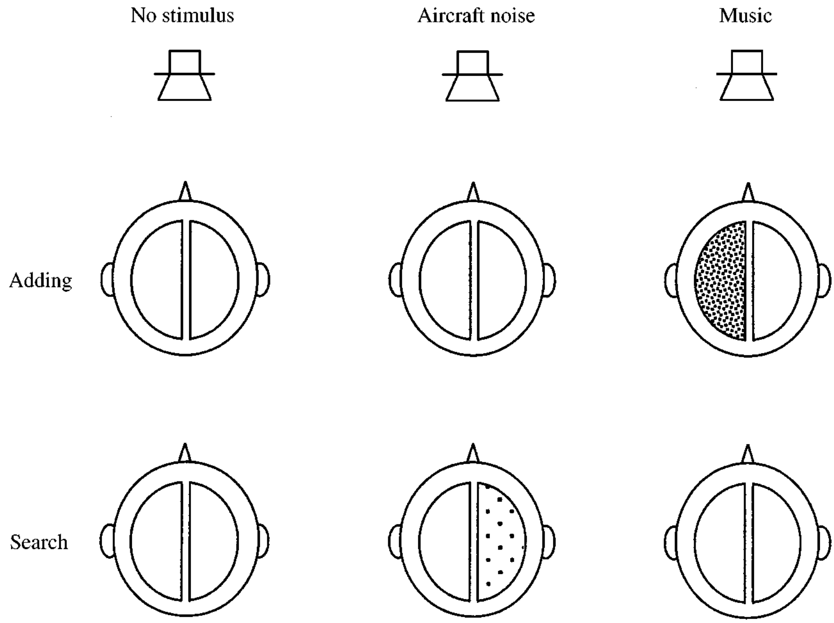
Figure 9. Reactions of babies in groups I and II and in groups III and IV to the noise and music stimuli.

only significant change, between children separated according to the living areas was found in the music group ($p < 0{\cdot}001$).

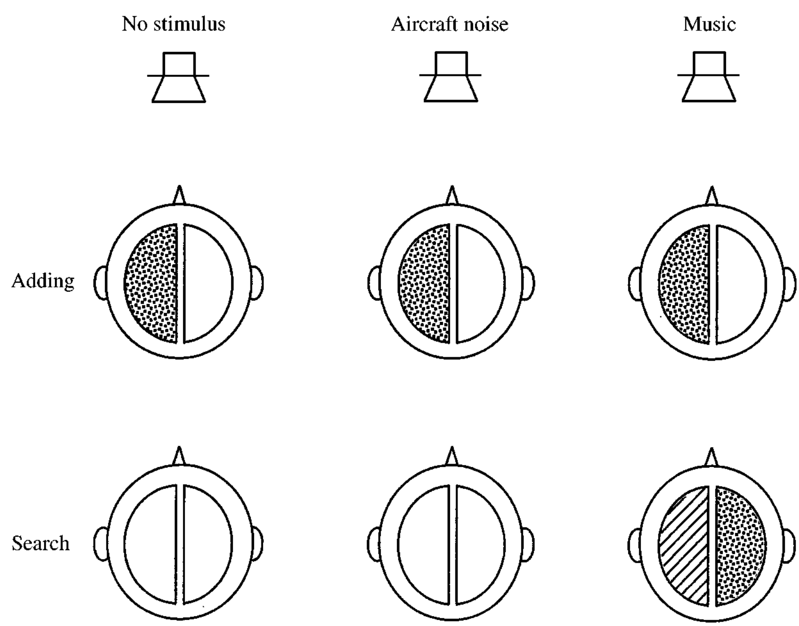
In the quiet living area [4], the effects of temporary music and noise stimuli on mental tasks (see Figure 8) were closely related to the content of the task being performed or to the specialization of cerebral hemispheres [16]. In the case of the addition task, there were no significant differences between the noise group and the no-stimulus group in the percentage of V-type relaxed children. This may support the theory that noise and calculation tasks are separately processed in the right and left hemispheres respectively [5]. Thus, as illustrated in Figure 10(a), no interference effects were evident. However, the percentage of relaxed children in the music stimulus group differs significantly from that in the noise group and the no-stimulus group. This may be explained by music perception and calculation being processed one after the other in the left hemisphere. On the other hand, music perception and search task may be independently processed in the left and right hemispheres. In the search task, although no significant differences in the number of V-type relaxed children could be observed under no-stimulus and music conditions. But, a difference was observed ($p < 0{\cdot}1$), so that an interference in the right hemisphere seems to be discernible [17]. The rather dispersive results of several other investigations of mental tasks could be well described by this explanation.

As shown in Figure 10(b), however, the effects of temporary sounds on mental tasks are quite different in the noisy area. In the case of the addition task, the proportion of V-type relaxed children was always increased in the noisy area, even under no-stimulus conditions (see Figure 6); this may thus be considered a chronic effect on mental performance. In the search task, the percentage of relaxed children increased greatly in the music group, but not in the noise group.

It is worth noticing that comparing the interference between the subjects whose responses are shown in Figure 10(a) and 10(b), daily noise affects the development of hemisphere specialization in children.



(a)



(b)

Figure 10. Explanations of interference between mental tasks and sound stimuli. According to the auditory–brain system model used in the present work, noise and music are, respectively, associated mainly with the right hemisphere and the left hemisphere. And the adding task and search task, respectively, may be associated mainly with the left hemisphere and the right hemisphere. (a) For children from a quite living area; (b) for children from a noisy living area. Interference effects shown by shaded areas differ remarkably between children from noisy and quiet living areas.

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