NOISE EXPOSURE FROM VARIOUS SOURCES
SLEEP DISTURBANCE
DOSE-EFFECT RELATIONSHIP ON CHILDREN

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Outline

Summary

This report summarized several studies on the extra-auditory effects of ambient noises on sleeping children. In relation to ambient noise, specific changes were reported in both sleep quality and quantity. Some of the effects were shown to have a dose-response relationship.

I. Introduction

Most of the information available on the effects of noise on people come from studies on young adults. There is a large body of knowledge that is concerned with the auditory and the extra-auditory effects of noise. Noise can interfere with sleep, can be a source of annoyance, and can act as a stressing agent. Other effects of noise, such as cardiovascular or autonomic effects to name a few, are less well understood and continue to be the subject of much debate and controversy.

It is possible that some of the information obtained from adults does not apply to children, and that there could be situations which only affect children, or affect them differently, and for which no data are available (Mills 1975). The present report, therefore, focuses only on those effects of noise exposure during sleep that may be more deleterious to fetuses, infants, children and adolescents; that may have possible health, and/or educational implications; that may have a high incidence; and that are amenable to investigation. The effects of noise on sleep and awakening from sleep are discussed along with gaps in basic knowledge.

In accordance with the title of this review, various noteworthy health-related topics of noise will not be addressed. These include the role of noise exposure and hearing loss or the topic of noise and speech communication.

This document relies largely on excellent summaries of the topic available in the scientific literature. Likewise, personal experience in the dose-effect relationship of noise on arousal from sleep in infants is reported.

II. Background

II.I. Noise

Noise is undesirable sound. Sound in vibration in a medium, usually air. Sound has intensity (loudness), frequency (pitch), periodicity, and duration.

- The loudness of sound in measured in decibels (dB), a logarithmic scale (Committee 1997). Since the human ear is more sensitive to the damaging effects of high frequency sound than to low frequency, a better correlate with noise-induced hearing loss can be obtained when low frequencies are filtered out. Filtered sound level, measured on a so-called A-weighted scale, is designated dB(A). Room conversation produces 60 to 70 dB(A), levels of 60 to 65 dB(A) often require the speaker to increase the voice level and vocal effort. Levels of 75 dB(A) often require the talker to shout (Mills 1975). Noise level outside of apartments near a busy freeway range from 52 to 84 dB(A), and inside the apartments from 52 to 70 dB(A). Rock music produces 100 to 120 dB(A).

The sound pressure level from a source of noise is inversely proportional to the square of the distance from the source. Environmental noise is expressed as a day-night average sound level (DNL). For the protection of the public health, the US Environmental Protection Agency has proposed a DNL of 55 dB during waking hours and 45 dB during sleeping hours in neighborhoods, and 45 dB in daytime and 35 dB at night in hospitals (American 1974).

- The frequency of sound is measured in cycles per second, designated hertz (Hz). The young human ear is sensitive to a frequency range of 20 to 20,000 Hz (American 1974). White noise, the auditory counterpart of white light, has equal energy in each frequency in the audible range.

II. II. Sleep

Sleep is cyclic in nature and comprises a number of stages. Stage I, characterized by low voltage, mixed frequency EEG (2 to 7 Hz) is a brief period following the awake state and is a prelude to the more prevalent Stage 2 (Non Rapid Eye Movement sleep, or NREM), which occupies approximatively 50% of the total sleep period. In this stage, 12 to 14 Hz sleep spindles and K complexes occur against a background Stage I pattern. Stages 3 and 4, also known as deep or delta sleep, are characterized by slow, high amplitude EEG waves, typically 2 Hz or less and in the range of 75 uV. These stages are usually observed in the early one-third of the night. The final stage, REM (rapid eye movement), occurs mainly in the last half of the night and is similar to Stage I, except that it is accompanied by dreaming, eye movements and muscle activity. This cycle of stages is typically repeated every 90 to 120 min, with decreasing Stage 4 activity as the sleep period progresses. The proportion of sleep stages changes with maturation. In newborns and young infants, an indeterminate sleep stage is scored, that includes both Active (REM) and Quiet (NREM) sleep characteristics.

II. III. Sleep-wake recording

II.III.A. Recording techniques

Some studies were conducted in the natural home environment of the children. Most studies on infants exposed to auditory stimuli have been, however, conducted in pediatric sleep laboratories to evaluate the infants' arousal thresholds to environmental noises. Monitoring were usually carried out in a quiet, dimly lit room at an ambient temperature ranging from 21° to 24°C (69.8°F to 75.2°F). All patients slept supine, without restraints. They were observed continuously during recordings. Their behavior and nursing interventions were charted. Feeding was administrated based on demand. The following variables were usually recorded simultaneously: scalp electroencephalograms with central, temporal and occipital leads, electro-oculograms, digastric electromyogram, and electrocardiogram. Respiratory movements were measured with the use of thoracic and abdominal strain gauges, and airflow by oral and nasal thermistors. Body movements were recorded by actigrams or piezoelectric sensors. Oxygen saturation was recorded continuously by a transcutaneous sensor. The data were collected on standard or computerized polygraph recorders.

II.III.B. Sleep scoring

In most standard laboratories, every 30-second period of the recordings was scored as NREM, REM, indeterminate sleep or wakefulness, according to criteria in the literature (Guilleminault and Souquet 1979). Sleep efficiency was defined as the time spent sleeping divided by the total recording time, multiplied by 100. Scoring was usually done visually by at least two independent scorers to ensure reliability. Scoring discrepancies among scorers were discussed and codes thus agreed upon were used in the data analysis.

In order to study 'arousals', appropriate definitions must be used for infants. The scoring method of arousals in adults edited by the American Sleep Disorder's Association can be applied to children, but not to infants. Since 1998, an international work force, the European Pediatric Wake-Up Club, has elaborated a method for the scoring of arousal in infants aged between 1 and 6 months. An awakening is scored when the infant cried and/or opened the eyes. These definitions were used in most studies.

II.IV. Auditory arousal and awakening thresholds

Awakening threshold reflects the tonic state of an unknown mechanism, or mechanisms, which permit sleep to continue in the face of stimuli which normally elicit responses during wakefulness, but also permit awakening to the most "urgent" stimuli. Furthermore, either this or a closely related mechanism also "evaluates" the signal in terms of past experience and "decides" whether an awakening is required. Such an adaptive mechanism represents the product of "careful" natural selection and deserves attention as a fundamental biological phenomenon. The clinical importance of malfunction of this mechanisms, as in the easily disturbed sleep of insomniacs, is apparent (Rechtschaffen et al. 1966).

II. IV. A. Auditory stimulation techniques

In several studies, white noises of increasing intensity were presented for 3 seconds via a loudspeaker to study auditory arousal thresholds, at some distance of either ear. The sound level was increased by 10 dB, ranging from 50 dB (A) to 100 dB (A). The time between each presentation was 1 minute. An auditory challenge was interrupted when the infant awakened, as defined by opening of the eyes and/or crying, or when a stimulation level of 100 dB (A) was reached. The auditory signal was identified on the sleep recording.

II.IV. B. Scoring of arousal and awakening

An arousal response was scored if within 10 seconds of the start of an auditory stimulation, polygraphic changes were seen indicating that the child had aroused, as defined above. Arousal thresholds were defined by the lowest auditory stimuli, expressed as dB(A), needed to induce an arousal. An auditory challenge was interrupted when the infant awakened, as defined by opening of the eyes and/or crying, or when a stimulation level of 100 dB (A) was reached.

An arousal response was scored if within seconds of the start of an auditory stimulation, polygraphic changes were seen indicating that the child had aroused, as defined above. Arousal thresholds were defined by the lowest auditory stimuli, expressed as dB(A), needed to induce an arousal.

II. IV. C. Factors that modify auditory arousal thresholds

By the time that most studies were conducted in infants, it became progressively evident that arousal and awakening thresholds are influenced by a variety of factors. These significantly modify the response to ambient noise by sleeping infants. Some factors inhibit the arousal response, while others enhance the response.

II. IV. C. 1 Prenatal and perinatal factors

- Age of gestation.

In 97 healthy infants, auditory awakening thresholds decreased significantly from the 44th to the 60th postconceptional week (Kahn et al. 1986). Awakening thresholds were defined as the infant opening the eyes and/or crying. Mean awakening thresholds dropped from 98.5+/-11 at the 44th postconceptional week to 83 dB(A) by the 60th postconceptional week.

- Cigarette smoke

To evaluate the effects of cigarette smoke on polygraphic arousal thresholds, 26 newborns were studied with polygraphic recordings for one night: 13 were born to mothers who did not smoke, and 13 were born to mothers who smoked (over 9 cigarettes per day) (Franco et al. 1999). Another group of infants with a median postnatal age of 12 weeks were also studied: 21 born to non-smoking mothers and 21 born to smoking mothers. The auditory arousal thresholds of the infants of both age groups were measured with the use of auditory challenges of increasing intensity, administered during REM sleep. More intense auditory stimuli were needed to induce arousals in newborns (p=.002) and infants (p=.044) of smokers than in infants of nonsmokers (mean value of 84+/-11 dB(A) for smokers and 81.6+/-20 for nonsmokers). Behavioral awakening (infants opening the eyes and/or crying) occurred significantly less frequently in the newborns of smokers (p=.002) than of nonsmokers.

It was concluded that newborn and infants born to smoking mothers had higher arousal thresholds to auditory challenges than those born to non-smoking mothers. From the present findings, it appeared that the impact of exposure to cigarette smoke occurred mainly before birth.

IV. II. C. 2. Postnatal factors

The following postnatal factors modify arousal from sleep:

- Sleep stage

In infants, auditory stimuli have generally indicated increased responses during active as compared with quiet sleep (Busby et al. 1994).

- Time of the night

In 31 infants, the arousal thresholds decreased across the night (mean value of 67+/-12.5 dB(A) in the 1st part of the night, for 51+/-3.5 in the 3rd part of the night; p=.017) (Franco et al. 2001). Similar findings had been reported in adult subjects (Rechtschaffen et al. 1966).

- Body position during sleep

To investigate whether prone or supine sleeping was associated with a different response threshold to environmental stimuli, 25 three-month-old healthy infants with a median age of 9 months were exposed to an auditory challenge while sleeping successively prone or supine (Franco et al. 1998). Three infants were excluded from the study because they awoke while their position was being changed. For the 22 infants included in the analysis, more intense auditory stimuli were needed to arouse the infants in the prone position (median of 70 db(A), range values 50 to more than 100 db(A)) than in the supine position (median of 60 db(A), range values 50 to 90 db(A)) (p=.011). Arousal thresholds were higher in the prone than in the supine position in 15 infants; unchanged in 4 infants; and lower in the prone position in 3 infants (p=.007). It was concluded that infants show higher arousal thresholds to auditory challenges when sleeping in the prone position than when sleeping in the supine position. The findings could not readily be explained. The difference in arousal thresholds could be related to difference in chest wall mechanoreceptor responses, or differences in blood pressure and/or central baroreceptors responses.

- Ambient room temperature

Two groups of healthy infants with a median age of 11 weeks were recorded polygraphically during one night: 31 infants were studied at 24°C and 31 infants at 28°C. To determine their arousal thresholds, the infants were exposed to white noises of increasing intensities during REM and NREM sleep (Franco et al. 2001). The arousal thresholds decreased across the night in the infants sleeping at 24°C (p= .017). The finding was not found for the infants sleeping at 28°C. When analysing the arousal responses according to time of the night, it was found that the auditory thresholds were significantly higher at 28°C (75+/-19 dB(A)) than at 24°C (51+/-3.5 dB(A)) between 03:00 hr and 06:00 hr (p=.003). These findings were only seen in REM sleep.

- Sleeping with the head covered by bedclothes

To evaluate the influence of covering the face of sleeping infants with a bed sheet, 18 healthy infants with a median of 10.5 weeks (range 8 to 15 weeks) were recorded polygraphically for one night (Franco et al. 2002). They slept in their usual supine position. During sleep, a bed sheet was gently placed on their face during 60 minutes. With the face free or covered by the sheet, the infants were exposed to white noises of increasing intensities during REM and NERM sleep. Compared to face free, during the face-covered periods, the infants had increases in pericephalic ambient temperature (p<.001), increases in REM sleep (p=.035) and body movements (p=.011) and a decrease in NREM sleep (p<.001). Respiratory frequency was increased in both REM (p=.001) and NREM (p<.001) sleep. With their face covered, the infants had higher auditory arousal thresholds (mean of 76+/-23 dB(A)) than whith the face free (mean of 58+/-14 dB(A)) (p=.006). The difference was seen in REM sleep only. A positive correlation was found between pericephalic temperature and arousal thresholds in REM sleep (r=.487; p=.003).

- Short sleep deprivation

Following short sleep deprivation, a study reported that in infants there was no measurable change in arousal propensity by auditory stimuli (1 kHz pure tone, delivered in the midline of the cot, from 73 dB and increased in 3 dB steps to 100 dB) during quiet sleep (Thomas et al. 1996). Another study was undertaken to evaluate the influence of a brief period of sleep deprivation on sleep and arousal characteristics of healthy infants (Franco et al. submitted). Thirteen healthy infants with a median age of 8 weeks (range 7 to 18 weeks) were recorded polygraphically during a morning nap and an afternoon nap in a sleep laboratory. They were two hours sleep-deprived, either in the morning or in the afternoon before being allowed to fall asleep. Six infants were sleep-deprived before the morning nap and seven before the afternoon nap. During each nap, the infants were exposed to white noises of increasing intensities in REM sleep to determine their arousal thresholds. Following sleep deprivation, the infants tended to have less gross body movements during sleep (p = .054). They had a significant increase in obstructive sleep apneas (p = .012). The infants'auditory arousal thresholds were significantly higher following sleep-deprivation (mean of 76+/-13.5 dB(A)) than during normal sleep (mean of 56+/-8.4 dB(A)) (p = .003) during REM sleep. It was concluded that short-term sleep deprivation in infants is associated with the development of obstructive sleep apneas and a significant increase in arousal thresholds.

- Pacifiers and breastfeeding

Fifty-six healthy infants were studied polygraphically during one night: 36 infants used a pacifier regularly during sleep; 20 never used a pacifier (Franco et al. 2000). Thumb users or occasional pacifier users were not included in the study. The infants were recorded at a median age of 10 weeks (range 6-19 weeks). To evaluate their auditory arousal thresholds, the infants were exposed to white noise of increasing intensity during REM sleep. Polygraphic arousals occurred at significantly lower auditory stimuli in pacifier-users than in nonusers (mean of 60+-11.6 with pacifiers, for 71+-15.3 without pacifier; p=.010). Compared to nonusers, pacifier-users were more frequently bottle-fed than breastfed (p=.036).

Among infants sleeping without a pacifier, breast-fed infants had lower auditory thresholds than bottle-fed infants (mean of 67.7+-13.0 breast-fed, for 77.7+-17.5 bottle-fed; p=.049). The question of how a pacifier contributes to protect the sleeping infant might be best explained by the observed loss of the pacifier early after sleep onset. This could contribute to disrupt the infant's sleep and favor arousals.

II.IV. C. 3. Factors that modify auditory arousal thresholds: Conclusions

Various factors modify auditory arousal responses from sleep in healthy infants. Some inhibit arousals while others enhance the response. To evaluate the effect and dose-effect relationship on children therefore requires the careful determination of confounders that may bias studies and lead to conflicting results.

Additional confounders should be added to the list of factors that modify arousal thresholds. These include past experience with the stimulus (Rechtschaffen et al. 1966), or the presence of meaning in the noise as both of them are of critical importance in determining the persistence of physical reactions to the noise (McLean and Tarnopolsky 1977). These are the reasons which lead most sleep-wake researchers to use white noises to stimulate the sleeping child.

Knowledge of these variables does little to clarify the physiological determinants of the awakening response, because we have little better idea of how such variables are related to possible physiological determinants than we have for the awakening response itself (Rechtschaffen et al. 1966).

These findings however, underline the significant dose-response relationship between ambient noise and arousal or awakening from sleep in infants.

III. Noise and sleep in children

III. 1. The fetus

The human fetus spends most of its time in a state equivalent to sleep, similar to that recorded in newborn infants. The healthy fetus in utero was shown to react to external noises. This is the result of the development of the human cochlea and peripheral sensory end organs. These complete their normal development by 24 weeks of gestation. Sound is well transmitted into the uterine environment. Ultrasonographic observations of blink-startle responses to vibroacoustic stimulation are fist elicited at 24 to 25 weeks of gestation, and are consistently present after 28 weeks, indicating maturation of the auditory pathways of the central nervous system (Committee 1997). The fetus reacts to 1 to 4 seconds of 100 to 130 dB of 1220- to 15000-Hz sound. The hearing threshold (the intensity at which one perceives sound) at 27 to 29 weeks of gestation is approximatively 40 dB and decreases to a nearly adult level of 13.5 dB by 42 weeks of gestation, indicating continuing postnatal maturation of these pathways.

Teratogenic effects have been described in animals prenatally exposed to noise (Committee 1997). These were associated with higher levels of cortisol and corticotropin hormones in the exposed animals. No such effects could be demonstrated in humans, in whom studies on the relation between exposure to noises during gestation and shortened gestation or lower birthweights were inconclusive or conflicting. It is possible that in these studies, noise could be a marker of other risk factors (Committee 1997). In conclusions, most studies on the effects of noise on perinatal health have been criticised, as being hampered by serious methodological limitations, both in terms of the measurement of exposure and outcome, and failure to control for other known determinants of the outcomes under investigation. The lack of properly controlled studies makes it difficult to draw conclusions about which effects ambient noise have on perinatal outcomes (Morrell et al. 1997).

IV.2. Newborn infants

A large number of investigations have been concerned with the responses of asleep newborn infants to acoustic signals. Many of the studies arise from a large and general interest in child development as well as from a need for hearing tests of infants (Mills 1975).

Infant incubators produce continuous noise levels of between 50 and 86 db (linear) (American 1974). Oxygen inlets produced an additional 2 dB (linear). Slamming of incubator doors and infant crying produced 90 to 100 dB(A) (American 1974). It was shown that inside incubators, background noise level is about 50 dBA and can reach 120 dBA (Committee 1997). Much of the energy is located below 500 Hz, between 31 and 250 Hz (Mills 1975).

Ambient noise appear to influence the quantity and quality of the sleep of newborns. Some newborns appear to be particularly responsive to ambient noises. Sleeping premature, anoxic, or brain-damaged infants detect intruding sounds better than sleeping, healthy, or term babies (Mills 1975).

Newborn infants spend most of their time sleeping. Some studies have documented hearing loss in children cared for in intensive care units (Committee 1997). Noise and some ototoxic drugs act synergistically to produce pathological changes of the inner ears of experimental animals (neomycin, kanamycin, sodium salicylate…). The relationship with the infant's clinical condition and associated treatments has however not yet been clearly defined. Infants exposed to sound levels of incubators are usually premature, on drugs, and in very poor health. Moreover, the exposures are continuous. A weak infant could spend weeks sleeping in such noise level without rest periods away from noise (Mills 1975).

High noise levels may be associated with other types of responses. In young infants, sudden loud noise (of approximately 80 dB) environmental noise induced hypoxemia.

Noise reduction was associated in neonates with increases in sleep time, in particular in quiet sleep (Committee 1997). It also resulted in fewer days of respiratory support and oxygen administration. Premature infants cared with noise reduction had a better maturation of electroencephalograms.

A Committee on Environmental Health of the American Academy of Pediatrics concluded that high ambient noises in the NICU changed the behavioural and physiological responses of infants (Committee 1997). For all the above observations and considerations, sound in infant intensive care units should be maintained under 80 dB(A) (Graven 2000). Among other recommendations, pediatricians were encouraged to monitor sound in the NICU, and within incubators, where a noise level >45 dB is of concern.

III. 3. Infants (1 month to 1 year-old).

Some studies of the effect of external noises on the sleep-wake reactions of infants were conducted in their natural home environment. The reactions of babies to aircraft noise were studied by means of electroplethysmography (PLG) and EEG (Ando and Hattori 1977). The recordings were done in the morning, in the infants' sleeping rooms. The infants were exposed to recorded noise of Boeing 727 at take off. The noise was presented at 70, 80 and 90 dB(A) in the peak level at the position of the babies'heads. The subjects, who had not been awakened by exposure to aircraft noise, were exposed to music (Beethoven's 9th Symphony) in levels of 70, 80 and 90 dB(A). The frequency ranged between 100 Hz and 10 kHz. It was found that the babies whose mothers had moved to the area around the Osaka International Airport before conception (Group I; n=33) or during the first five months of pregnancy (Group II; n=17) showed little or no reaction to aircraft noise. In contrast, babies whose mothers had moved closer to the airport during the second half of the pregnancy or after birth (Group III; n=10 or IV; n=3) and the babies whose mothers lived in a quiet living area (Group V; n=8) reacted to the same auditory stimuli. The babies in groups I and II showed differential responses on whether the auditory stimuli were aircraft noise or music. Abnormal PLG and EEG were observed in the majority of babies living in an area where noise levels were over 95 dB(A). It was concluded that the difference in reactivity to aircraft noise may be ascribed to a prenatal difference in time of exposure to aircraft noise. The reactions diminished after the sixth months of life in group I and II, and the ninth month in groups III-V. This phenomenon may be explained as habituation to aircraft noise after birth. However, in all groups, no habituation occurred for a noise level over 95 dB(A) (Ando and Hattori 1977). This study was critized, as the authors did not adjust for several important determinants of birthweight, such as prematurity and the mother's age, weight, smoking status or socioeconomic status (Morrell et al. 1997).

Noise levels may be constantly high in pediatric units. The mean noise levels measured in a center of a surgical recovery room were 57.2 dB(A), while those measured at the patients'heads were 65.6 dB(A) (American 1974). In a medical unit (6-bed wards containing 5 infants between 3 and 17 months) peak sound levels were recorded on the pillow of the cot for 12 min (Keipert 1985). Infant crying produced 75 to 90 dB(A) and a beeper around 76 to 78 bB(A). Peak noise levels recorded at the nurses'station were about 78 dB(A) for telephone, 80 for infant crying, public address system, adult talking, and up to 90 dB(A) for child talking (Keipert 1985).

In a study was conducted on infants exposed to 50 to 80 dB(linear) in the range of 100 to 7,000 Hz (American 1974), a level of 70 to 75 dB (linear) for three minutes led to obvious disturbance or awakening in two thirds of the children. All infants awakened after 75 dB(linear) for 12 minutes.

In other studies conducted on the effects of awakenings and arousals, it was shown that white noise intensity was significantly lower to elicit polygraphically scored arousals than to induce awakenings (Franco et al. 1998).

III. 4. Toddlers – Preadolescents (8 to 12 years old) – Adolescents (13 to 18 years old)

Developmental variations in auditory arousal thresholds during sleep were investigated in four groups of normal male subjects : children (n=6; 5-7 years old), preadolescents (n=10; 8-12 years old), adolescents (n=10;13-16 year old), and young adults (n=10; 20-24 years old) (Busby et al. 1994). Arousal thresholds were determined during NREM and REM sleep for tones (3-s, 1,500-Hz pure tones delivered in an ascending series of increasing intensity, 5-dB increments beginning at 30 dB SPL ("Sound pressure level") re 0.0002 dynes/cm2 until awakening or maximum intensity of 120 dB) presented via earphone insert on a single night following two adaptations nights of undisturbed sleep. Age-related relationships were observed for both awakening frequency and stimulus intensity required to effect awakening, with awakenings occurring more frequently in response to lower stimulus intensities with increasing age. In children, 43.1% of stimuli induced awakenings, in preadolescents 54.8%, adolescents 72% and adults 100% (X2=60.37; p<.001). Partial arousals (brief EEG desynchronization and/or EMG activity with the subjects returning to sleep) occurred in 9.8% of children, 4.8% of preadolescents, 12.2% adolescents, 0% adults. Although stimulus intensities required for awakening were high and statistically equivalent across sleep stages in non-adults, higher intensity stimulus were required in Stage 4 relative to Stage 2 and REM sleep. Frequency of awakening increased with age, whereas stimulus intensities required to effect these awakenings decreased with age. These relationships were maintained for individual sleep stages. These results confirm previous observations of marked resistance to awakening during sleep in preadolescent children and suggest that processes underlying awakening from sleep undergo systematic modification during ontogenic development. The observed resistance to elicited awakening from sleep extending up to young adulthood implies the presence of an active, developmentally related process that maintains sleep (Busby et al. 1994).

In another study, 5- to 7-year-old children were shown to be 10-15 dB less sensitive to pure tones than 22- to 30-year-old adults (Mills 1975). Another report on 8-12 year-old male hyperactive and normal children showed that these children were awakened with auditory stimulus intensity levels of up to 123 dB SPL ("Sound pressure level"), much higher than values reported for adults (range of 50-85 dB) (Busby et al. 1994).

In a study on 4 children (2 males), aged 5 to 8 years old on the effects of simulated sonic booms (68 dB(A) near the subjects' ears), 94.1% of the subjects showed no change, 5.9% had shallower sleep, but none aroused or had or behavioural awakening. In general, the frequency of arousal or behavioural awakenings and of sleep stage changes increased with age (up to 75 y) (Lukas 1975).

In a prospective longitudinal investigation, which employed non-exposed control groups, effects of aircraft noise prior to and subsequent to inauguration of a new airport as well as effects of chronic noise and its reduction at an old airport (6 to 18 month post relocation), were studied in 326 children aged 9 to 13 years (Bullinger et al. 1999). The psychological health of children was investigated with a standardized quality of life scale as well as with a motivational measure. In addition, a self-report noise annoyance scale was used. In the children studied at the two airports over three time points, results showed a significant decrease of total quality of life 18 month after aircraft noise exposure as well as a motivational deficits operationalized by fewer attempts to solve insoluble puzzles in the new airport area. Parallel shifts in children's attributions for failure were also noted. At the old airport parallel impairments were present before the airport relocation but subsided there after (Bullinger et al. 1999).

In a study, the effects of ambient noise on autonomic responses could be demonstrated in children. In 6 to 12 year-old children exposed to intermittent traffic noise during four nights (at a rate of 90 noises per hour; peak intensity of the noise, 45, 55 and 65 dB(A) varied semi-randomly) and two quiet nights: heart rate was affected and relatively higher in noise during REM and Stage 2 than during delta sleep (Muzet et al. 1980, in Abel 1990).

IV.3. Sleep deprivation in children

The effects of sleep deprivation were evaluated in children. The findings only indirectly pertain to this general report, although repeated noise-induced sleep disruption favors sleep deprivation.

In another study, 15 healthy infants aged 78+/-7 days were studied during two nights; one night was preceded by sleep deprivation (kept awake for as long as possible beyond their habitual bedtime: median onset 150 min; range 0-210 min) (Thomas et al. 1996). Thirteen slept supine, 12 were breastfed, 4 were from smoking parents. Following sleep deprivation, infants maintained a greater proportion of quiet sleep (44 vs 39%; p=.002). There was no measurable change in arousal propensity by either graded photic (stroboscope) or auditory stimuli (1 kHz pure tone, delivered in the midline of the cot, from 73 dB and increased in 3 dB steps to 100 dB) during quiet sleep.

In 49 Finish children (26 boys) aged 7 to 12 years interviewed, together with their parents and school teachers, and recorded for 72 h with a belt-worn activity monitor during weekdays. The objectively measured true sleep time was associated with teacher-reported psychiatric symptoms. The decreased amount of sleep was associated more with externalising than internalizing types of symptoms (aggressive and delinquent behavior, attention, social, and somatic problems) (Aronen et al. 2000).

In a survey, we could show that out 100 belgian school children, 9 to 12 year old, those with poor sleep (insomnia) were also showing more frequent poor school performance (failure to comply with expected grades) than good sleepers. The relation between poor sleep and noisy environment was however not evaluated (Kahn et al. 1989).

V. Conclusions

This report summarized several studies on the extra-auditory effects of ambient noises on sleeping children. In relation to ambient noise, specific changes were reported in both sleep quality and quantity. Some of the effects were shown to have a dose-response relationship.

Several limitations to the present report should be discussed. Firstly, we do not know whether the inferance that is often made that the effects of noise might develop with a longer exposure time (Abel 1990) is correct. Serious cardiorespiratory or autonomic changes, such as increases in blood-pressure could only develop following long-time exposure starting from childhood. This, in fact, has never been documented, nor has the extent of intersubject variability, due to difference in susceptibility. Secondly, we have no information to evaluate whether adaptation to ambient noise could limit the effects observed during short-term experiments. Thirdly, as the existing research data are applicable to generally healthy children, we do not know how the reported findings could be applied to ill children, children receiving medical treatments or very young premature infants. Finally, as most studies were conducted in laboratory controlled environments, we do not know the correlation between these studies and the effects of noise in the home. The multifactorial effects of environment on sleep and arousal controls could be much more complex than expected. On might predict that, as for adults, the effects of noise on the child's sleep and health are very complicated and depend upon the spectrum and level of the noise, temporal aspects of the noise, psychological responses to the noise, and the nature of the evaluation technique. The complexity of the conditions related to sleep-wake controls was illustrated by the review of confounding factors affecting auditory arousal thresholds.

Despite these limitations, it can be concluded that, based on the evidence available, the extra-auditory effects of noise could be pervasive, affecting the children's physical and psychological well-being. Changes in sleep quantity and quality together with autonomic reactions are seen when a child is exposed to ambient noise during sleep. Ambient noise exerts a dose-effect relationship on changes of sleep-wake behaviors. These reflect modifications induced within the brain of the sleeping child. It remains, however, to be determine what pervasive effects long-term exposure to ambient noise have on the child's development, health and well-being. Evidence should also be defined to support an enforcement of strategies for noise reduction at the source as suggested by some studies. Noise-induced health effects on children, a clinical and public health concern, should be evaluated by further studies.

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