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Review of the effect of aircraft noise on sleep disturbance in adults

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Abstract

Noise exposure generated by air traffic has been linked with sleep disturbances. The purpose of this systematic review is to clarify whether there is a causal link between aircraft noise exposure and sleep disturbances. Only complete, peer-reviewed articles published in scientific journals were examined. Papers published until December 2010 were considered. To be included, articles had to focus on subjects aged 18 or over and include an objective evaluation of noise levels. Studies were classified according to quality. Given the paucity of studies with comparable outcome measures, we performed a narrative synthesis using a best-evidence synthesis approach. The primary study findings were tabulated. Similarities and differences between studies were investigated. Of the 12 studies surveyed that dealt with sleep disturbances, four were considered to be of high quality, five were considered to be of moderate quality and three were considered to be of low quality. All moderate- to high-quality studies showed a link between aircraft noise events and sleep disturbances such as awakenings, decreased slow wave sleep time or the use of sleep medication. This review suggests that there is a causal relation between exposure to aircraft noise and sleep disturbances. However, the evidence comes mostly from experimental studies focusing on healthy adults. Further studies are necessary to determine the impact of aircraft noise on sleep disturbance for individuals more than 65 years old and for those with chronic diseases.

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Full Text

Introduction

Noise produced by aircrafts has led to conflict between airports and citizens living in their vicinity that can be traced back to the 1960s. [1] Recently, the increase of air traffic and the rapid expansion of cities have accentuated this problem. Several studies have been conducted to assess the effect of aircraft noise on sleep.

According to the World Health Organisation (WHO), disturbance of sleep is not only a health concern in itself, it has also been reported to be associated with other health problems. [2] Even though there are many uncertainties regarding the chronic health effects of minor sleep disturbances, decreased total sleep time is associated with obesity, [3],[4] hypertension, [5] diabetes [6] and increased mortality. [7]

At least two other reviews have focused on the effects of aircraft noise on sleep disturbance. [2],[8] However, these two reviews did not explicitly report their search strategies and did not evaluate the quality of the revised studies. Standards and guidelines of systematic reviews have highlighted the fact that individual study quality should be considered in systematic reviews in order to obtain the best estimates of study results. [9],[10],[11],[12]

This systematic review focuses on the association between aircraft noise and sleep disturbances. We considered noise emitted by aircraft taking off or landing and by any flight trajectories that expose the population to the noise of their engine. Both field and experimental laboratory data were considered. Our systematic review is the first to focus exclusively on aircraft noise and sleep disturbance using study design and bias assessment to evaluate the study quality and select studies.

Methods

Only original, peer-reviewed articles published in scientific journals in English or French were examined. To be included, articles had to focus on subjects aged 18 or over and had to report an objective evaluation of noise levels. Studies had to focus on aircraft noise to be included in our review. Studies that did not distinguish aircraft noise from other types of noise were excluded. Studies with no measurable sleep outcomes were also excluded from this review. Studies or parts of studies focusing on sleep disturbances were considered for inclusion. Studies focusing on morning-after effects were excluded.

The Pubmed, Medline, embase and psychinfo search engines were consulted using aircraft or airport and noise as keywords. Studies published until December 2010 were considered. We employed a search strategy that was not particularly sensitive, yet highly specific at the same time. In addition, we used a "snowball" strategy, consulting the references included in all of the studies on noise and sleep patterns (including available review articles) to ensure that all relevant studies were selected. Lastly, we consulted experts in the field and colleagues at the Institut National de Santé Publique du Québec to identify further published studies that we may have missed for inclusion in our review. Abstracts were independently analyzed by two authors (LFT and SP). Diverging opinions were resolved by discussion.

Study quality

In order to consider quality, we assessed both study design and presence of biases (systematic error) of the studies retrieved.

We considered that experimental studies were of greater quality than cross-sectional studies, that cross-sectional studies could only be of moderate and low quality and that studies attempting to measure individual-level effects with complete ecological designs were only of low quality. [13],[14] Natural experiments were included in the experimental studies category. [14] These studies include those where noise levels were not controlled by the researchers but occurred in field settings and were recorded and were correlated to the subjects' responses. All experimental studies were of the repeatedtreatment design, where exposure and outcome covary over time. In general, this design is strong for internal validity. [15]

We defined minor biases as those likely to affect the relationships between the variables studied but unlikely to compromise the results of the study. Major biases are those that by themselves could invalidate the results of a study. The quality of the studies was assessed using the following biases and parameters: Selection bias refers to populations studied (those exposed to noise and those not exposed to it) that were not comparable, classification bias refers to data on noise exposure or on health effects that were measured inaccurately or were not properly validated and confounding bias refers to the presence of significant confounding variables associated with noise exposure and sleep disturbance that were not accounted for. [16]

[Table 1] presents how study quality was ranked based on both design and biases. For example, experimental studies had to have no major bias to be considered of high quality, whereas cross-sectional studies with no major bias were considered of moderate quality. All ecological studies using aggregated data were classified as being of low quality.{Table 1}

[Table 2] presents the various biases present within studies. Response rates lower than 30% were considered major biases. Response rates between 30% and 60% were considered minor biases. The use of methods other than polysomnography to assess sleep disturbance were considered major classification biases. These methods included the use of questionnaire, push buttons, actigraphy or seismosomnography (see [Table 3] for a description). Still, we considered that there was a minor classification bias in one study (Basner), where sleep disturbance was assessed by polysomnography because sleep disturbance was based on the most sensitive sleep stages.{Table 2}{Table 3}

Regarding noise exposure, we considered that when modelled or measured residential noise exposure levels were not available, there were major biases; in cross-sectional studies, individual exposure estimates based on modelling were considered to induce minor biases.

We decided to use a best-synthesis approach as described by Slavin, 1995. [32] Hence, of all studies reviewed, we present only the results of those of moderate or high quality.

Noise exposure

Sound levels are measured in decibels (dB). Average sound levels (L Aeq) are calculated based both on the variations of sound pressure over time and on the duration of the noise. A weighted average is therefore used to measure exposure. In the studies reviewed, it was seen that the average can represent a 24-h period or be divided into different periods (typically daytime, evening and night time). L Aeq values can refer to various other durations (e.g., L Aeq22-23h ,). L night is an L Aeq used for night time noise of an 8-h duration. L den (day, evening, night) is an equivalent sound level over 24 h in which sound levels during the evening (19h00 to 23h00) are increased by 5 dB(A) and those during the night (23h00-07h00) by 10 dB(A).

Maximum sound levels are also used to measure exposure when the sound fluctuates over time; examples include aircraft noise on take-offs or landings. L Amax measures the average maximum A-weighted sound level, in dB, over a given time interval, usually 0.125 ms or 1 s. In some studies, sound exposure level (SEL) is also used. SEL is a metric used to describe the noise energy produced from a single noise event. It is computed from measured dB(A) sound levels and integrates all the acoustic energy contained within the event and integrated over 1 s.

As previously mentioned, for a study to be included in our review, it had to include an objective estimate of noise exposure. Such estimates may be real-time measurements (inside subjects' homes-which is ideal-or outside) or modelled noise levels (generated noise exposure contours for given geographical areas). Studies using subjects exposed to recorded aircraft noises played back in a laboratory setting during the night were also included in our review. Studies that analyzed noise from various sources had to specifically distinguish aircraft noise from other noise sources in our analysis to be included in our review.

Measurement of sleep disturbances

Possible effects of noise on sleep are generally grouped into three categories: the immediate effects of noise on sleep (sleep disturbance and physiological effects), the secondary effects of the sleep disturbances (morning-after effects) and the long-term health effects. [33] Sleep disturbance is defined as any deviation, measurable or subjectively perceived, from an individual's habitual or desired sleep behavior. [34] Categories of sleep disturbances considered for our review include awakenings, sleep quality, medication taken to control sleep, total sleep time, time spent in slow wave sleep (SWS) (previously known as stage three and four sleep), [35] sleep stage changes and arousals as defined in Basner et al. 2008 [19] and time spent in rapid eye movement stage of sleep (REM).

Polysomnography is the only valid method to evaluate and measure sleep stages. Polysomnography is also the gold standard for many types of measures, including awakenings and total sleep time. Polysomnography comprises electroencephalogram (EEG) measurements of brain activity, electrooculogram (EOG) measurements of eye activity and electromyogram (EMG) measurements of muscle activity. [18] In the reviewed studies, different methods were used to measure awakenings. [Table 2] compares these methods. The individual's body movements (motility) during sleep can be linked to awakenings by using methods such as actigraphy and seismosomnography. Actigraphy measures movements of the wrist and seismosomnography measures small movements of the body and a change of heart rate or breathing rate. Actigraphy has a positive predictive value of 50% or less compared with detection of awakenings measured by the gold standard polysomnography, which limits its validity. [26],[30] Seismosomnography was designed to have better sensibility and specificity than actigraphy and to have a greater ease of analysis and of use than polysomnography. [21] However, seismosomnography is subject to the same limitations as actigraphy as it is also based on body movement. [36] Seismosomnography has yet to be validated against polysomnography.

Methods that depend on the subject reporting any spontaneous awakenings during the night by pressing a button on a device (defined as behavioural awakenings), or completing a sleep quality questionnaire the next morning, lack positive predictive value because many awakenings are not long enough to be recalled or to induce the pressing of a button. In fact, subjective evaluations of awakenings by questionnaire do not correlate well with objective data obtained by polysomnography for individuals with sleep disorders. [31] Actigraphy and questionnaires are the least-expensive methods and are easier to use and to analyze than the other methods. Polysomnography and seismosomnography are more expensive and result in a complex set of data, giving this method high sensitivity and specificity but low ease of analysis and usability. [21]

Data analysis

Given the paucity of studies with comparable outcome measures, we did not perform a metaanalysis. For this reason , we undertook a narrative synthesis. Narrative synthesis is a method to synthesize research results in the context of systematic reviews , where the summary of the findings of the studies is a narrative (as opposed to a statistical summary). Usually, a narrative synthesis is used when there is too much study heterogeneity that precludes any meaningful statistical summary, as is the case for this review. [37] The primary study findings were tabulated. Similarities and differences between studies were investigated.

Results

We identified 2652 articles with our first-stage search strategy. An expert identified three further articles on the subject. The majority of studies were rejected because they did not focus on sleep, but on other health aspects related to aircraft noise. Two studies were excluded because the focus of the study was to compare rail, road and aircraft noise and the authors did not provide independent analysis of each type of noise and sleep disturbance. [38],[39] Three studies were excluded because they focused on morning-after effects rather than sleep disturbances. [39],[40],[41] Four studies were excluded because they focused specifically on the cardiovascular effects of aircraft noise and not on sleep per se. [36],[42],[43],[44] One study by Basner et al. 2008 [19] used a subsample of another published study by Basner et al. 2005. [17] However, the research question was different and hence both studies were presented in this review.

Twelve studies evaluating the relationship between aircraft noise and sleep disturbance met our inclusion criterion. Of those articles, eight were experimental studies, three were cross-sectional studies and one was an ecological study. All experimental studies involved within-subject comparison.

[Table 3] presents the biases in each of the studies of high, moderate and low quality. Four of 12 studies were classified as high quality. [17],[1]8,[20] Five were considered to be of moderate quality. [21],[22],[23],[24],[25] Three of the studies were classified as being of low quality because of important biases. [26],[27],[28] The three studies of lower quality were not evaluated further.

Two studies specifically focused on the impact of aircraft noise on sleep structure (total sleep time, SWS stage sleep time, REM stage sleep time, awakenings, etc.) [17],[19] Six studies evaluated the impact of aircraft noise levels on awakenings. [18],[19],[20],[21],[22],[23] Four studies used polysomnography to measure awakenings. [17],[18],[19],[20] Awakenings were also measured using actigraphy [23] and push buttons. [22],[23] One study measured motility as a proxy for awakenings using a seismosomnograph. [21] Sleep disturbances were evaluated by the use of sleep medication in two studies. [24],[25] Sleep quality was also evaluated in one study, but the study did not indicate whether and how the two questionnaires used had been validated. [22] Hence, it was impossible to categorize biases arising from these questionnaires and the results were not considered reliable and will not be considered in this review. This leaves nine studies for our analysis that follows.

[Table 4] presents the cities, study period, recruitment process and study objectives and [Table 5] presents noise events characteristics, measurement of sleep outcomes and findings. All high-quality studies were conducted in Germany by the same group of researchers. [17],[18],[19],[20] All studies were conducted since the 1990s. The participants in the experimental studies were generally young and healthy, with no study participant being more than 65 years. All experimental studies that described the recruitment process used volunteers. [17],[18],[19],[20],[21] Three experimental studies were conducted in the laboratory with pre-recorded aircraft noise events (ANE) that were played back. [17],[19],[20] One experimental study was conducted in the subject's home but with pre-recorded ANE that were played back, [21] and in three studies the noise was monitored indoor from outside noise events. [18],[22].[23] In addition, in one of those studies, noise was also monitored outdoors. [23] {Table 4}{Table 5}

In the two cross-sectional studies, noise contours were used to estimate noise exposure. [24],[25] Those two studies used stratification to maximize exposure to various noise levels in their recruitment process. [24],[25] One study used a postal questionnaire and reminder letters for non-responders. [24]

Concerning the objectives of the studies, five studies aimed to specifically study the impact of aircraft noise on sleep disturbance. [17],[18],[19],[20],[23] One study focused on the impact of noise on sleep, but did not specify in its objectives that aircraft noise constituted the only significant noise source. [22] One study compared the impact of the impact of noise, rail and aircraft noise on sleep parameters. [20] The two cross-sectional studies focused on the effects of aircraft noise on the use of medication, including sleep medication. [24],[25]

One study focusing on sleep structure demonstrated that increasing the number of noise events or increases in L Amax result in decreased SWS time and increased awakening frequency. [17] For example, eight ANE of 80 dB(A), 32 ANE of 70 dB(A) or 64 ANE of 65 dB(A) resulted in close to a 10-min decrease in SWS time. They also resulted in an increase in awakenings, up to eight-times, for 64 ANE of 65 dB(A). The other study focusing on sleep structure demonstrated that ANE of 45 dB(A) and 65 dB(A) result in change in sleep structure. [19] Indeed, the number of awakenings, sleep stage changes and arousal as observed by polysomnography caused by ANE increases significantly when compared with baseline nights with no noise events.

Basner et al. 2006 demonstrated that aircraft noise was associated with increased probability of awakenings. In this study, no increase in probability of awakenings was observed up to aircraft noise levels of 32.7 dB(A). [18] However, at 70 dB(A), there was a 9% increase in awakenings. These results were corroborated by two studies using polysomnography where increases in aircraft noise also resulted in increased probability of awakenings. [19],[20] Noise events were correlated with behavioural awakenings that occurred within 5 min after the noise event. [22],[23] All studies using motility measured with actigraphy and seismonosomnography as a proxy to awakenings had similar results. [21],[23] In one study, it was shown that every 1 dB increase in indoor SEL increased the probability of motility by 1.2%. [23] In Brink et al. 2008, motility was more important when subjects were exposed to 60 dB(A) noise when compared with 50 dB(A) [OR 1.03 (95% CI 1.02-1.05)]. [21] Increased ambient noise levels had effects that were opposite to those of sporadic ANE. Indeed, each 1 dB increase in ambient noise level reduced the odds of awakening in the presence of a noise event by 5%. [22]

Franssen et al. 2004 showed that ANE occurring between 22 h and 23 h were strongly associated with the use of over-the-counter sedative or sleep medication. [24] In Floud et al. 2010, the use of anxiolytics was associated with the aircraft noise level during the night (L night). [25] However, no association was found between aircraft noise and use of hypnotics. [25]

Discussion

Our systematic review demonstrates that ANE have impacts on sleep disturbances. All studies of moderate to high quality performed to date showed a positive association between increases in aircraft noise exposure and the deterioration of sleep outcomes. As the sound levels increase, the probability of awakening increases [17],[18],[20],[22],[23] and awakening times last for longer periods. [18] Individuals exposed to higher levels of noise have been shown to have shorter periods of SWS. [17] The use of over-the-counter sedative or sleep medication increased in the presence of ANE occurring in the evening. [24],[25] Hence, noise events were linked to sleep disturbance in all moderate- to high-quality studies using different designs and measures.

The night noise guidelines published by the WHO comprised a literature review that concluded that there is sufficient evidence to indicate that environmental noise exposure during sleep results in arousals, sleep stage changes, awakening, self-reported sleep disturbance and increase of medication use. Furthermore, our review complements the WHO review with an assessment of study quality. Furthermore, because the assessment of the quality of the studies on aircraft noise and sleep disturbances has never been performed before, this evaluation will be informative for the design of future studies of high quality that will cover noise and sleep disturbances.

On the other hand, Michaud et al. 2007 in their review of field studies of aircraft noise-induced sleep disturbance concluded that the methodological differences between the studies renders the interpretation of results of the studies between aircraft noise and sleep disturbances difficult. [8] The review by Michaud et al. 2007 included five studies, two of which are included in our review, and three studies that were not included in our review because they were not peer reviewed. The two studies were graded as moderate quality in our review. In addition, all of the studies reviewed by Michaud et al. 2007 monitored awakenings with actigraphy, questionnaires or push button. None of the studies reviewed used polysomnography to measure awakenings. Hence, all of the studies reviewed used sleep measurement methods with a low positive-predictive value to measure awakenings, leading to non-differential misclassification biases. If there is a true effect of noise on awakenings, such non-differential misclassification biases would lead to an underestimation of the true effect, which is possibly why Michaud et al.'s 2007 results are difficult to interpret. Our review is more comprehensive as it attempted to cover different types of sleep disturbances, to include studies that used polysomnography and to include more high-quality studies. However, even with our results, risk quantification is difficult given that different methods were used in each study.

In our methodology, we assessed the quality of studies and then only reviewed those of the high- and moderate-quality studies. This review is subject to several limitations. First, in the high-quality studies reviewed, individuals were individuals with no chronic diseases and were aged between 18 and 65 years. Hence, the results of this systematic review cannot be generalized to children or to the elderly. All high quality studies were derived from one group of researchers; it would give further credence to these findings if similar results were found by a different team of independent researchers. Only articles written in French or English were reviewed; there is some literature on aircraft noise and sleep that was written in German and hence some important findings may have been missed. Of course, as in any systematic review, there is the possibility of "publication bias," namely that studies with inconclusive or null results were not published. Another limitation pertains to the fact that, using the best-synthesis approach, we only reviewed studies of high and moderate quality. However, there were only three studies that, according to our criteria, were of poor quality and were excluded. Their inclusion would not have changed our conclusions. Finally, we classified study quality in high, moderate and low quality. Our classification is subjected to debate, especially for studies categorized as moderate. There are no gold standards for the rating of studies. Hence, it is possible that other authors will not rate studies like we did. However, we are confident that our approach is useful in discerning what constitutes good, moderate or poor evidence.

There are many gaps in our knowledge that need to be further investigated. Most of the high-quality studies were experimental studies performed in healthy young individuals. Further research is thus necessary to better characterize the impact of aircraft noise on total sleep time, awakenings, SWS stage sleep time and REM stage sleep time using L Night noise metrics in older individuals or individuals with chronic diseases. The role played by annoyance in sleep disturbances should also be better characterized. Indeed, the studies by Floud et al. 2010 indicated that there might be differential sensitivity to noise that may result from annoyance. [25] Morning-after effects should be systematically reviewed. New evidence is also emerging from recent and ongoing studies that may link sleep disturbance with cardiovascular health. [36],[43],[44] There is still a lot of uncertainty regarding the threshold noise levels at which individuals start to awaken. Furthermore, there is a need to document the influence of background noise on aircraft noise effects. Based on high-quality evidence, the best available estimation of the dose-response curve is presented in the Basner et al. 2006 study and could be used for modelling the impact of aircraft noise on sleep. [18] However, some uncertainty persists for the exact dose-response curve, both for awakenings and for the duration of awakenings, especially for individuals older than 65 years and for individuals with chronic diseases. Research is also needed to better identify which sound level and duration will affect the duration of awakenings and have acute or chronic impacts on health.

Conclusion

There is evidence of a causal association between exposure to night time aircraft noise and the following sleep disturbances: increased awakenings, increased motility, decreased SWS time and non-prescribed sleep medication. However, there are many research gaps that were identified. There is a need for further research on the effect of aircraft noise on sleep disturbance for individuals aged more than 65 years and for individuals with chronic diseases and pre-existing sleep disorders.

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