Markov State Transition Models for the prediction of changes in sleep structure induced by aircraft noise

Mathias Basner[1,3*], Uwe Siebert[2,3]

1 German Aerospace Center (DLR), Institute of Aerospace Medicine, 51170 Köln, Germany

2 Department of Public Health, Medical Decision Making and Health Technology Assessment, UMIT, Eduard Wallnöfer-Zentrum I, 6060 Hall i.T., Austria

3 Institute for Technology Assessment and Department of Radiology, Massachusetts General Hospital, Harvard Medical School, Boston, MA, USA

* corresponding author: e-mail: mathias.basner@dlr.de

ABSTRACT

OBJECTIVES: To quantitatively assess the effects of the introduction of a nocturnal air traffic curfew at Frankfurt Airport on sleep structure.

METHODS: A six state (Wake, S1, S2, S3, S4 and REM) Markov state transition sleep model was built. Transition probabilities between states were calculated with autoregressive multinomial logistic regression based on polysomnographic laboratory study data. Monte Carlo simulation trials were performed for modelling a noise-free night and three noise scenarios: (1) traffic at Frankfurt Airport on 16 August 2005, (2) as (1), but flights between 11 pm and 5 am cancelled and (3) as (2), with flights between 11 pm and 5 am from (1) rescheduled to periods before 11 pm and after 5 am.

RESULTS: The results indicate that there will be a small benefit for airport residents compared to the current situation even if all traffic is rescheduled (average time spent awake -3.2 %, S1 -4.6 %, S2 -0.9 %, S3 +3 %, S4 +9.2 %, REM +0.6 %, number of sleep stage changes -2.5 %). This benefit is likely to be outweighed by the increase in air traffic during shoulder hours, especially for those who choose to or have to go to bed before 10:30 pm or after 1 am.

CONCLUSIONS: Alternative strategies might be necessary to both guarantee undisturbed sleep of airport residents and to minimize economic and legal disadvantages accompanied by a traffic curfew. The models developed in this investigation may serve as a valuable tool for optimizing air traffic patterns at airports, and therefore guide political decision making.

INTRODUCTION

Aircraft noise may cause changes in sleep structure and impair recuperation. People living in the vicinity of airports are very concerned about possible short- and long-term effects of a chronically disturbed sleep on health. Frankfurt Airport plans to build a new runway in order to meet increasing traffic demands. The airport applied for a ban of air traffic between 11 pm and 5 am in order to compensate people living in the highly populated vicinity of Frankfurt Airport for increased traffic volumes during the day. Some of the flights starting or landing between 23:00 and 05:00 today are likely to be rescheduled to periods before 23:00 or after 05:00. Therefore, it is unclear whether and to what extend sleep of airport residents will benefit from an air traffic ban in the night.

OBJECTIVES

To quantitatively assess the impact of the introduction of a ban of air traffic at Frankfurt Airport between 23:00 and 05:00 on sleep structure using epidemiological and decision-analytic methods. The main question was whether a ban of air traffic will still be beneficial for residents in terms of sleep structure if all nighttime air traffic is rescheduled to periods before 23:00 and after 05:00.

METHODS

Analyses were based on a polysomnographical laboratory study on the effects of aircraft noise on sleep performed at the German Aerospace Center (DLR) in Cologne between 1999 and 2003 (Basner et al. 2004; Basner & Samel 2005). A six state (sleep stages Wake, 1, 2, 3, 4 and REM) Markov state transition model was used to simulate nights with and without aircraft noise. Transition probabilities for the Markov models were calculated with autoregressive multinomial logistic regression (de Vries et al. 1998). Both regression and simulation results were validated with empirical data. Different times of falling asleep were considered in the analyses. The outcome variables "time spent in the different sleep stages", and "number of sleep stage changes". Three noise scenarios were compared with a noise-free night and with each other:

(1) **Scenario 1 (Noise)**: the current situation in Frankfurt with nocturnal air traffic,

(2) **Scenario 2 (Ban)**: a ban of air traffic between 23:00 and 05:00, and

(3) **Scenario 3 (Rescheduled)**: as (2), but with flights that took place between 23:00 and 05:00 in (1) rescheduled to periods before 23:00 and after 05:00.

RESULTS

A first-order autoregressive multinomial logistic regression model with elapsed sleep time as the only additional explanatory variable was used for the calculation of transition probabilities. Monte Carlo simulation trials showed that a ban of air traffic without rescheduling of flights lead to sleep structural improvements. These were diminished if 2005 traffic that took place between 23:00 and 05:00 was rescheduled to periods before 23:00 and after 05:00, but still, a small benefit remained: Compared to the 2005 situation without a ban of air traffic, average time spent awake decreased from 43.1 to 41.7 min (-3.2 %), S1 decreased from 9.2 to 8.7 min (-4.6 %), S2 decreased from 212.8 to 210.8 min (-0.9 %), S3 increased from 37.2 to 38.3 min (+3.0 %), S4 increased from 23.5 to 25.7 min (+9.2 %), REM increased from 84.7 to 85.3 min (+0.6 %), the number of sleep stage changes decreased from 121.3 to 118.3 (-2.5 %, see Table 1).

Table 1: Expected values of simulation trials for the four noise conditions. Weighted averages are shown, taking into account the distribution of times of falling asleep in a German adult population. Empirical 2.5 and 97.5 percentiles are given in parenthesis.

Variable	No Noise	Noise	Ban	Rescheduled
Wake [min]	**35.5** (19.5, 54)	**43.1** (26.2, 62.8)	**40.0** (23.1, 59.5)	**41.7** (24.9, 61.1)
S1 [min]	**7.2** (2.5, 13)	**9.2** (3.8, 15.7)	**8.3** (3.3, 14.7)	**8.7** (3.7, 15.2)
S2 [min]	**210.9** (155.5, 264)	**212.8** (161.8, 262.2)	**211.2** (158.9, 261.8)	**210.8** (158.7, 261.5)
S3 [min]	**40.4** (19, 65.5)	**37.2** (17.7, 60.6)	**38.9** (18.4, 63.4)	**38.3** (18, 62.3)
S4 [min]	**28.6** (5.5, 61.5)	**23.5** (2.2, 53)	**26.3** (5.1, 57.9)	**25.7** (2.9, 57)
REM [min]	**87.9** (38, 145.5)	**84.7** (38, 139.1)	**85.8** (37.9, 142.2)	**85.3** (37.6, 141.1)
Number of Sleep Stage Changes	**107.2** (84, 131)	**121.3** (96.4, 146.9)	**115.7** (91.3, 140.8)	**118.3** (93.5, 143.8)

These results were weighted according to the number of people falling asleep at specific times. In contrast to that, unweighted results showed that the impact of the time of falling asleep on sleep structure was much stronger than the traffic scenario itself. For example, the largest difference in time spent awake was observed within scenario 3 (Rescheduled), where it increased from 38.2 min when falling asleep at 23:15 to 57.9 min (+51.5 %) when falling asleep at 20:45 (see Figure 1).

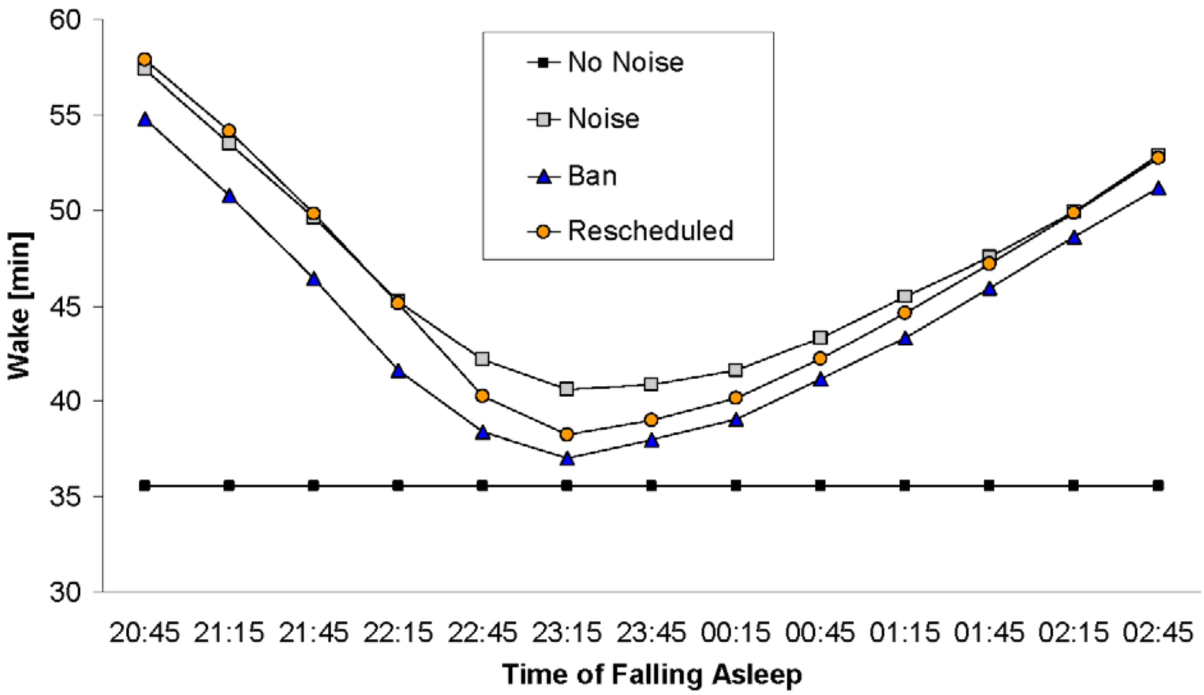

Figure 1: Time spent awake depending on traffic scenario and on time of falling asleep

DISCUSSION

If a ban of air traffic between 23:00 and 05:00 is introduced at Frankfurt Airport, our models indicate that it will be beneficial for sleep structure of affected people even if all traffic is rescheduled to periods before 23:00 and 05:00 (a worst case scenario). However, the expected benefits are rather small. At the same time, the results of the analyses stress the importance of air traffic during shoulder hours, which will increase in case of an expansion of Frankfurt Airport, both because of a general increase of traffic and because of flights rescheduled from the period between 23:00 and 05:00. Several limitations have to be borne in mind for the interpretation of the results, which are discussed in detail elsewhere (Basner 2006).

CONCLUSIONS

The results indicate that the small sleep structural benefits of the introduction of a noise-free period between 23:00 and 05:00 are likely to be outweighed by far by the impact of air traffic during shoulder hours. Simultaneously, a ban of air traffic between 23:00 and 05:00 will be accompanied by severe economic and legal disadvantages. Therefore, alternative strategies might be necessary to both guarantee undisturbed sleep of airport residents and to minimize economic and legal disadvantages. The models developed here may serve as a valuable tool for optimizing air traffic patterns at airports, and therefore guide political decision making.

A detailed report of the study can be found here (Basner 2006):

http://www.dlr.de/me/Portaldata/25/Resources/dokumente/flugphysiologie/FB_2006-07_markov.pdf

REFERENCES

Basner M (2006). Markov state transition models for the prediction of changes in sleep structure induced by aircraft noise. FB 2006-07. Köln: Deutsches Zentrum für Luft- und Raumfahrt (DLR).

Basner M, Samel A (2005). Effects of nocturnal aircraft noise on sleep structure. Somnologie 9: 84-95.

Basner M, Buess H, Elmenhorst D, Gerlich A, Luks N, Maaß H, Mawet L, Müller EW, Müller U, Plath G, Quehl J, Samel A, Schulze M, Vejvoda M, Wenzel J (2004). Effects of nocturnal aircraft noise (Vol. 1): Executive summary. FB2004-07/E. Köln: Deutsches Zentrum für Luft- und Raumfahrt (DLR).

de Vries SO, Fidler V, Kuipers WD, Hunink MG (1998). Fitting multistate transition models with autoregressive logistic regression: supervised exercise in intermittent claudication. Med Decis Making 18: 52-60.