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ORIGINAL PAPER

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Noise perception, heart rate and blood pressure in relation to aircraft noise in the vicinity of the Frankfurt airport

Abstract The aim of this study was to evaluate subjective noise perception and objective parameters of circulation in the vicinity of the Frankfurt airport. Two areas were selected in which aircraft noise was the predominant source of noise (and was) created by planes induced by take off but not during landing. Data of residents living in the two areas were observed over a period of twelve weeks, one area being exposed to air traffic noise for three quarters of the given time, the other for one quarter of the time. *Methods* Fifty three volunteers (age 50–52±15 y) monitored their blood pressure and heart rate over a period of three months by using an automatic device with digitized readings. They also protocolled their own subjective perception of noise and sleep quality. Thirty one probands were living West of the airport (West group) and were exposed to a nocturnal equivalent continuous air traffic noise level of $L_{eq(3)} = 50$ dB(A) outside, during flight direction 25 to the West. Twenty two probands were living East of the airport (East group) and were exposed to $L_{eq(3)} = 50$ dB (A) during flight direction 07 to the East. During the opposite flight directions air craft noise corresponded to $L_{eq(3)} = 40$ dB(A) in both areas. Frankfurt airport operates direction 25 for about 75% of the time on average and direction 07 for 25% of the time. *Results* The average blood pressure was significantly higher in the West group with higher noise exposure. Morning systolic blood pressure was 10 mmHg and diastolic pressure 8 mmHg higher in the West group. Throughout the observation period, the East group showed a parallel between daily changes in noise and subjective noise perception. In the West group such a parallel did not appear. This reaction was considered to be the consequence of the high noise exposure of the West group. *Conclusion* It is concluded that a population exposed to a nocturnal equivalent continuous air traffic noise level of $L_{eq(3)} = 50$ dB(A) for three quarters of a given time has a higher average blood pressure compared to a population exposed to the same equal energy noise level for only one quarter of the time. Within the East group a parallel between noise exposure and noise perception was observed, while in the West group this parallel did not appear. The difference is considered to be the consequence of higher noise stress levels in the West group. The data are in accordance with recent epidemiological studies and indicate that a nocturnal aircraft noise of $L_{eq(3)} = 50$ dB(A) can have negative effects on subjective noise perception and on objective parameters of circulation.

Key words noise research – noise perception – annoyance – hypertension – stress reaction

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Introduction

In a cross sectional study performed in the vicinity of the Stockholm airport an increased incidence of arterial hypertension as a consequence of aircraft noise could be demonstrated [1]. With a time weighted equivalent continuous aircraft noise level of FBN >55 dB(A) the incidence was increased by a factor of 1.6, in comparison to noise levels below FBN=50 dB(A). In Berlin a cross sectional study performed over a period of two years showed an increasing number of persons requiring medical treatment since they developed arterial hypertension [2]. The factor of increase was 1.9 with a nocturnal noise level of $L_{eq(3)}=55$ dB(A) for road noise outside, in comparison to noise levels below $L_{eq(3)}=50$ dB(A). For an outside road noise level of 55 dB(A) and with an open bedroom window the relative risk rose to 6.1.

In a Swedish study published by Öhrström et al. in 2005 a significant increase in the incidence of hypertension, and in the use of anti-hypertensive drugs, in relation to traffic noise was observed in men living for ten or more years in the same flat. The rise in hypertension began at a 24 h equivalent continuous noise level of $L_{eq(3)}=55$ dB(A) outside [3].

These and other results [4–15] have raised concern about tolerable noise levels. A rise in blood pressure can lead to serious health problems due to the fact that arterial hypertension is one of the most significant risk factors in incidents of strokes and myocardial infarction. Because 50% of the general population in Western societies is faced with cardiovascular diseases and will finally die from them, any increase in the prevalence of hypertension could have epidemic consequences. Recent studies have shown that even a rise in blood pressure within the "normal" range by 10 mmHg can influence cardiovascular prognosis leading to twice as many myocardial infarctions and strokes compared to people with optimal blood pressure [16, 17].

Aim

The present study aims to investigate whether, in the vicinity of the Frankfurt airport, one of the largest continental European airports, modest aircraft noise may have an influence on subjective noise perception, heart rate and blood pressure.

It was asked whether, during an observation period of twelve weeks, correlations exist between objective noise, subjective noise perception, perception of sleep quality, heart rate and blood pressure. In addition it was asked whether differences in the above parameters exist between residents living West and East of the Frankfurt airport, which predominantly operates in the westerly direction.

Methods

Characteristics of the two residential areas and determination of noise levels

Residential areas were selected with air traffic noise being the predominant source of noise. Average noise levels were taken from official maps edited by the Hessian environmental office (Hessisches Landesumweltamt). Two areas were selected: one West and one East of the airport, both with nocturnal aircraft noise levels of $L_{eq(3)}=50$ dB(A) outside. This level was present during direction 25 in the West and during direction 07 in the East. In contrast, during direction 07 the West area was exposed to $L_{eq(3)}=40$ dB(A) and during direction 25 the East area to $L_{eq(3)}=40$ dB(A) only. Daytime noise levels in both areas were about 5 dB(A) higher than night time noise levels, with similar differences between the two flight directions. The difference in noise levels depending on the air traffic's direction was due to the fact that in the selected living areas planes had different routes depending on whether they were taking off or landing. In both areas noise was predominantly created by planes taking off.

Daily noise levels were determined by the air traffic's direction in relation to the airport, along with data edited in the official "aircraft noise report" (Fluglärmreport) by the Frankfurt Airport (Fraport). Measured data was available for the daily average of 24 hours for both air traffic directions. Beyond this, the average measured data on flight patterns per month were also available for comparison.

Participants

Voluntary male and female probands were recruited in both residential areas. Participants had to have been living in each of the respective areas for a longer time, they were required to be at home at least during the night time, and be willing to cooperate for a period of 12 weeks. Noise created by air traffic had to be the predominant source of noise in each individual's experience. Shift work, frequent absences from home or frequent travel were considered criteria for exclusion. The intention was to recruit 25 people in both groups.

Training

After confirmation of the individual's addresses being located in the respective noise corridor, all participants were visited in their flats. They were informed that the study consisted of daily measurements of heart rate and blood pressure as well as daily protocol notes, and this over a period of 12 weeks.

General information about circulation was given and several measurements with an automatic device (Visomat Uebe Company) were performed in the presence of the investigator. Possible sources of error were demonstrated in detail.

Measurements and protocols

Probands were requested to take measurements and protocol the results of heart rate and blood pressure every morning and evening. In addition they were asked to write down daily notes about their own subjective perception of loudness of noise as well as of quality of sleep. Noise perception was graded as "silent", "medium" or "loud", sleep quality as "good", "medium" or "bad".

All participants had to fill in a questionnaire about their history of diseases, medication, general perception of noise, sleeping with open, hinged or closed windows etc.

Information

Participants were informed about the voluntary character of this study. Termination of cooperation would be possible at any time and without any consequences. Handling of participants data was stringent in agreement with the standards required by German law. Publication would occur without the appearance of any personal data. All personal data would be destroyed at the end of study. All participants had the opportunity to ask questions. Finally an informed consent was signed.

Handling of data – statistics

All notes on perception of noise and sleep quality and all data from measurements were taken from the protocols and stored electronically for analyses, including the use of statistic program-packages (e.g. SPSS 12).

The descriptive statistics contain the average measurements for each individual, average measurements for the two groups as well as for the three months, with standard deviations.

Group differences were tested with the student t-test. Correlations were calculated using Pearson coefficients. Cross correlations were made for the comparison of changes in noise with perception of noise, heart rate and blood pressure.

Results

Observation periods

The study was started in October 2002. In December when there was a spell of very cold winter weather, so that some of the participants may have closed their windows, the study was interrupted and continued in April and May 2003. Since in October 2002 not all participants from the East group were included, these probands were followed until June 2005.

Groups

All participants were exposed to nocturnal aircraft noises of 50 or 40 dB(A) respectively, except for one participant from the West group, who lived in an area with 50 dB(A) during flight direction 25 but with only 30 dB(A) during direction 07. Thirty-one participants living in the West group and twenty-two in the East group were included. All participants finished the study. Anthropometrical data in both groups showed no essential differences (Table 1).

Table 1 Anthropometrical data

	N	male	Years (range)	Year ave ± s	Size aver±s	Weight ave ±	BMI ave ±
West group	31	45%	14–71	50±15	170±10 cm	73±15 kg	25±4
East group	22	36%	26–76	52±15	170±9 cm	73±16 kg	25±5

Ave – average; *s* – standard deviation

Table 2 Sleeping with open, hinged or closed windows and share of smokers

	Sleeping with windows			Share of smokers
	open	hinged	closed	
West group	13%	68%	19%	9.7%
East group	14%	64%	23%	13.6%

Table 3 Medical history and medication

	Hyper-tension	Myocardial infarction	Dia-betes	Beta-blocker	ACE inhib.	Other medic.	None
West group	26%	3.2%	3.2%	19%	6.5%	23%	52%
East group	14%	4.5%	4.5%	0%	9%	45.5%	45.5%

Questionnaire

General sensitivity to noise was noted more often in the West than the East group: sensitivity to noise was claimed by 65% of the West group, compared to 36% of the East group.

With regard to sleeping with open, hinged or closed windows and to smoking habits, no relevant differences were apparent (Table 2).

With regard to medical history and medication there were more probands with hypertension and anti-hypertensive medication (beta-blockers) in the West group (Table 3).

Completeness of data

From the twelve week period a total of 5496 measurements from the West as well as a total of 3446 measurements from the East group were expected. There were 454 missing measurements in the West group corresponding to 8.3% and 222 missing measurements in the East group corresponding to 6.4%. In the vast majority the reason for not performing measurements was absence from home at the time. Thus a total of 8,266 measurements could be analyzed plus an equal number of protocol notes about noise perception.

Relation between daily changes in noise levels, noise perception, perception of sleep quality, heart rate and blood pressure

During some periods of time, close parallels could be drawn between daily noise levels taken from the "Aircraft noise report" (Fluglärmreport) and the perception of aircraft noise in the East group. An example of this can be seen in Fig. 1 during the month of November: In the first half of the month with flight direction 25, noise exposure of the East group was low. This corresponded with the perception of silent nights by almost all participants in the East group. With the change in traffic direction to the East (07) in the middle of the month, medium or loud noise perception was noted from about 50% of participants in the East group.

In the West group corresponding mirror-like noise perception in periods with loud or low noise was not apparent. As seen in Fig. 2, a positive correlation between the number of take offs and a perception of loud noise was present in the East group with a determination coefficient of R^2 being 0.3. The correlation for the West group was also significant but in contrast to the East group only barely, with R^2 equal to 0.067. As seen in Table 4, significant correlations were also present in the East group between take offs and blood pressure (morning systolic pressure trend, morning diastolic, evening systolic and evening diastolic significant) as well as for take offs and heart rate (evening). Again, the West group showed only insignificant values except for diastolic blood pressure in the evening.

A cross reference of the two groups showed differences in the correlation between changes in noise perception and changes in actual aircraft noise exposure. Cross reference of the amount of take offs and noise perception revealed a significant correlation in the East group but not in the West group. From Fig. 3 it can be seen that in the East group a significant decrease in the perception of silent nights takes place in correspondence to the days with higher aircraft noise exposure. In the West group however no clear changes, uniform trends, or any remarkable correlations to "noisy" days were present.

Similarly, a pattern in the correlation between subjective perception of quality of sleep and aircraft noise exposure was present in the East group, although no such remarkable correlation existed in the West group.

With regard to measurements of circulation parameters, during some periods a relationship between objective noise and blood pressure was obvious. Fig. 4 gives an example from the East group during the month of June. In the middle of the month and at the end there were periods of noise in the East created by flight direction 07. Subjective noise perception paralleled the noise curve. Apparently the second burst of noise created more annoyance as compared to the first although the amount of noise was similar. Systolic blood pressure increased slightly with the first peak but markedly with the second peak. The same was true for diastol-

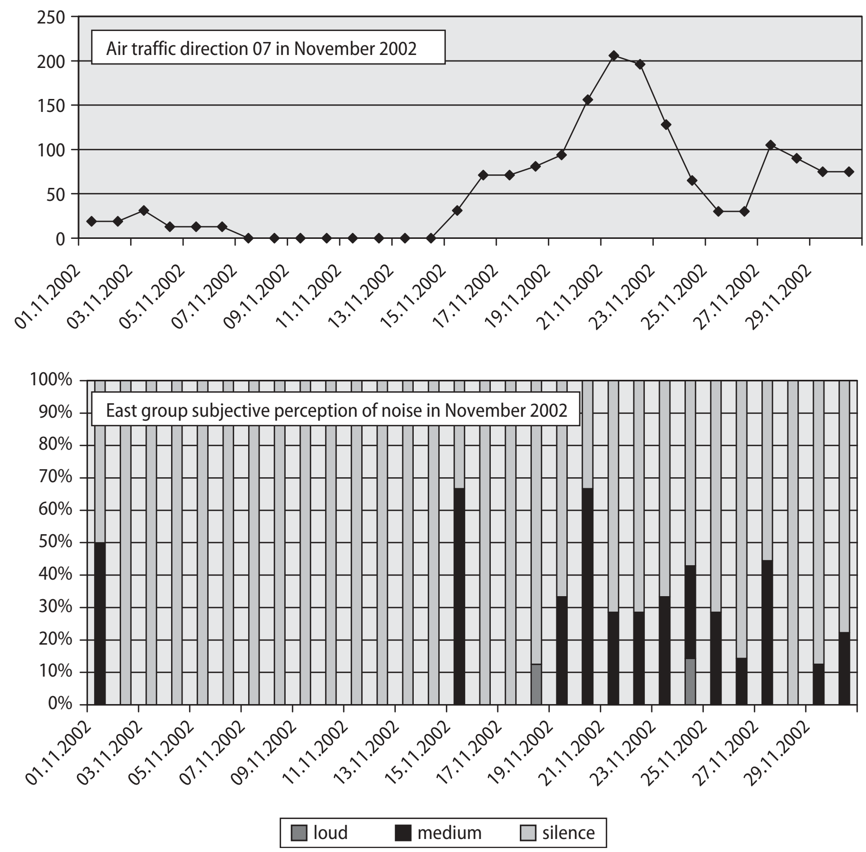

Fig. 1 Objective noise (above) and subjective noise perception (below) from the East group in November 2002. Flights to the East (traffic direction 07) were used only in the second half of the month. With the noise beginning on November 15, the perception of mean or loud noise started, while in the first half of the month noise was perceived as silent by all participants of the group, except for one day

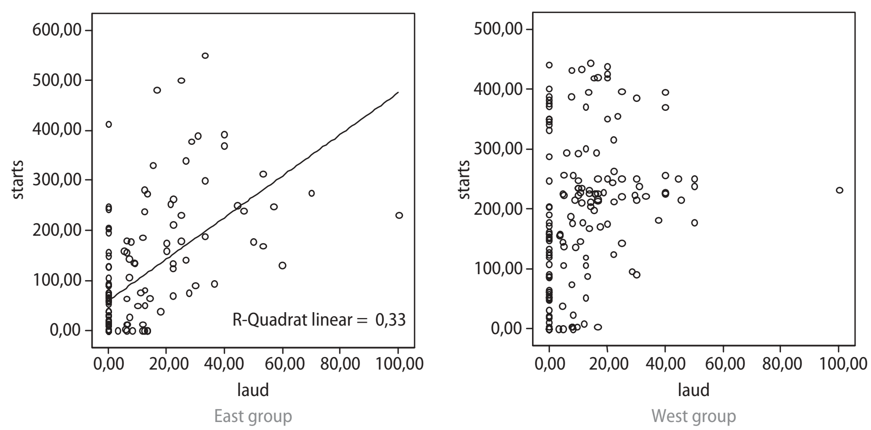

Fig. 2 The correlation between number of starts per day and loudness of subjective noise perception. While in the East group a positive correlation with a determination coefficient of R^2 of 0.3 was present, in the West group the correlation is weak with a determination coefficient of R^2 equal to 0.067 only

ic pressure. The correlations seen in Table 4 show the most significant correlations predominantly in the East group.

Relation between monthly changes in noise level, noise perception, heart rate and blood pressure

Monthly average noise levels were derived from the corresponding flight directions. On average the flight directions in Frankfurt are in direction 25 for about 75% of the time and direction 07 for 25% of the time, i.e. take off direction to the West being most predominant. Thus the West group was exposed to loud noise more often and over remarkably longer periods of time. During the observation period measurements in October and November were fairly consistent with an average value of 17% in direction 07 in October and 22% in November. In the short observation period from December 1–10, the pre-

Table 4 Correlations between number of daily take offs to the East (07) or to the West (25) respectively with subjective noise perception, quality of sleep, blood pressure (*sm* systolic morning, *dm* diastolic morning, *sev* systolic evening, *dev* diastolic evening) and heart rate (*m* morning, *ev* evening). Pearson coefficients and significance for East and West group

	Noise perception		Quality of sleep		Blood pressure				Heart rate	
	loud	low	good	bad	sm	dm	sev	dev	m	ev
East	0.575	–0.532	–0.229	0.221	0.156	0.243	0.202	0.190	ns	0.190
2p	0.000	0.000	0.005	0.007	0.058	0.003	0.013	0.020		0.020
West	0.259	–0.235	–0.171	ns	ns	ns	ns	0.295	ns	ns
2p	0.001	0.004	0.037					0.000		

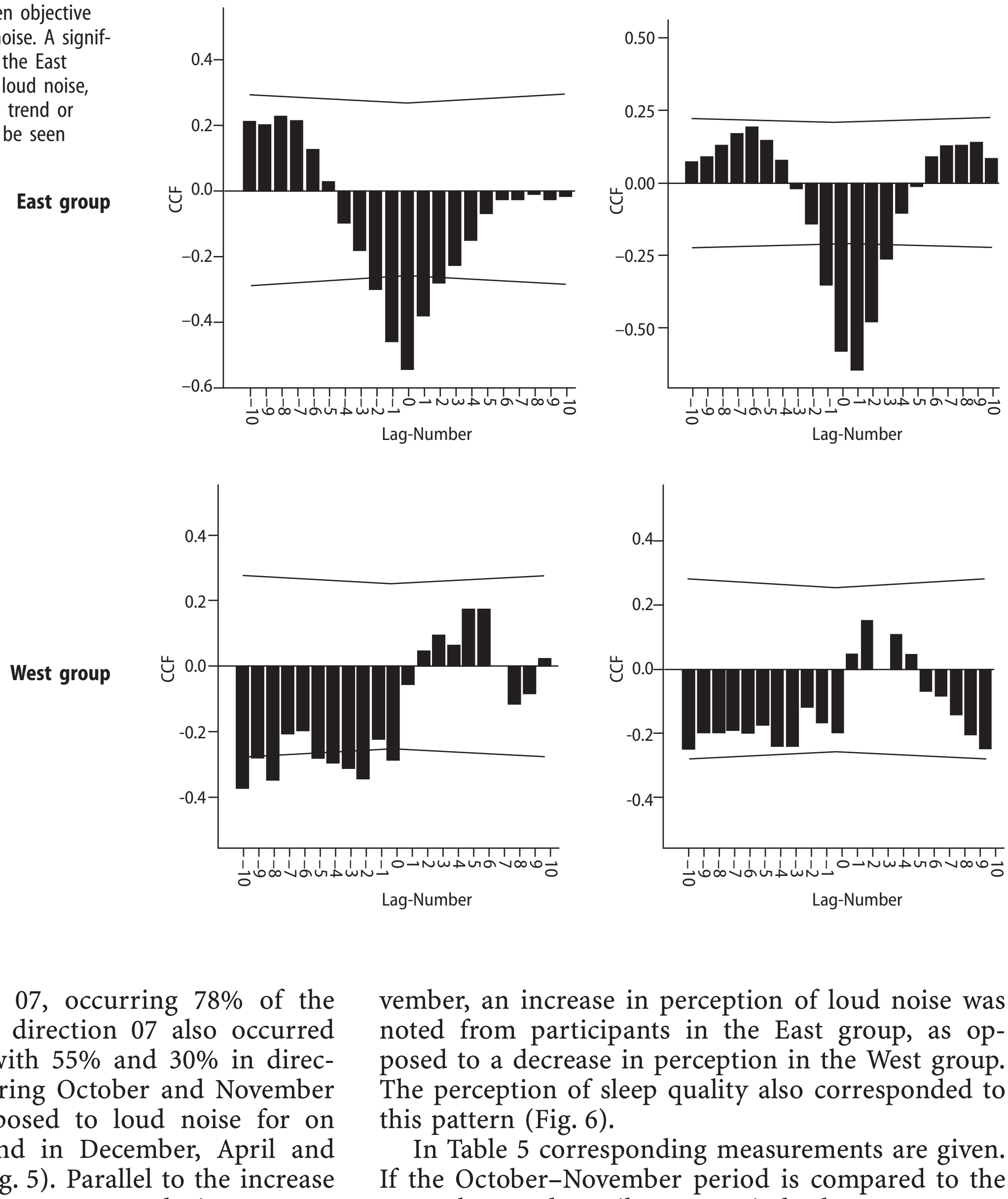

Fig. 3 The cross correlation between objective noise and subjective perception of noise. A significant negative correlation is seen in the East group corresponding to the days of loud noise, while in the West group no uniform trend or correlation to the days of noise can be seen

dominant direction was 07, occurring 78% of the time. In April and May direction 07 also occurred more often than usual with 55% and 30% in direction 07, respectively. During October and November the East group was exposed to loud noise for on average 19% of time and in December, April and May for 42% of time (Fig. 5). Parallel to the increase in noise exposure of the East group during December, April and May, as opposed to October and November, an increase in perception of loud noise was noted from participants in the East group, as opposed to a decrease in perception in the West group. The perception of sleep quality also corresponded to this pattern (Fig. 6).

In Table 5 corresponding measurements are given. If the October–November period is compared to the December and April–May period, the West group presents with a decrease in the perception of "loud"

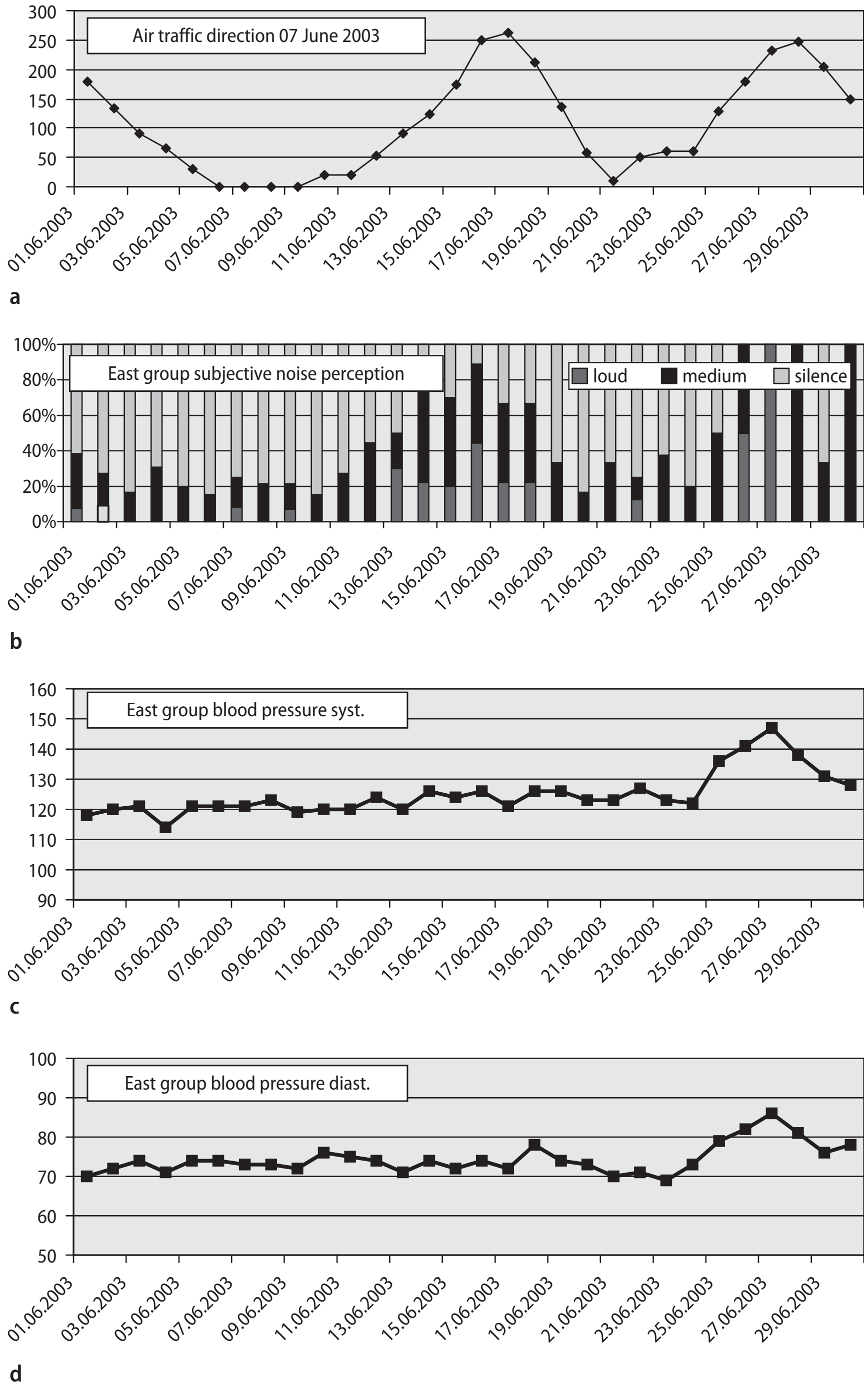

Fig. 4 Objective noise (**a**), subjective noise perception (**b**), systolic (**c**) and diastolic (**d**) blood pressure in the East group in June 2003. Between noise and noise perception a parallel is apparent. The second burst of noise was perceived as louder than the first despite the equal intensity in objective noise. Systolic and diastolic pressure shows an increase particularly in relation to the second burst of noise

and an increase in the perception of "silent", while, during the same periods, the East group reveals an increase in "loud" and a decrease in "silent" in a mirror-like behaviour. The increase in perception of loud noise noticed in the East group with increased aircraft noise exposure was proportionally stronger, compared to the decrease in perception of loud noise with decreased noise exposure in the West group. Likewise, a similar behavior was seen with regard to the quality of sleep (Table 6).

The average measurements of blood pressure from October–November compared to those from December and April–May showed a decrease in the West and an increase in the East group. This occurred in parallel with the average increase in percent of flight in direction 07 and the decrease in

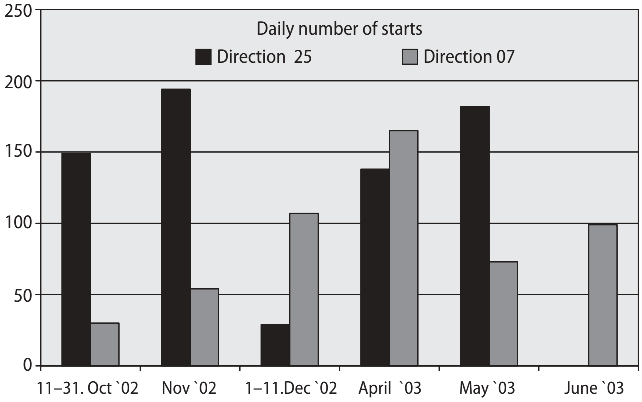

Fig. 5 Traffic direction of the Frankfurt airport within the observation periods. In October and November 2002 the normal distribution with about 25% direction 07 to the East and about 75% direction 25 to the West was present. In December however direction 07 was predominant and in April and May it was also used more often and over longer periods than usual

flights in direction 25 in the respective months (Figs. 5 and 6). The average values of subjective noise perception and of subjective perception in sleep quality stood in direct relation to changes in objective noise and to blood pressure. All values showed a proportionally stronger change in the East compared to the West group (Fig. 6).

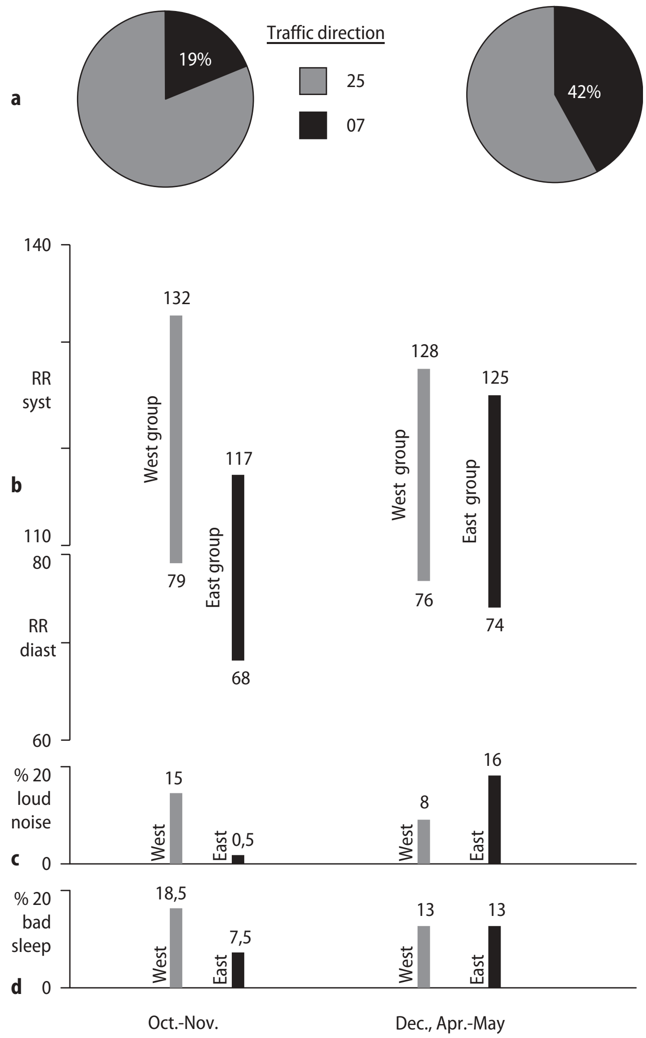

Fig. 6 Average values in traffic directions (**a**), blood pressure (**b**), noise perception (**c**) and perception of sleep quality (**d**) from October–November 02 compared to average values from December 02 and April–May 03. With the increase in traffic direction 07 from 19% to 42% and a corresponding decrease in traffic direction 25 a decrease in the average blood pressure in the West group and an increase in the East group occurred. Noise perception and perception of sleep quality occurred in parallel, the amount of change being proportionally smaller in the West group compared to the East group

Comparison of West and East group with monthly noise levels.

During the time when the groups were compared the average systolic and diastolic pressure in the mornings was higher in the West group (Fig. 7). The differences were highly significant (systolic pressure 10 mmHg (4–15), diastolic pressure 8 mmHg (5–16)). If all participants with hypertensive blood pressure values (three from the East and eight from the West group) were excluded from evaluation, differences were smaller but remained significant (systolic

Table 5 Aircraft noise perception

	West group				East group			
	n	loud (%)	medium (%)	silent (%)	n	loud (%)	medium (%)	silent (%)
October	19	24	39	37	2	0	47	53
November	31	12	38	50	12	1	16	83
December	30	10	33	57	12	24	35	41
April	22	5	32	63	18	12	31	57
May	15	12	38	50	15	15	28	57
June	–	–	–	–	9	10	28	62

Table 6 Quality of sleep

	West group				East group			
	n	good (%)	medium (%)	bad (%)	n	good (%)	medium (%)	bad (%)
October	19	38	41	21	2	71	24	5
November	31	42	43	15	12	57	33	10
December	30	42	45	13	12	45	42	13
April	22	46	40	14	18	53	32	15
May	15	45	44	11	15	55	34	11
June	–	–	–	–	9	63	27	10

pressure 7 mmHg (3–11), diastolic pressure 4 mmHg (2–12)).

The measurements in the evening showed a similar pattern, but a complete disappearance of the differences between the two groups occurred in April and May.

Discussion

Equivalent continuous noise levels ($L_{eq(3)}$) expressed as dB(A) are considered as useful parameters for the comparison of different noise levels. Additional prerequisites for comparison are comparable frequencies and loudness of single events particularly during the night. Even characteristics of noise such as noise created by planes after take off or noise before landing may lead to differences in subjective noise perception [42]. For the present study, therefore, it is important that between the two groups the only difference was frequency and duration of noise exposure. On the other hand an essential part of the evaluation is based upon comparison within the groups.

The measurements were performed by the participants themselves with an automatic devise with digitized readings of the values for systolic as well as diastolic pressure and heart rate. Thus the "white coat effect" was avoided [18–24].

Subjective influences on measured values were minimized by the digitized readings. In addition the participants had no assumption about the presumable results. Participants from the West group did not know participants from the East group. All probands entering the study performed the measurements throughout the study period of twelve weeks.

The study was designed to compare objective changes of noise levels with changes in subjective perception of noise [25–28] and in objective parameters of circulation. Although the study was based on noise levels during the night, the influence of noise during the day can not be excluded. Equivalent continuous noise levels during the day time in the two investigated residential areas are about 5 dB(A) higher than during the night, both levels being dependent on flight directions. A sharp distinction between aircraft noise at night and during the day was not possible on a daily basis, since only average daily noise levels from 0–24 h were known.

It may be assumed however that the morning values of heart rate and blood pressure were predominantly influenced by the noise during the preceding night in contrast to the evening levels, probably more influenced by daytime noise. During the day participants were partially exposed to other noise sources from outside the home. Thus the relation of the morning values to the noise levels, as well as the longer persisting differences in the morning values between the East and West groups, appears to underscore the importance of noise at night.

The observation of different perceptions of daily changes in noise in the West and East groups deserves explication. It is evident from this study that residents living in the selected area West of the Frankfurt airport were exposed to more and longer periods of noise compared to residents living in the selected area East of the airport. In addition to the difference in average blood pressure between the groups, a difference was also documented with regard to subjective perception of changes in noise levels. While the East group promptly reacted to changes in noise levels, the West group showed reduced or completely non-existent relationships between noise levels and noise perception. Apparently the participants in the West had reached a higher level of stress in which they were no longer able to perceive periods of less noise as being any different from louder periods. Due to the higher amount of equivalent continuous noise levels in the West group, the ability to perceive periods of less noise as more silent was absent.

The observed pattern may be the consequence of an overstimulation of the sympathetic system [29–

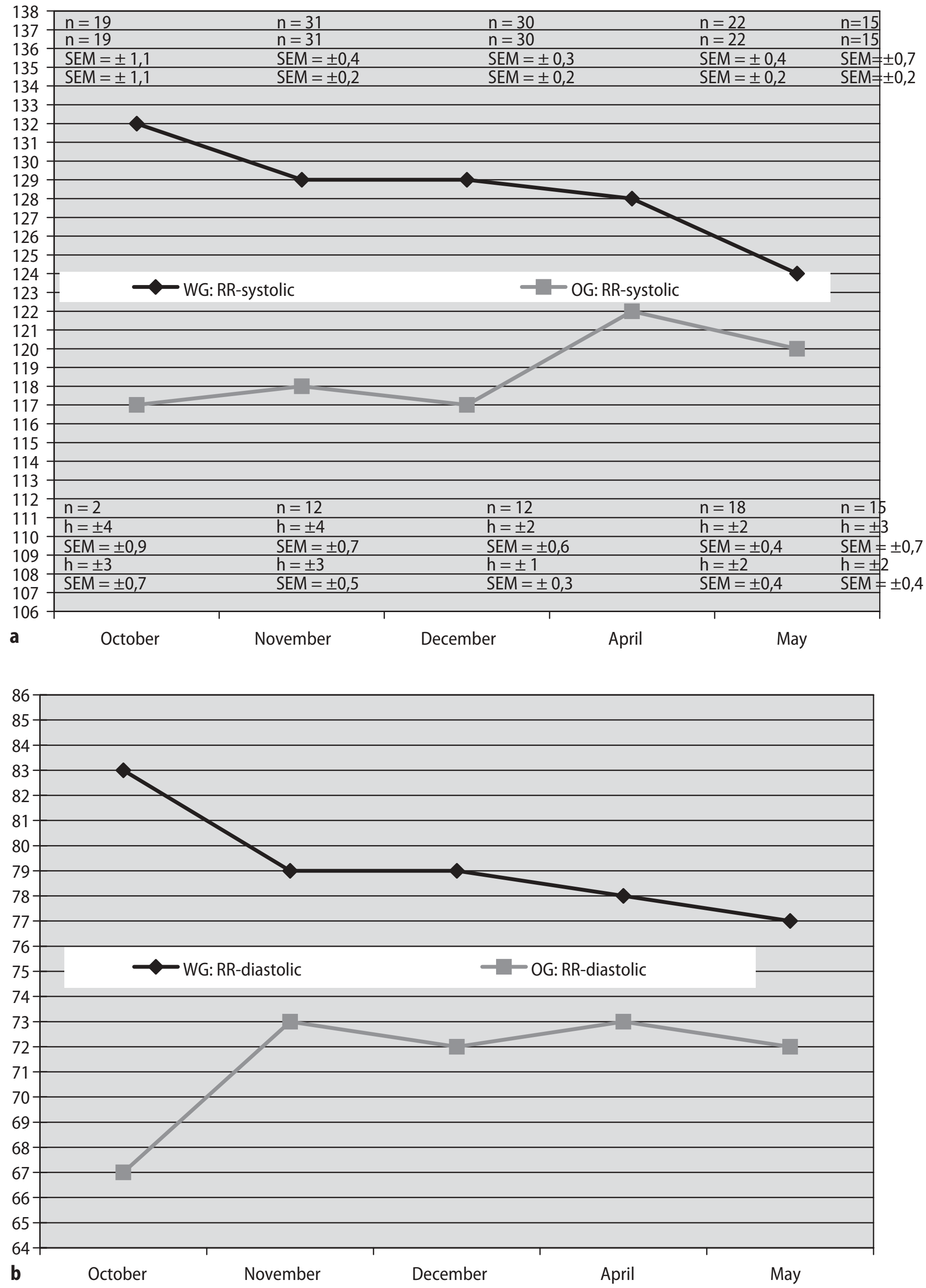

Fig. 7 Morning systolic blood pressure (**a**) and diastolic blood pressure (**b**) in the observation periods October, November, December 2002 and April and May 2003. Average values per month from measurements in the morning are shown. The values are taken from all participants in both groups. The systolic pressure in the West group was 10 (4–15) mmHg and the diastolic pressure 8 (5–16) mmHg higher compared to the East group. When the participants with hypertension in both groups were excluded the differences persisted with the higher values in the West group. Within the observation periods values from the West group declined and values from the East group rose in parallel with the change in noise created by the difference in traffic directions exposing the East group to more and the West group to less noise

33]. The relation between stress and hypertension is well known, although the development of chronic hypertensive disease usually involves additional genetic or environmental factors [34].

Concerning the higher blood pressure in the West group compared to the East group, the difference is probably the consequence of more noise exposure to the West group. On the other hand, differences in group composition can not be excluded. However an unequal distribution of hypertensive patients in the two groups was not responsible for the discrepancies. The differences of higher blood pressure in the West and lower in the East, as well as the changes throughout observation periods, persisted after exclusion of all hypertensive probands in both groups. The higher incidence of hypertension in the West group might simply be the consequence of living in a louder area for a long time. Large studies on the prevalence of hypertension in areas with more noise, along with the increased use of anti-hypertensive drugs in such areas, strongly advocate such an assumption [1–4]. On the other hand, a parallel between noise perception, changes in blood pressure and noise levels was documented within the East group independent from any possible difference between the groups.

Conclusions – clinical relevance

This study proves that in residential areas with an nocturnal equivalent continuous aircraft noise levels of between 40 and 50 dB(A) outside, depending on air traffic direction (and a daily aircraft noise level between about 45 and 55 dB(A) outside depending on traffic directions), changes in perception of noise and in blood pressure occur parallel to changing levels of aircraft noise. Depending on the frequency and duration of the noise, alterations in subjective noise perception and in objective circulatory parameters were documented parallel to the changes in average aircraft noise levels.

In the West group, with longer and more frequent exposure to aircraft noise, an impeded answer to alterations in noise levels compared to the East group was documented. This behaviour is known from stress of different origin but to our knowledge has not yet been described in association with air traffic noise.

Throughout the study period the West group with longer and more frequent noise periods showed higher systolic and diastolic blood pressure values in the morning compared to the East group. Although the average values of both groups remained within the normal range, the difference is not trivial. It is well known that an increase in average blood pressure of 10 mmHg in a given population corresponding to a transition from optimal to normal blood pressure results in an almost doubled risk of experiencing a cardiovascular event such as a stroke or myocardial infarction in the following years [35–38].

The study is in line with recent studies on the relation between noise and hypertension or use of anti-hypertensive drugs respectively. In all these studies an increase in incidents or prevalence of hypertension as a disease requiring medical treatment was found, starting with a noise level of 50–55 dB(A). These studies were undertaken with populations exposed to noise created by street traffic. It is also well documented that air traffic noise can produce the same amount of annoyance even with 5 dB(A), less noise than street traffic.

The present study revealed pathological changes of noise perception and blood pressure occurring with 50 dB(A) compared to 40 dB(A). Thus a nocturnal equivalent continuous aircraft noise level of 50 dB(A) outside can produce disturbances in noise perception and the circulatory system. To avoid alterations in health, the amount of tolerable noise levels has to be kept markedly below this level. The recommendation given in 2001 in Neufahrn by most German scientists working in this field, to keep nightly aircraft noise levels below 45 dB(A) and below 50 dB(A) during the daytime, is in agreement with our findings [39].

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