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CAN EXPOSURE TO NOISE AFFECT THE 24H BLOOD PRESSURE PROFILE? RESULTS FROM THE HYENA STUDY.

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Abstract

Objective: To study the association between exposure to transportation noise and blood pressure (BP) reduction during night-time sleep. **Methods:** 24-hour ambulatory BP measurements at 15-minutes intervals were carried out on 149 persons living near 4 major European airports. Noise indicators included total and source-specific equivalent indoor noise, total number of noise events, annoyance scores for aircraft and road-traffic night-time noise. Long-term noise exposure was also determined. Multivariate linear regression analysis was applied. **Results:** The pooled estimates show that the only noise indicator associated consistently with a decrease in BP dipping is road traffic noise. The effect shows that a 5dB increase in measured road traffic noise during the study night is associated with 0.8% (-1.55,-0.05) less dipping in diastolic BP. Noise from aircrafts was not associated with a decrease in dipping, except for a non-significant decrease noted in Athens where the aircraft noise was higher. Noise from indoor sources did not affect BP dipping. **Conclusions:** Road traffic noise exposure maybe associated with a decrease in dipping. Noise from aircrafts was not found to affect dipping in a consistent way across centers and indoor noise was not associated with dipping.

Introduction

Transportation noise, defined as undesirable sound mainly from road and air traffic, is an environmental stressor that has been associated with cardiovascular end-points such as ischaemic heart disease and hypertension.[1,2] Excessive central nervous system activation by environmental stimuli such as noise, leading to hyperactivity of the sympathetic autonomic nervous system (ANS) and the hypothalamic-pituitary-adrenal axis is the mechanism proposed to explain the effects of noise on the cardiovascular system.[3,4] One of the most important aspects of environmental noise exposure with regard to health effects is sleep disturbance.[5]

During sleep, a state of reduced sympathetic and preponderant parasympathetic ANS tone, blood pressure (BP) shows a physiologic decline (dipping) [6], measured usually as a percentage BP decline with reference to daytime values. Dipping shows a normal distribution in the general population [7] and its absence ("non-dipping") is consistently found in situations with impairment of the ANS, either central [8,9] or peripheral.[10, 11] Non-dipping, together with enhanced BP variability, have also been reported as persisting consequences of major stressful events such as earthquakes.[12] Moreover, there is evidence that non-dipping may be associated with the quality of sleep and that sleep disturbance may contribute to its causation due to pathologic conditions of the individual [13] or to extrinsic factors.[14] Finally, non-dipping has been proposed as an independent risk factor for cardiovascular morbidity [15, 16], although it is not always reproducible on individual basis when a second ambulatory BP monitoring (ABPM) is performed.[17]

Within the wider framework of the European project "HYENA" [18], in the present study we investigate the a-priori hypotheses that exposure to noise, either long-term or acute during the specific study night, can affect BP dipping, assessed by ABPM, in subjects living in the vicinity of four major European airports.

Methods

a. Sampling

The hypotheses for the present study were stated a-priori and included in the initial protocol as a separate working package of the HYENA study. The sample was selected from the main sample of the HYENA project (age range 45-70 years) and consisted of subjects living around 4 European airports with night flights: Athens (Greece), Malpensa (Italy), Arlanda (Sweden) and London Heathrow (U.K.). Details on the sampling procedures of the HYENA project are reported elsewhere.[18] The desired sample size for the present study was based on power calculations for finding a difference in BP dipping between participants chronically exposed to aircraft noise and non-exposed ones. Based on the data reported by Staessen et al [7] and according to our power calculations, a total of 100 subjects chronically exposed to aircraft noise and 100 non-exposed would give us a power of 80% to detect an increase of 4.8 units in the night/day BP systolic ratio and 5.8 units in the night/day BP diastolic ratio.

The following exclusion criteria were applied in the selection of subjects: 1) antihypertensive medication, 2) diagnosis of diabetes mellitus, 3) diagnosis of obstructive sleep apnoea syndrome, 4) diagnosis of secondary hypertension, 5) working in night shift,

6) using sleeping pills and sedatives, 7) diagnosis of (or self-reported) hearing impairment, 8) regular use of ear plugs, 9) diagnosis of atrial fibrillation (confirmation of absence of this condition was also made from the ABPM recordings). Criteria 1–6 were applied as they affect the night-time BP; criteria 7 and 8 as they modify noise exposure; and criterion 9 as it hinders ABPM.

Approval for the study was granted by each center's Ethical Committee and all participants gave written informed consent.

b. Measurements and data management

Long-term noise exposure assessment to transportation noise (aircraft and road traffic separately) for each participant according to his/her residence is based on the HYENA project's A-weighted equivalent noise level for a whole 24h period averaged over a year (LAeq24h), (precisely the year 2002 for the HYENA project), and is described elsewhere.[18]

Noise exposure assessment during the study night was done by continuous noise measurement with the type I "CESVA SC310" [19] noise-meter (integration time 125ms "LAF") as well as noise recording with an mp3 recorder connected to the noise-meter's high-quality microphone were done during the study night in each participant's bedroom. Each participant was followed up for one night. From the 125ms values we calculated the A-weighted equivalent noise level for every second (LAeq 1sec) and subsequently for the whole night-time sleeping period (defined by sleep log filled in by the participants) as:

$$LAeq(night) = 10 * \log(\sum_{i=1}^{t} 10^{(0.1 * LAeq1\sec, i)}) - 10 * \log(t)$$

where t is the sleeping time in seconds.

Using playback and visualization of sound recordings on a computer, the source of each event was identified and synchronized with the sound measurements with a program written for this purpose. An event was defined as present if its indoor A-weighted maximum level (LAmax) exceeded 35dB. Noise events were classified into 4 categories according to source: indoor source, aircraft, road traffic, and other outdoor source. Other outdoor events were very rare and thus excluded from the analysis. We calculated for each noise event the LAmax and the sound exposure level (SEL) which represents the event's sound energy. From the SEL we calculated the equivalent sound level of noise events averaged over the whole sleeping period for each participant.

Non-invasive twenty-four-hour ABPM, with heart rate measurements, was performed at 15 minutes' intervals with the validated "Mobil-O-Graph" device [20], including the night of sound measurements. The 15 minute frequency has been implemented before [21] and was chosen as optimal for frequent measurements without excessive sleep disturbance. Each participant completed shortly after waking up a questionnaire indicating sleeping hours and providing subjective information on his/her quality of sleep, and on disturbance from the ABPM device. "Waking" and "sleeping" BP values were defined, in keeping with current practice, from the questionnaire data [22] and BP dipping from day to night was calculated as mean BP during awake time minus mean BP during night-time and divided by mean BP during awake time. BP values during any daytime sleep ("siesta") were excluded because

their inclusion as awake values is known to underestimate nocturnal BP dipping [23]. The three instruments (noise meter, noise recorder and ABPM device) and the participants' alarm clock were synchronized at one minute precision.

Specially trained staff installed the noise equipment, placed the ABPM device on the participants and gave them written instructions, during a home visit at least three hours before normal sleeping time. Each participant was instructed not to engage in unusually heavy activity during the measurements' period and filled in a sleep log indicating actual sleep times.

We also used, alternatively to the objective noise levels, the annoyance scores provided by the participants via questionnaire, administered to the whole HYENA sample via interview. Due to the limited availability of instruments, the study was done at different time periods in each center: in Athens from April 2004 to December 2004, in Milan from December 2004 to July 2005, in Stockholm from September 2005 to December 2005 and finally in London from December 2005 to February 2006. Subjects were examined on different days.

c. Statistical analysis

Multiple linear regression models were applied for the data from each center separately in order to assess long-term or night-time noise effects on BP dipping (systolic and diastolic). The noise exposure based on the annual estimate (LAeq24h and Lnight) for aircraft and road traffic were used as long-term noise exposure variables. Other noise exposure

variables used alternatively were the A-weighted equivalent noise level measured indoor during the study night (LAeq night) and the equivalent sound levels of source-specific noise events (aircraft, road traffic and indoor source) averaged over the whole sleeping period for each participant. The number of source-specific events (aircraft, road traffic and indoor source) with LAmax exceeding 35dB during the study night and the annoyance scores from chronic exposure to air and road traffic during night-time was also used as exposure variables. Moreover, self-reported disturbance from the ABPM device and quality of sleep, as assessed via questionnaire, were used alternatively as independent variables as they have been reported to affect nocturnal BP.[24] To account for potential confounding effects we applied multiple linear regression models with BP dipping as outcome and sex, age (years), current smoking habits (smoker/non-smoker), body mass index (as weight in kg divided by height squared in m^2) and working status on the day of the measurements (working/not working) as covariates, since these factors have been reported to affect BP dipping.[25-27] After obtaining the four center specific effect estimates using multiple linear regression models, we then combined the center specific results using either fixed or random effects meta-analysis depending on the absence or presence of heterogeneity. [28] All reported p-values are based on two-sided hypotheses and the significance level used was 5%. Data analysis was performed using Intercooled Stata 8.2 (Stata Corporation, College Station, Texas).

Results

The initial sample size target of 50 subjects per center was not reached in most centers, as the field work was particularly demanding. Furthermore, 12 subjects were excluded due to technical problems with the sound monitoring or ABPM equipment. Exclusion criteria relative to ABPM included duration of examination less than 21 hours, fewer than 70 valid readings, reading success lower than 80%, and no-reading interval(s) longer than 2 hours. The total sample consisted of 149 subjects, of which 62 in the non-exposed noise category and 87 in the exposed noise category (Table 1). When taking into account noise long-term noise exposure variables and noise annoyance scores the sample consisted of 149 subjects, while when using indicators obtained only from the measured indoor noise during the specific study night (total noise equivalent of the specific night and source-specific noise) 9 subjects were excluded from the analysis due to noise equipment failure during that specific study night. Table 1 shows the descriptive characteristics of the samples. Systolic and diastolic BP dipping both displayed a normal distribution (data not shown) with values similar to those previously reported from large databases [6].

Table 1: Descriptive characteristics of the 149 subjects participating in the study, by study center.

	Athens (n=46)	**London (n=20)**	**Milan (n=50)**	**Stockholm (n=33)**
Systolic dipping (mean; SD) (%)	13.6 (6.53)	17.2 (5.91)	13.5 (6.51)	17.1 (6.68)
Diastolic dipping (mean; SD) (%)	15.3 (8.26)	20.4 (6.52)	16.0 (7.21)	19.3 (8.12)
24-hour systolic BP (mean; SD) mmHg	120 (16.1)	115 (14.1)	118 (14.6)	116 (17.6)
24-hour diastolic BP (mean; SD) mmHg	72 (11.2)	71 (11.4)	72 (11.0)	71 (11.9)
Awake systolic BP (mean; SD) mmHg	129 (14.1)	126 (9.9)	127 (11.8)	127 (13.7)
Awake diastolic BP (mean; SD) mmHg	78 (10.2)	79 (8.7)	79 (9.3)	78 (9.9)
Asleep systolic BP (mean; SD) mmHg	111 (13.2)	104 (8.7)	109 (11.8)	105 (14.1)
Asleep diastolic BP (mean; SD) mmHg	66 (8.6)	62 (7.1)	66 (8.6)	63 (8.8)
Age (mean; SD) yrs	53 (7.7)	58 (7.3)	56 (7.9)	56 (6.3)
Sex (n; male %)	15 (32.6)	8 (40.0)	26 (52.0)	16 (47.1)
Chronic Exposure to noise (n; exposed %)	29 (63.0)	10 (50.0)	33 (66.0)	15 (44.1)
Smoking habits (n; yes %)	22 (52.2)	0 (0.0)	6 (12.0)	5 (14.7)
BMI (mean; SD) kg/m^2	28 (4.1)	26 (2.3)	26 (4.4)	26 (3.6)
Working on the day of measurements (n; yes %)	18 (39.1)	7 (35.0)	17 (34.0)	31 (91.2)

Table 2 and Figure 1 shows descriptive data on the noise and annoyance indicators used. The number of aircraft events during the night-time sleep was higher in Athens compared to the other centers. The presence of subjects with no or few night aircraft events was explained by the sampling procedure through which a number of subjects were selected from the main sub-sample of low exposure to aircraft noise and by the fact that an event

was defined by noise measured indoors with LAmax>35dB. The median indoor noise equivalent measured during the study night-time sleep (LAeq night) was higher in Athens compared to the 3 other centers. Also, the median aircraft noise level (based on SEL10) measured indoor during the study night was higher in Athens. However, the median road traffic noise levels (based on SEL10) were similar in the four samples.

Table 2: Median values and (25th-75th quartile) of the various noise indicators (annual and measured indoor during the study night) and of the various annoyance scores for the 149 subjects participating in the study, by study center.

	Athens (n=46)	**London (n=20)**	**Milan (n=50)**	**Stockholm (n=33)**
Long term noise exposure				
LAeq24h air* (dB)	53 (44 – 56)	42 (31 – 63)	55 (36 – 60)	39 (20 – 55)
LAeq24h road** (dB)	43 (37 – 47)	50 (45 – 55)	51 (37 – 59)	49 (40 – 56)
Lnight Aircraft▲ (dB)	43 (36 – 46)	31 (24 – 58)	42 (25 – 46)	27 (20 – 51)
Lnight Road traffic▲▲ (dB)	40 (34 – 44)	42 (37 – 47)	43 (31 – 51)	43 (36 – 50)
Measured indoor noise during the study night				
LAeq night*** (dB)	42 (38 – 46)	35 (34 – 42)	37 (35 – 39)	36 (33 – 40)
No. of events from all sources+	42 (26 - 60)	15 (0 – 114)	25 (17 – 32)	16 (11 – 23)
No. of aircraft events+	19 (5 – 32)	0 (0 – 17)	2 (0 – 7)	0 (0 – 5)
Aircraft noise++ (dB)	26 (18 – 32)	0 (0 – 20)	10 (0 – 23)	0 (0 – 11)
No. of road traffic events+	1 (0 – 7)	0 (0 – 38)	0 (0 – 1)	0 (0 – 6)
Road traffic noise++ (dB)	0 (0 – 18)	0 (0 – 20)	0 (0 – 8)	0 (0 – 12)
No. of indoor events+	14 (6 – 22)	0 (0 – 22)	14 (10 – 21)	9 (5 -15)
Indoor noise++ (dB)	33 (26 – 36)	0 (0 – 25)	27 (23 – 30)	27 (24 – 31)
Annoyance from aircrafts day✦	8 (6 – 10)	3 (2 – 5)	5 (0 – 9)	1 (0 – 6)
Annoyance from aircrafts night✦	6 (1 – 10)	2 (0 – 5)	2 (0 – 6)	0 (0 – 3)
Annoyance from road traffic day✦	0 (0 – 2)	2 (1 – 4)	2 (0 – 6)	2 (0 – 4)
Annoyance from road traffic night✦	0 (0 – 0)	0 (0 – 2)	0 (0 – 0)	0 (0 – 2)

*modeled long term aircraft noise exposure based on annual estimate
** modeled long term road traffic noise exposure based on annual estimate
▲modeled long term night aircraft noise exposure based on annual estimate
▲▲ modeled long term night road traffic noise exposure based on annual estimate
*** measured indoor noise during the study night-time sleep
+ number of events>35dB during the study night
++ noise from source specific events (LAeq based on SEL10) during the study night
✦ annoyance score with range 0-10 (10 = highly annoyed)

Table 3 shows the pooled effect estimates of the noise exposure indicators, of long-term annoyance from aircrafts and road traffic, of sleep quality during the study night and of disturbance from the device on BP dipping, after adjusting for potential confounding effects. The pooled estimates from all 4 centers show that the only noise indicator associated consistently with decrease in BP dipping is higher road traffic noise during the study night. The effect is statistically significant only on diastolic dipping and shows that a 5dB increase in measured road traffic noise during the study night is associated with 0.8% less dipping in diastolic BP. The effect estimates of LAeq24h and Lnight which express the effect of modeled long term aircraft and road traffic noise exposure respectively were consistently identical between the 4 cities (data not shown). Other variables expressing noise exposure or long-term annoyance from aircraft or road traffic noise were not associated with BP dipping in a consistent way across the four centers (Figures 2-4). However, in Athens where measured aircraft noise was much higher, there is a consistent decrease in dipping in all models with aircraft, road traffic, indoor source and measured indoor noise indicators (Figures 2, 3 and 4).

Table 3: Pooled effect estimates of various noise indicators on blood pressure dipping.

Results from fixed effects models (except where noted).

Model	Systolic dipping (%) (95% CI)	Diastolic dipping (%) (95% CI)
Long term noise exposure		
LAeq24h air* (5dB)	0.10 (-0.30 , 0.50)	0.10 (-0.40 , 0.55)
LAeq24h road** (5dB)	-0.45 (-0.95 , 0.50)	-0.55 (-1.10 , 0.05)
LAeq24h air✓ (5dB)	0.10 (-0.75 , 0.90) ⇳	0.25 (-0.30 , 0.75)
LAeq24h road traffic✓✓ (5dB)	-0.43 (-0.96 , 0.10)	-0.51 (-1.12 , 0.11)
Lnight Aircraft▲ (5dB)	0.18 (-0.25 , 0.61)	0.16 (-0.33 , 0.64)
Lnight Road traffic▲▲ (5dB)	-0.48 (-0.98 , 0.02)	-0.55 (-1.12 , 0.02)
Measured indoor noise during the study night		
LAeq night*** (5dB)	0.42 (-0.77 , 1.60)	0.36 (-0.94 , 1.65)
No. of events from all sources+	-0.01 (-0.05 , 0.03)	0.002 (-0.04 , 0.04)
No. of aircraft events+	0.002 (-0.08 , 0.09)	0.03 (-0.07 , 0.12)
Aircraft noise++ (5dB)	-0.05 (-0.55 , 0.50)	0.05 (-0.50 , 0.65)
No. of road traffic events+	-0.01 (-0.08 , 0.05)	-0.002 (-0.06 , 0.06)
Road traffic noise+++ (5dB)	-0.55 (-1.25 , 0.10)	-0.80 (-1.55 , -0.05)
No. of indoor events+	-0.001 (-0.11 , 0.11)	-0.01 (-0.14 , 0.11)
Indoor noise++++ (5dB)	0.45 (-0.32 , 1.21)	0.41 (-0.42 , 1.23)
Annoyance from aircrafts night✦ (one unit)	0.09 (-0.22 , 0.40)	0.11 (-0.25 , 0.46)
Annoyance from road traffic night✦	0.05 (-0.42 , 0.52)	-0.06 (-0.61 , 0.48)

(one unit)		
Sleep quality✦✦(one unit)	1.03 (-0.003 , 2.07)	0.95 (-0.28 , 2.18)
Device disturbance✦✦✦ (one unit)	-0.23 (-2.44 , 1.97) ⇳	-0.32 (-2.34 , 1.71) ⇳

* modeled long term aircraft noise exposure based on annual estimate
**modeled long term road traffic noise exposure based on annual estimate
✓ Modeled long term aircraft noise exposure based on annual estimate, adjusted for road traffic noise
✓✓ Modeled long term road traffic noise exposure based on annual estimate, adjusted for aircraft noise
▲ modeled long term night aircraft noise exposure based on annual estimate
▲▲ modeled long term night road traffic noise exposure based on annual estimate
***measured indoor noise during study night-time sleep
+ number of events>35dB during the study night
++ noise from aircrafts (LAeq based on SEL10) during the study night
+++noise from road traffic (LAeq based on SEL10) during the study night
++++noise from indoor sources (LAeq based on SEL10) during the study night
✦annoyance score with range 0-10 (10 = highly annoyed)
✦✦ score with range 1-5 (5=slept very good)
✦✦✦score with range 1-5 (5=very much annoyed by ABPM device)
⇳ significant heterogeneity

Finally, better reported quality of sleep was associated with an increase in dipping which was nearly significant (p-value =0.09) whilst annoyance from the ABPM itself was associated with decreased dipping only in the Athens sample. The corresponding results for systolic BP dipping were similar, with the exception of significant heterogeneity in the effects of the annual estimate of the aircraft noise exposure, adjusted for road traffic noise. The effect of the reported disturbance from the ABPM device showed significant heterogeneity between centers.

Discussion

We tested the hypothesis that exposure to noise, either short-term, i.e. during the study night, or long-term, can affect the physiologic BP decline during sleep. In the present paper a decrease in BP dipping (especially diastolic) is associated only with road traffic noise during the study night, even though the attributed noise to road traffic events was low. No overall effect was observed of aircraft or indoor noise in the 4 centers. However the measured night-time noise from aircraft, which was done indoors, in the subjects' bedroom, was considerably and significantly higher in the Athens sample. If the results of the aircraft related noise effects and annoyance are observed, it is seen that consistent estimates of a decrease of dipping are obtained for Athens which are not statistically significant due to the low statistical power in one sample. This may imply that the aircraft noise indoors in the other samples was generally below a threshold for the studied effect. Noise, and more specifically recorded transportation noise, is known to be able to cause BP elevations

during sleep in laboratory conditions.[29, 30] In our previously published paper on the same individuals [31] we showed that higher BP measurements are associated with noise events from aircrafts, road traffic, or indoor sources.

Thus, although noise events were associated with BP elevations [31], these were not of sufficient magnitude or number in each individual in all centers so as to affect the day-night BP ratio. A larger sample or a larger number of noise events might have been able to detect this. Another explanation might be that individuals with more noise, BP elevations and possibly arousals during the study night also had higher BP during the morning after (most 24h BP monitorings started in the afternoon before the study night) and thus their day-night BP ratio was not affected. Higher awake BP has been reported in individuals with arousals and sleep fragmentation.[32]

Modeled long-term noise exposure was not found to be associated with BP dipping during our study night. A possible explanation is that environmental noise at the exposure levels of our study subjects may not activate the sympathetic ANS on a long-term basis, at least not to the extent needed to produce non-dipping, or non-dipping may not be a sensitive indicator of ANS disturbance. It should be noted that non-dipping is found more consistently in individuals with diseases associated with severe, clinically manifested or paraclinically diagnosed peripheral or central ANS impairment such as diabetes mellitus, familial amyloid polyneuropathy, stroke, and Shy-Drager syndrome, and therefore the exclusion of individuals with diabetes mellitus and diagnosed hypertension, who might respond more to environmental stressors, may have led to the underestimation of the effect.

[8-11] Furthermore it has been reported that non-dipping is not always reproducible when a second ABPM is performed on the same individual [17] supports the view that it may not be an indicator of chronic or permanent dysfunction of the organism. It would have been preferable to include more study nights per subject, which was impossible considering the burden imposed on the subjects and the limited availability of the equipment.

Alternatively, the specific estimation of long-term noise may be subject to misclassification error which lowers the power to detect an effect. This may have resulted in the discrepancy of the results of measured and estimated noise. Furthermore, it should be noted that measured noise indoors takes into account the homes noise insulation which may be especially important for night-time exposure.

Finally, although BP measurements on noise-exposed or unexposed subjects were all performed with ABPM, the effect of cuff inflation on sleep and on nocturnal BP of subjects sensible to the disturbance from the device [24] may have masked the chronic (and presumably small) effects of noise we were looking for. Our results of the effects of greater self-reported disturbance from the device on decrease in BP dipping showed significant heterogeneity between centers and that of self-reported sleep quality during the study night did not reach the nominal statistical significance level, although it was nearly significant and considerably low showing that better sleep and less disturbance from the device were associated with greater BP dipping.

Summary Box

What is already known on this subject?	What does this study add?
Noise is an environmental stressor that has been associated with hypertension, mainly in laboratory studies. Specifically there is evidence that transportation noise can cause blood pressure elevations during sleep in laboratory conditions.	The present study was done in order to investigate the association between exposure to transportation noise and blood pressure (BP) reduction during night-time sleep. To our knowledge, this study is the first based on noise measurements in a population living under their normal conditions at home. Our results provide some evidence that road traffic noise may contribute to less BP dipping during sleep and they also indicate that there may be an effect of aircraft noise in locations with night time flights. Thus, preventive measures should be considered to reduce transportation noise during night-time.

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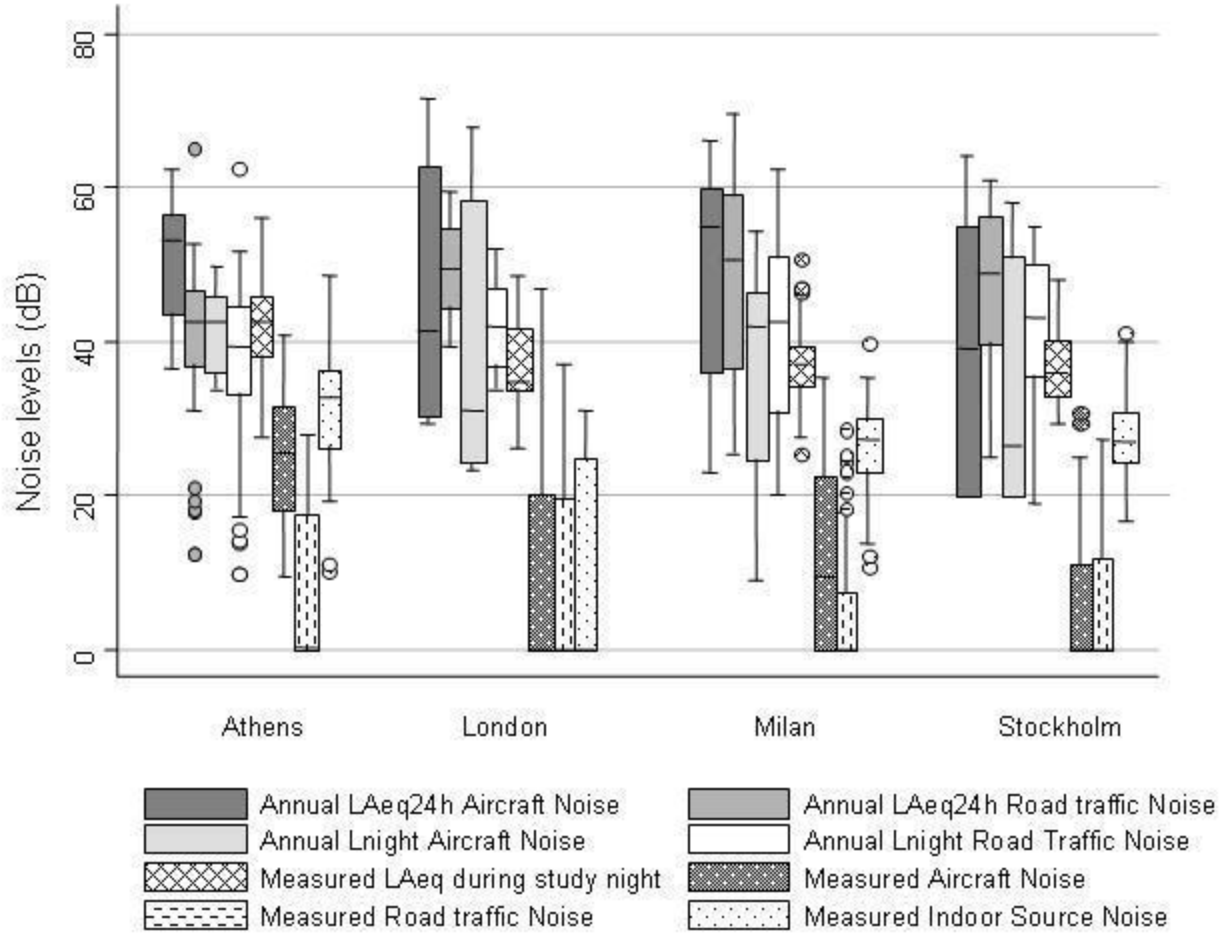
Figure Legends

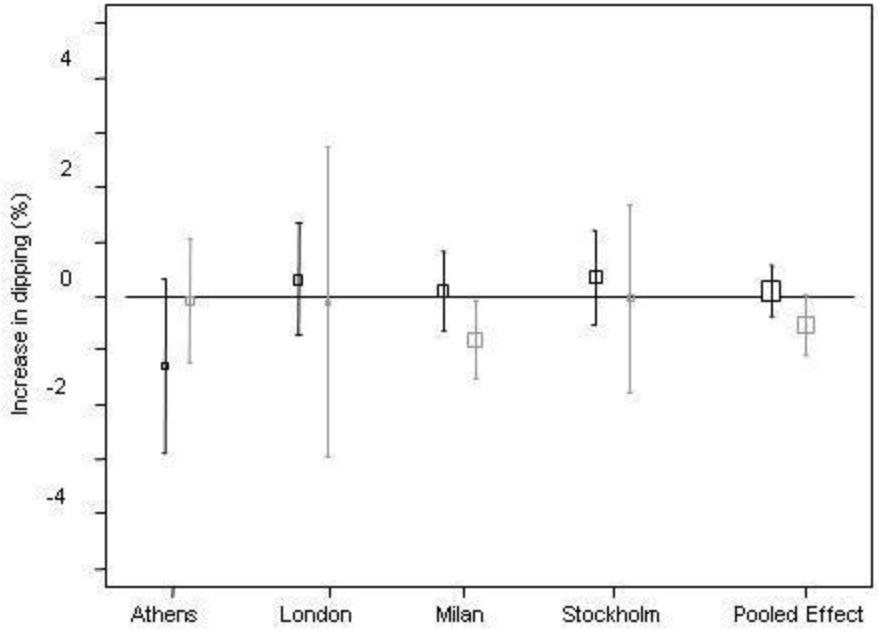
Figure 1: Box plots of the various noise indicators (annual: LAeq24h Air, LAeq24h Road traffic, Lnight Aircraft & Lnight road traffic noise; measured during the study night: LAeq night, Aircraft, Road traffic & Indoor source noise).

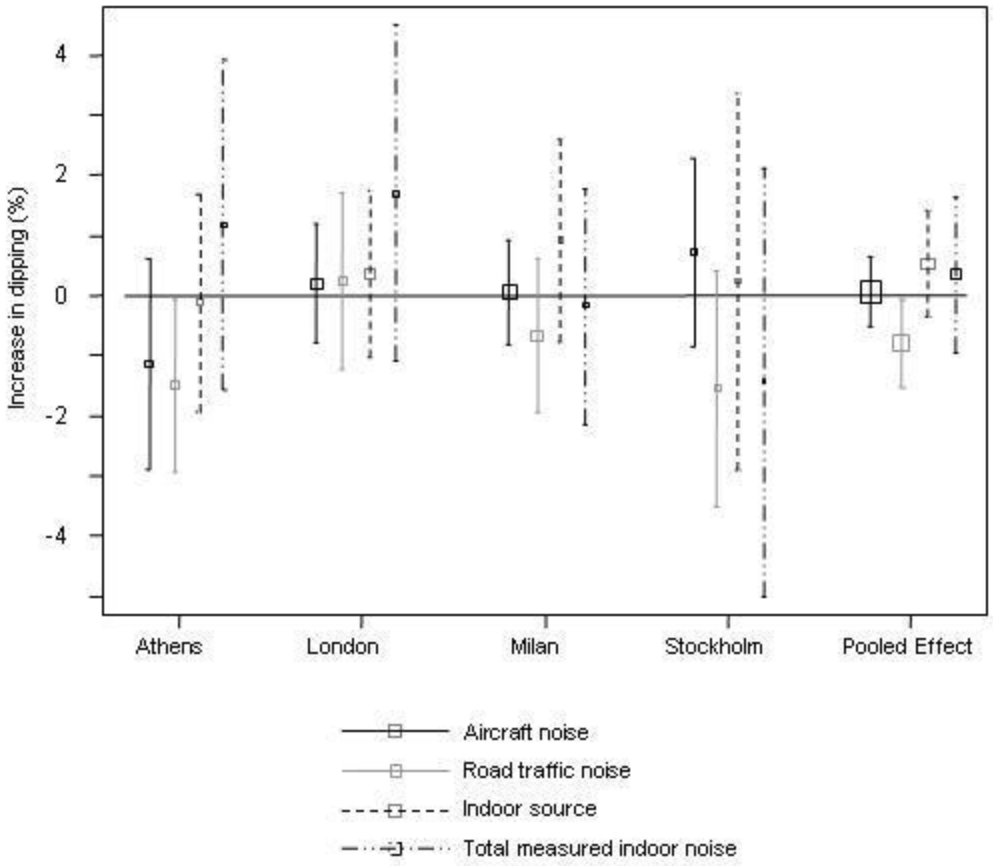
Figure 2: Center-specific and pooled effect estimates & 95% confidence interval of a dB(A) increment in long term aircraft (black) & road traffic (gray) noise exposure on diastolic dipping.

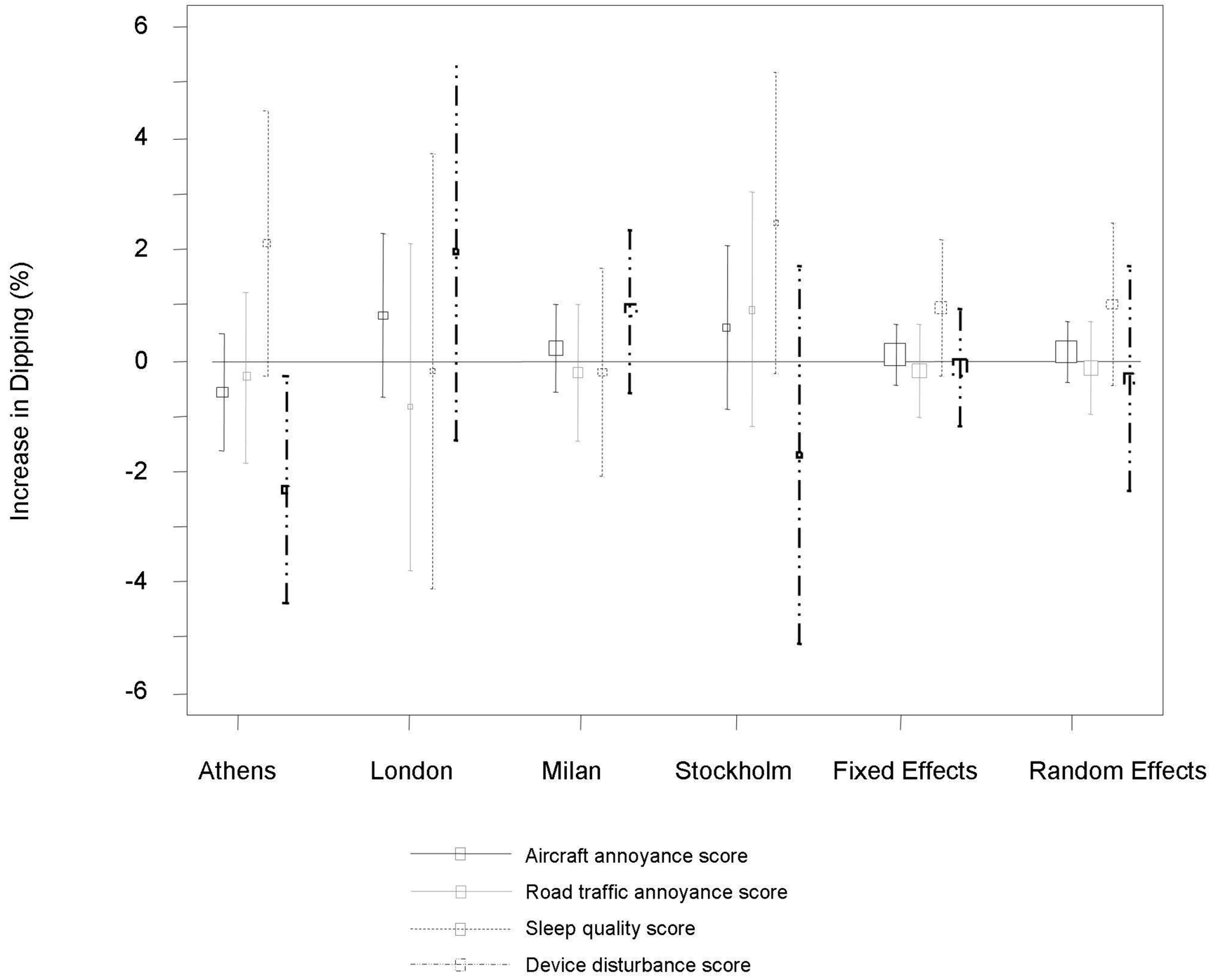
Figure 3: Center-specific and pooled effect estimates & 95% confidence interval of a 5dB(A) increment in measured indoor noise during the study night from aircrafts, road traffic, indoor source & total measured indoor noise during the study night – time period on diastolic dipping.

Figure 4: Center-specific and pooled effect estimates & 95% confidence interval of a one unit increase in sleep quality & device disturbance score during the study night, annoyance score from aircrafts & road traffic noise during the night on diastolic dipping..


Noise levels (dB)
0
20
40
60
80
Athens
London
Milan
Stockholm
Annual LAeq24h Aircraft Noise
Annual LAeq24h Road traffic Noise
Annual Lnight Aircraft Noise
Annual Lnight Road Traffic Noise
Measured LAeq during study night
Measured Aircraft Noise
Measured Road traffic Noise
Measured Indoor Source Noise


Increase in dipping (%)
4
2
0
-2
-4
Athens
London
Milan
Stockholm
Pooled Effect


Increase in dipping (%)
4
2
0
-2
-4
Athens
London
Milan
Stockholm
Pooled Effect
Aircraft noise
Road traffic noise
Indoor source
Total measured indoor noise


Increase in Dipping (%)
6
4
2
0
-2
-4
-6
Athens
London
Milan
Stockholm
Fixed Effects
Random Effects
Aircraft annoyance score
Road traffic annoyance score
Sleep quality score
Device disturbance score