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A field investigation on associations between environmental noise and adolescent physiological sleep: An Equal-Life study

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ABSTRACT

There is a need for field studies incorporating objective measures of both noise and sleep. Within the EU project Equal-Life we performed an in-depth field study to investigate associations between nocturnal noise exposure and physiological sleep. Participants (n=109; 68 female) were adolescents/young adults (18-19 years) recruited from within the longitudinal birth cohort STARS, around Gothenburg, Sweden. The noise exposure and sleep of each subject was investigated for four consecutive nights, from Tuesday night to Saturday morning. Outdoor noise was measured with sound level meters mounted outside bedroom windows. Indoor noise measurements and audio recordings were made in the bedrooms. Sleep was measured with a headband (DREEM3) incorporating dry EEG electrodes. Questionnaires were administered every evening and morning, and included items on daytime activities, sleepiness (Karolinska Sleepiness Scale), sleep quality, sleep disturbance by noise, and the bedroom environment. Outdoor noise measurements were obtained for 465 days and nights. Nighttime levels ranged from 35.8 to 73.7 dB L_{night} (mean±SD 47.6±5.5 dB L_{night}). Twenty-four hour levels ranged from 39.5 to 69.1 dB $L_{\mathrm{AEq,24h}}$ (mean±SD 51.3±5.4 dB $L_{\mathrm{AEq,24h}}$). Data analysis is ongoing, and results will be presented at the congress. We will determine associations between average noise levels (L_{night}, and L_{AEq} during the EEG-derived sleep period) and sleep structure. We will also determine acute effects of discrete noise events on sleep fragmentation including noise-induced awakenings and changes of sleep stage.

Keywords: Environmental noise, Sleep, Field study, Adolescents

INTRODUCTION

Mental health issues have largely been neglected in environmental research, but pose an increasing public health problem in Europe. This is especially true for early childhood and adolescence, as these are vulnerable developmental phases. Thus, differential exposure to physical and/or social environments during childhood may have a profound impact on an individual’s health status as an adult. The EU-funded Equal-Life project will develop and utilise the exposome concept in an integrated study of the external exposome and its social aspects and of measurable internal physiological factors and link those to a child's development and life course mental health. This will be done using a novel approach combining exposure data to characterise, measure, model and understand influences at different developmental stages. The goal is to propose the best supportive environments for all children.

The ongoing Study of Adolescence Resilience and Stress (STARS) study has the overall aim of investigating how stress, physical and mental wellbeing and recovery during adolescence affect the risk of developing cardiovascular problems, such as hypertension, in adulthood, and how family, peers, school and lifestyle affect these relationships. The STARS cohort is described elsewhere.[1] As a first step towards understanding the mediating or moderating role of sleep in the pathway between the exposome and mental health, we here describe an observational cross-sectional study nested within the STARS cohort, Specifically, we investigate the associations between measured environmental noise exposure and physiological and self-reported sleep.

MATERIALS AND METHODS

Study Design

The study used a cross-sectional design. Study subjects were recruited from within the STARS cohort, during the period of second follow-up, i.e. at age 18. To be eligible, they were first required to consent to continuing in the STARS cohort. The study was approved by the Swedish Ethical Review Authority (Dnr 2021-05323-02). All subjects provided informed consent, were compensated with 800 SEK (around €70) for participating and were free to discontinue from the study at any time and without providing a reason.

Study subjects slept at their normal bedtimes for four consecutive nights (Tuesday night through to Saturday morning) with a headband that registered electrophysiological sleep. Concurrent noise measurements were made in the bedroom and outside the bedroom window. Questionnaires were completed every evening to record daytime activities and every morning to record self-reported sleep and restoration. All equipment was set up at the subject’s home by the research time on the Monday or Tuesday afternoon prior to the first (Tuesday) study evening. During this visit, we also demonstrated how to operate and wear the sleep headband. All study equipment was collected by the research team on the weekend after the final (Friday) night.

Noise Measurement

Outdoor noise levels were measured continuously with custom-built sound level meters (SLMs). SLMs were mounted on or close to the bedroom window (example in Figure 1). They were powered by mains electricity delivered by Power Over Ethernet (POE), via cables that were sufficiently thin that windows could still be fully closed. SLMs continuously transmitted measurement data via internal 3G modems to a central server. We continuously monitored the connection status, and if interruptions in connection occurred we contacted the study participants to determine and fix, if possible, the problem. If the 3G connection was lost but the SLM continued to be powered, it continued to measure data and store to internal memory. When the connection was re-established, stored data were then uploaded to the server.

Figure 1 Typical mounting of outdoor sound level meter. A: Sound level meter. B: power cable passing through window gap while window fully closed.

Indoor noise levels were measured in the bedrooms with Class 1 SLMs (Nor140, Norsonic, Tranby, Norway). All SLMs were synchronised to atomic clock time and calibrated each week prior to deployment. To aid with identification of noise sources, i.e., to separate exterior traffic noise from interior sounds like snoring, raw audio was recorded for sound events exceeding 35 dBA. For privacy reasons, this was done only between 21:00-09:00, which was *a priori* hypothesised to incorporate the likely full sleep period.

Physiological Sleep Measurement

Sleep physiology was recorded with the Dreem 3 headband (Dreem, Paris, France), see Figure 2. Fontal and occipital dry electrodes (Fp1, F7, F8, O1, O2) registered EEG signals. Participants were provided extenders so that they could change the sizing of the headband to ensure a comfortable fit. We provided lightweight nylon headbands that could be worn on top of the Dreem 3, to further secure it in place if necessary.

Figure 2 DREEM headband

Sleep data were automatically uploaded to secure servers at the end of each sleep period. Daily checks were performed to ensure subject compliance and high data quality. If the sleep data were of poor quality, for example due to a poor fit of the headband, we contacted the subjects by telephone to provide remote support and instruction to prevent the issue in subsequent nights.

Sleep macrostructure was derived with the DREEM algorithms. Evaluated metrics were total sleep time (TST); sleep onset latency; wakefulness after sleep onset; the amount of wake, rapid eye movement (REM) sleep, and non-REM stages N1, N2 and N3 evaluated as both absolute durations and percentage of the sleep period; sleep efficiency (percentage of the sleep period spent in a non-wake stage); number of sleep stage shifts; number of awakenings; and EEG arousal index (n/h).

Questionnaires

Questionnaires were administered electronically every study evening and morning. We performed daily checks to ensure that subjects completed these. If they did not, we contacted them with a reminder.

Morning questionnaires contained items on sleep quality; tiredness; stress; irritation; sleepiness (Karolinska Sleepiness Scale[2]); lights out and rise times; estimated sleep latency, sleep disturbance by road, rail, and/or other noise sources; screen use in the hour prior to bedtime; number of awakenings due to sound/alerts from their mobile phone; noise-induced poor sleep, awakenings, difficulty falling asleep, and tiredness; window position (closed, ajar, or fully open); and satisfaction with thermal environment (from too cold to too warm).

Evening questionnaires contained items on tiredness; stress; irritation; daytime sleepiness; daytime napping; daytime exercise; and stimulant and depressant use in the 8h prior to bedtime (energy drinks, coffee, nicotine, medication, alcohol, and narcotics).

RESULTS

Participants

One hundred and nine subjects aged 18-19 years were recruited (Table 1). The majority were a late chronotype, i.e. had a preference for later sleep and wake times. They were generally satisfied with their sleep, in that only a minority perceived their sleep quality as bad or very bad and sleep disturbance by noise was low. There was substantial spread in the modelled annual average noise levels, although the majority were clustered between 45-55 dB $L_{\text{AEq,24h}}$.

Table 1 Overview of study subjects

Variable	Level	N (%)
Sex	Male	41 (37.6%)
	Female	68 (62.4%)
Chronotype	Definite morning type	7 (6.4%)
	Somewhat morning type	28 (25.7%)
	Somewhat evening type	42 (38.5%)
	Definite evening type	32 (29.4%)
Perceived sleep quality	Very good	28 (25.7%)
	Quite good	36 (33.0%)
	Neither good nor bad	27 (24.8%)
	Quite bad	14 (12.8%)
	Very bad	4 (3.7%)
Sleep disturbance by road traffic in last 3 months	Not at all	90 (82.6%)
	Somewhat	16 (14.7%)
	Quite a bit	3 (2.8%)
	Very	0 (0%)
	Extremely	0 (0%)
Annual average road traffic noise exposure at most exposed façade [a]	<40 dB $L_{\text{AEq,24h}}$	7 (7.5%)
	40<45 dB $L_{\text{AEq,24h}}$	8 (8.6%)
	45<50 dB $L_{\text{AEq,24h}}$	20 (21.5%)
	50<55 dB $L_{\text{AEq,24h}}$	35 (37.6%)
	55<60 dB $L_{\text{AEq,24h}}$	14 (15.1%)
	60<65 dB $L_{\text{AEq,24h}}$	4 (4.3%)
	≥65 dB $L_{\text{AEq,24h}}$	3 (3.2%)

[a] Extracted from publicly available modelled noise maps based on 2018 traffic flow data in Gothenburg city (https://karta.miljoforvaltningen.goteborg.se/) or from noise contours provided by the European Environment Agency (https://noise.eea.europa.eu/). Data available for N=91 subjects only, the remaining 16 lived outside the mapped areas (and as such would likely be in the <40 dB category).

Noise Exposure

Outdoor noise data were successfully measured for N=408 nights (95.6% of expected). Noise data of four subjects was missing for all nights due to technical problems. For a fifth subject, the power supply to the recorder was lost overnight on three of the four study nights, and data are available for Thursday night only.

Outdoor noise data are summarised in Table 2 and Figure 3. Noise levels were not significantly different during the week than the weekend (linear mixed model with subjects as random effect, p=0.056).

Table 2 Acoustic data, outdoor measurements

	N (%)	L_{night} mean	L_{night} std dev	L_{night} range
Weekday	307 (95.6%)	47.7 dB	5.4 dB	35.8-73.7 dB
Weekend	101 (95.3%)	47.1 dB	4.9 dB	38.5-62.6 dB

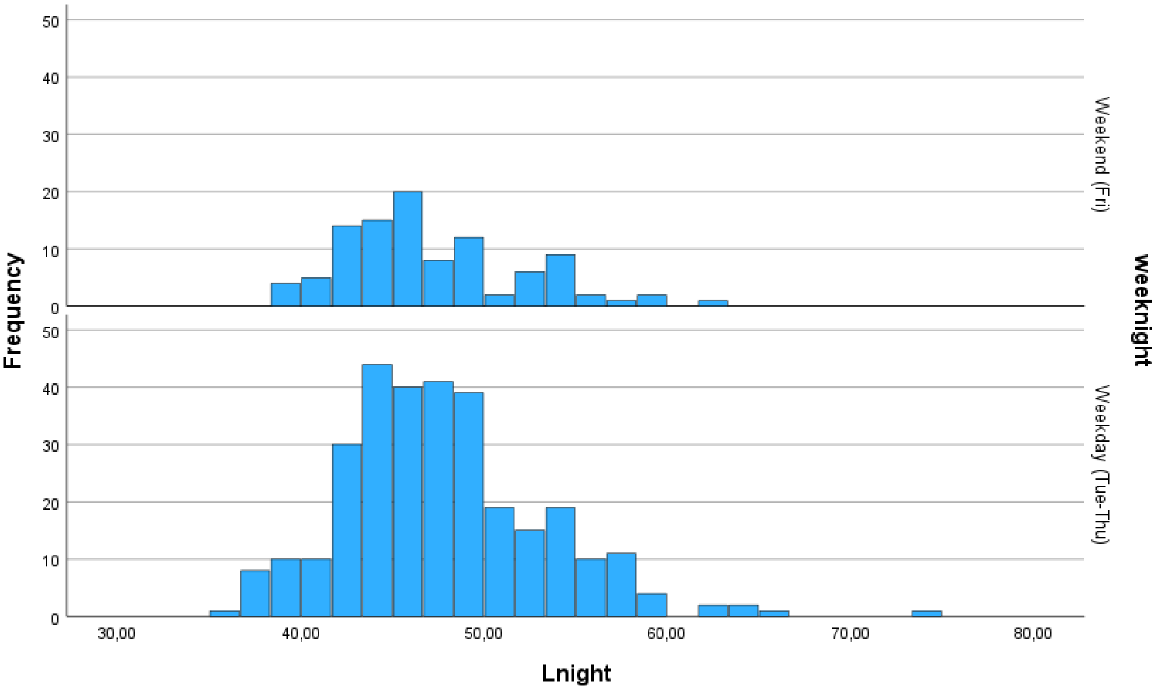

Figure 3 Distribution of average outdoor noise levels at the weekend (top) and on weekdays (bottom).

Sleep

In terms of overall signal quality, 75.5% of the sleep measurements had good data throughout the night. Therefore all sleep metrics can be calculated for these nights. The lower data quality in the remaining 24.5% of measurements was mainly due to the headband being worn poorly. The ability to determine sleep metrics from these measurements depends on the specific metric evaluated, because the algorithm may still be able to pick out the most important EEG characteristics from even a noisy (i.e. low quality) signal. TST for example could be calculated for N=42 (38.5%) of the lower quality records, meaning that TST is available for 84.9% of all nights.

DISCUSSION

Statistical analysis of collected data is ongoing to determine how environmental noise affects sleep. Results of these analyses will be presented at the ICBEN 2023 Congress. Future work will expand beyond the single exposure of noise into the wider exposome, and incorporating aspects from the physical exposome (e.g. air pollution, access to green space) but also the social and internal exposome. Results will be leveraged to determine the mediating or moderating role of physiological sleep in the exposome-mental health relationship.

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