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A laboratory study on the impact of tyre noise on sleep, cognition and blood metabolome

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ABSTRACT

Within the EU-project Low particle Emissions and lOw Noise Tyres (LEON-T), we experimentally investigated the effects of nocturnal tyre noise on sleep and the subsequent changes in indicators of cognitive and cardiometabolic function. In this first study, fifteen young healthy participants (8 women; mean±SD age 22.4±3.0 years) slept for six consecutive nights in our acoustically optimised sleep laboratory. They were exposed to nocturnal tyre noise of varying level (35 or 40 dB(A) L_{night} at the pillow) and traffic composition (continuous or intermittent [96 discrete events]). Sleep was assessed with polysomnography. Questionnaires on sleep quality, disturbance, restoration, and affect were administered. Cardiovascular/autonomic response was measured with electrocardiography and finger photoplethysmography. Blood samples were collected every morning for metabolomics analysis. Cognitive performance across multiple domains was measured every morning and evening with a computerised test battery. Data are analysed in linear mixed models (random subject effect) adjusted for age, sex, noise sensitivity and time in study. Compared to quiet baseline, nights with tyre noise were associated with higher noise-induced sleep disturbance, higher fatigue, difficulty maintaining sleep, worse sleep satisfaction than usual, and non-restorative sleep. Point estimates indicate that intermittent noise was more disturbing than continuous noise, particularly for 40 dB(A) L_{night}, although post-hoc differences between exposures were not statistically significant. There were no significant effects on subjective sleep quality, sleepiness, estimated sleep latency, number of recalled awakenings, or positive or negative affect. Further analyses are currently underway (physiologic sleep, cognition, metabolomics) and will be presented at the congress.

Keywords: Tyre noise, Sleep, Polysomnography, Metabolomics, Neurobehavioural function, Electrocardiography

INTRODUCTION

Sleep is a highly complex process that is essential for physical and mental function.[1-5] Experimental investigations on sleep loss and sleep fragmentation reveal adverse physiologic changes that are precursors to disease, including neurodegeneration.[6-13] Accordingly, epidemiologic studies consistently find associations between chronic short or interrupted sleep and negative health outcomes including increased risk for obesity, diabetes, hypertension, cardiovascular disease and all-cause mortality.[14-18] Sleep of sufficient quantity and quality is therefore a key component of health, and its disruption by environmental stressors, including noise, has important public health implications.

Traffic noise is a highly prevalent environment stressor that contributes to sleep loss and fragmentation. However, reductions in total sleep time and sleep fragmentation by nocturnal traffic noise are generally less severe than in studies of experimentally-induced sleep restriction. Nevertheless, sleep disturbance by traffic noise in the long-term may lead to the development of disease, particularly cardiometabolic diseases,[19-30] and chronic exposure to nocturnal traffic noise is associated with many of the same cardiovascular diseases and metabolic disorders linked with restricted and fragmented sleep. This suggests overlapping mechanistic pathways between long-term sleep restriction and noise exposure and the genesis of disease, although evidence linking metabolic outcomes to chronic noise exposure is sparser.[31]

Within the EU-project Low particle Emissions and lOw Noise Tyres (LEON-T), we are experimentally investigating the effects of tyre noise on sleep and biomarkers of cardiometabolic risk. Here we present the first of these experimental studies.

MATERIALS AND METHODS

The study was approved by the local ethics committee (Swedish Ethical Review Authority, 2022-03513-01). The study protocol was registered prior to subject recruitment on ClinicalTrials.gov (NCT05611619). Study subjects provided informed consent prior to the start of the study, were financially compensated for their participation, and could discontinue at any time without explanation.

Study protocol

The study took place in the sound environment laboratory (SEL) at the University of Gothenburg Department of Occupational and Environmental Medicine. The SEL is a high-fidelity research laboratory equipped to simulate a typical apartment, including three individually light-, sound- and vibration-isolated private bedrooms. Ceiling mounted speakers in each room allowed us to create a realistic acoustic environment by transmitting sound exposures from the control room to each bedroom individually.

The study used a prospective within-subjects cross-over design. Participants spent six consecutive nights in the SEL, with a sleep opportunity between 23:00-07:00. The first night was a habituation period to the study protocol and for familiarisation with the test procedures. Study nights 2-6 were experimental nights and were randomly assigned across participants using a Latin square design to avoid first-order carryover effects. One of these nights was a quiet Control night to assess individual baseline sleep, metabolic profile, and cognitive performance. The remaining four nights involved exposure to tyre noise using a 2×2 factorial design, with combinations of intermittent or continuous noise (described in further detail below), and two different sound pressure levels (35 or 40 dB L_{night}).

Study subjects arrived at the SEL by 20:00 each evening. They then completed the *Cognition* test battery,[32,33] comprising of 10 computerised tests covering a range of cognitive domains: sensorimotor speed, spatial learning and memory, working memory, abstraction

and concept formation, spatial orientation, emotion identification, abstract reasoning, complex scanning and visual tracking, risk decision making, and vigilant attention. Each night we recorded physiologic sleep with polysomnography (PSG) and cardiovascular activity with electrocardiography (ECG) and finger photoplethysmography. Each study morning subjects completed *Cognition*, and completed a short questionnaire including different dimensions of sleep quality and disturbance in the preceding night,[34] sleepiness,[35] and sleep disturbance by noise.[36] Every morning except the first (i.e. after the habituation night), subjects also provided a 4ml blood sample for metabolomics analysis.

Subjects could follow their normal daytime routine, but were prohibited from alcohol, ingesting caffeine after 15:00, and napping, checked with measures of daytime activity via wrist actigraphy monitors worn continuously throughout the study. Because extreme and/or variable dietary behaviour can affect the metabolome/lipoprotein profile,[37] participants were required to eat the same evening meal on each day of the laboratory study, which was confirmed via a food diary.

Noise exposure

Representative tyre noise was synthesised based on analysis of measurements of N=20 different tyres under different operating conditions (50/70/90 kmph speed, steering, traction, engine on or engine off).[38] Synthesised sounds were needed so that specific acoustical characteristics of the sound could be manipulated. Two traffic flow patterns were implemented. One was of continuous traffic, representative of a distant highway. The other was intermittent exposure to single noise events, representing vehicle pass-bys on a road directly outside the bedroom window. These single events involved the 12 possible combinations of three tonalities (0 dB, 1.5 dB or 3 dB tonality) by four maximum sound pressure levels in 3-dB increments (see below for level ranges). Each of these 12 combinations occurred once per hour across the full night, for a total N=96 events (12/h) during intermittent noise nights. The interval between noise events was randomised between 3.0 to 7.0 minutes (mean interval 5.0 minutes).

Noise exposures were filtered in a frequency-dependent manner to simulate the outdoor to indoor attenuation of a typical building façade. This filter resulted in a 25 dBA reduction compared to theoretical outdoor levels of 60 or 65 dB L_{night}. In the intermittent noise nights, this yielded maximum indoor sound pressure levels of 53.4-62.4 dB and 58.4-67.4 dB $L_{AF,max}$ for the two levels of L_{night} respectively.

All sound pressure levels were calibrated to 10 cm above the pillow in each bedroom prior to the study, so that levels accurately reflect the noise exposure of the subjects during sleep.

RESULTS

Participants

Fifteen healthy participants (see Table 1) were recruited via public advertisement around the University of Gothenburg campus and online. They were habitually good sleepers with a habitual mean bedtime closely aligning with the experimental sleep opportunity times. They did not suffer from any sleep disorder, use any sleep medications or medications with potential side effects impacting sleep. All participants had normal hearing, which was assessed via pure tone audiometry to 20 dB HL.

Table 1 Study subjects

Variable	Level / Metric	Value
Sex (n)	Male	7
	Female	8
Age	Mean ± SD	22.4 ± 3.0 years
	Range	18-30 years
Habitual sleep quality (PSQI) [39]	Mean ± SD	2.7 ± 1.1
	Range	1-5
Weinstein noise sensitivity score [40]	Mean ± SD	67.2 ± 15.2
	Range	37-93
Annoyance at home by road (0-10 ICBEN-scale) [36]	Mean ± SD	1.47 ± 2.1
Annoyance at home by rail (0-10 ICBEN-scale) [36]	Mean ± SD	0 ± 0
Annoyance at home by air (0-10 ICBEN-scale) [36]	Mean ± SD	0.5 ± 1.0
Sleep disturbance at home by road (0-10 ICBEN-like scale)	Mean ± SD	0.4 ± 0.7
Sleep disturbance at home by rail (0-10 ICBEN-like scale)	Mean ± SD	0.1 ± 0.5
Sleep disturbance at home by air (0-10 ICBEN-like scale)	Mean ± SD	0.1 ± 0.5
Road noise exposure at home [a]	Mean ± SD	54.6 ± 6.9 dB $L_{AEq,24h}$
	Range	47.5-67.5 dB $L_{AEq,24h}$
Chronotype (n) [b]	Definite morning type	2
	Somewhat morning type	3
	Intermediate type	4
	Somewhat evening type	4
	Definite evening type	2

[a] Extracted from publicly available modelled noise maps based on 2018 traffic flow data (https://karta.miljoforvaltningen.goteborg.se/). Data available for N=12 subjects only, the remaining three lived outside the mapped area.
[a] Based on single-item question

To check subject compliance to the self-regulated lights out time (23:00), we manually scored actigraphy data during the in-lab study period. Across all subjects and study nights, the mean ± SD lights out time was 22:58 ± 00:10. This indicates good adherence to the protocol. The actigraphy records indicated that one subject was non-compliant with the no-napping protocol, and had daytime naps on two study days (~2.5 h sleep on each occasion).

Data completeness

One subject dropped out after completing 4 of the 6 study nights. As a result, there are no data for the quiet Control or 35 dB impulsive exposure nights for this subject. Data completeness for all outcomes is summarized in Table 2. Almost all missing data were due to the subject dropout. Insufficient blood volume could be collected on one study morning. No other data were missing.

Table 2 Data completeness for all outcomes across all 15 subjects and all 6 study nights

Measure	Total expected data (n)	Data obtained (n)	Data completeness compared to expected
Blood	75	72	96.0 %
PSG	90	88	97.8%
Questionnaires - morning	90	88	97.8%
Questionnaires - evening	90	88	97.8%
Cognition - morning	90	88	97.8%
Cognition - evening	90	88	97.8%
Food diary	75	73	97.3%
Actigraphy (in-lab period)	105	103	98.1%

DISCUSSION

We aimed to investigate the consequences of sleep disturbance by tyre noise. To this end, in a controlled laboratory setting we collected data across a range of biological, psychological, and cognitive domains. Study adherence was good, and there was minimal data loss due to participant dropout or technical failure. Statistical analysis of collected data is ongoing to determine how different patterns of tyre noise affect sleep, cognition and concentrations of blood plasma metabolites. Results of these analyses will be presented at the ICBEN 2023 Congress.

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