PROCEEDINGS of the
23rd International Congress on Acoustics

9 to 13 September 2019 in Aachen, Germany

The effect of road traffic noise spectrum on sleep

Valtteri HONGISTO[1,2]; Saana MYLLYNTAUSTA[3]

[1] Finnish Institute of Occupational Health, Turku, Finland

[2] Turku University of Applied Sciences, Turku, Finland

[3] University of Turku, Turku, Finland.

ABSTRACT

PURPOSE. Two façades having nominally equivalent sound insulation declaration, such as R_w+C_{tr} value, may have very different frequency behaviors leading to different spectrum of road traffic noise (RTN) indoors. Because spectrum affects annoyance of sound, spectrum may also affect sleep quality. Our purpose was to determine, how the spectrum of RTN affects sleep.
METHODS. Twenty-one participants slept three nights in a sleep laboratory in three different conditions: LF (low frequency prominence, 37 dB), HF (high frequency prominence, 37 dB), and Q (control, quiet, 19 dB). Conditions LF and HF were created by filtering an outdoor recording of RTN through two filters corresponding to two different sound insulation spectra but equal value of R_w+C_{tr} = 37 dB. Sleep quality was measured both objectively (polysomnography) and subjectively (questionnaires).
RESULTS. Subjective sleep quality was worse in conditions LF and HF than in Q. Duration of slow wave sleep (deep sleep) was shorter in LF and HF than in Q. LF and HF did not differ from each other. After the experiment, most of the participants rated condition HF as the most disturbing for sleep.
CONCLUSIONS. High frequency RTN may be more adverse for sleep than low frequency RTN, but more research is needed.

Keywords: Sleep, environmental noise, façade sound insulation

1. INTRODUCTION

Nighttime noise level regulations concern usually the upper limit for the A–weighted equivalent sound pressure level (SPL) during the nighttime, such as $L_{Aeq22\text{-}07}$. In addition to that, penalty is often applied if the sound contains specific properties which may increase the annoyance of sound, such as impusivity or tonality. According to several studies, also the spectrum of sound affects annoyance (2–5). This suggests that the spectrum could also affect sleep disturbance.

Proper façade sound insulation is the most important way of protecting residents from environmental noise. The dimensioning of the façade is usually made in Europe by a dimensioning a minimum value for the sound insulation using a single-number quantity of ISO 717-1 standard (6). Different single-number quantities are, however, used in different countries. In Finland, the target value for the entire façade and for façade components are described by R_w+C_{tr}. The sound insulation spectrum of two different façade constructions having the same value of R_w+C_{tr} can, however, differ drastically (Figure 1a). The frequency dependence of sound insulation may, therefore, affect sleep.

There is at least one study which has studied the sole effect of spectrum (7) on sleep quality. They found that ground-borne noise from railway tunnels having larger emphasis on high frequencies affected sleep more than similar sound having larger emphasis on low frequencies with the same L_{Aeq}. Studies about the effects of the spectrum of road traffic noise (RTN) do not exist.

Our purpose was to determine, how the spectrum of RTN affects sleep when L_{Aeq} = 37 dB.

[1] -

[2] valtteri.hongisto@turkuamk.fi

[3] saakar@utu.fi

2. MATERIALS AND METHODS

We conducted a sleep study in laboratory conditions. The participants were recruited from student organizations. The inclusion criteria were normal hearing, a fairly regular sleep-wake rhythm, and being a normal sleeper (e.g. absence of sleep apnea). The participants were also required to live in an apartment building close to or nearby a busy road, as we wanted to avoid volunteers who are not accustomed to neighbor or environmental noise. It was also required that the participants did not do shift or night work, or take naps regularly.

The study sample consisted of 21 healthy volunteers (19 women). Their mean age was 25 years. The participants were given 60 Euro gift token for their participation. The experiment was approved by the ethics committee of the Hospital District of Helsinki and Uusimaa.

Our study involved three ***sound conditions***, LF, HF, and Q. The spectra are shown in Figure 1b. Each of them were presented in three different rooms (Figure 2). *Sound condition* LF consisted of RTN having more emphasis on low frequencies (37 dB $L_{\mathrm{Aeq,8h}}$) than *sound condition* HF (37 dB $L_{\mathrm{Aeq,8h}}$). *Sound condition* Q was a reference condition representing full silence (17 dB $L_{\mathrm{Aeq,8h}}$).

RTN for the laboratory experiment was recorded at a busy urban crossroads between 10 p.m. and 7 a.m. (Figure 1b, outdoor noise). The SPL of *sound condition* LF ($L_{\mathrm{in,LF}}$) was obtained by reducing the the sound reduction index (R_{LF} of Figure 1a) from the SPL of outdoor RTN (L_{out}), i.e. $L_{\mathrm{in,LF}}=L_{\mathrm{out}} - R_{\mathrm{LF}}$. Similarly, $L_{\mathrm{in,HF}}=L_{\mathrm{out}} - R_{\mathrm{HF}}$. The resulting *sound conditions* LF and HF had, therefore, drastically different spectra but the same A-weighted SPL (Figure 1b). The time profile of nocturnal RTN is shown in Figure 1c.

The study was conducted in the sleep laboratory of Finnish Institute of Occupational Health (Figure 2a) during fall 2014. The participants slept in the laboratory for 4 successive nights (Mon–Fri). The first night was reserved for habituation. Repeated measures design was applied so that each participant slept one night from 11 p.m. to 7 a.m in each room. The order of the rooms (*sound conditions*) was counter-balanced. Sound was produced into the room using loudspeakers hidden behind fake windows. The target spectrum of Figure 1b in the position of sleeper's head in the room was obtained by applying one-third-octave filtering (Adobe Audition).

Objective sleep quality was measured using polysomnography. Subjective sleep quality was determined using questionnaires on mornings and evenings. Furthermore, the *sound conditions* with respect to their sleep disturbance were ranked retrospectively after the whole experiment by a questionnaire.

Statistical analysis was done using ANOVA or Friedman's test. Paired comparisons between two *sound conditions* were done with paired-samples t-test or Wilcoxon signed-rank test.

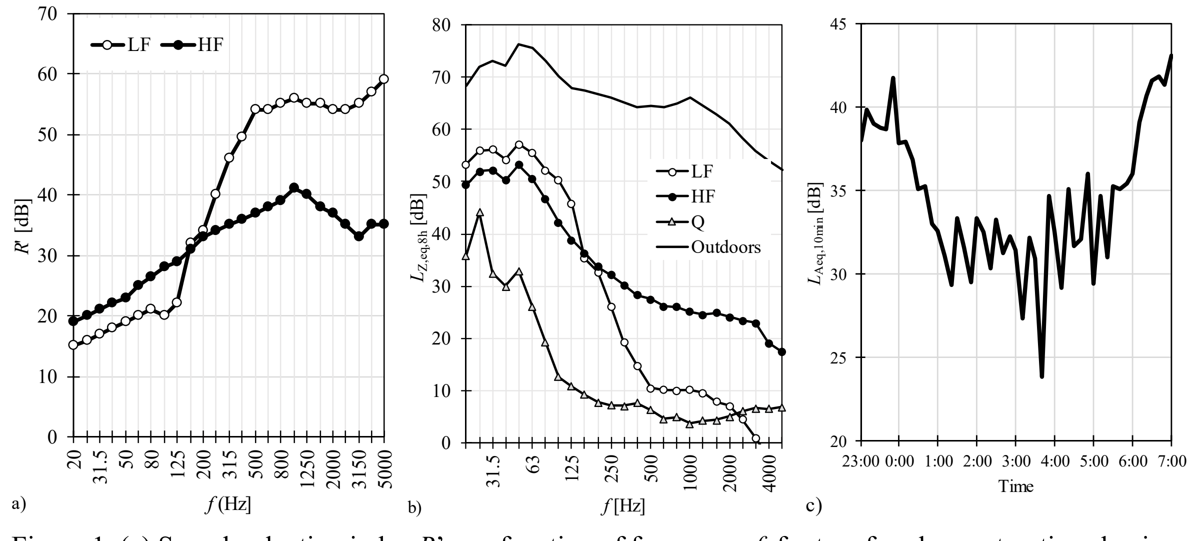

Figure 1. (a) Sound reduction index R' as a function of frequency, f, for two façade constructions having nominally the same airborne sound reduction index against road traffic noise, $R_{\mathrm{w}} + C_{\mathrm{tr}}$ = 37 dB. (b) Unweighted 8-hour equivalent SPL, $L_{\mathrm{Zeq,8h}}$, as a function of frequency for *sound conditions* LF, HF, and Q. (c) The 10-minute equivalent A-weighted SPL of RTN as a function of time in the experimental room.

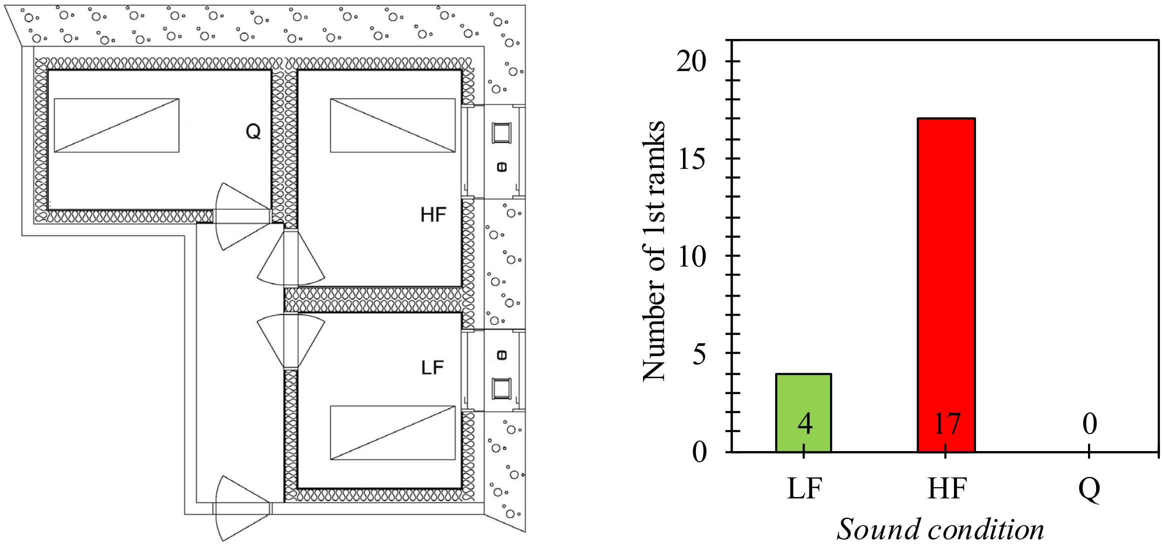

Figure 2. Left: the layout of the laboratory indicating three rooms for each *sound condition* LF, HF, and Q. Right: retrospective ranking of the three *sound conditions* with respect to their sleep disturbance.

3. RESULTS

Duration of slow wave sleep (SWS) was shorter in *sound condition* LF and HF than in Q. *Sound condition* did not have other effects on objective measures (Table 1). Subjective sleep quality was worse for many measures in *sound conditions* LF and HF than in Q (Table 2). However, *sound conditions* LF and HF did not differ statistically significantly from each other for any measure. RTN was the only environmental factor notably affecting sleep quality after the first night when the participants habituated to the environment (Table 3). After the experiment, 81% of participants rated the *sound condition* HF worst with respect to sleep disturbance (Figure 2b, p<0.001).

4. CONCLUSIONS

RTN presented at a level of 37 dB L_{Aeq} had an adverse effect on sleep both with subjective and objective measures compared to silence (17 dB). The finding concerned both studied RTN spectra, i.e. LF (low frequency content higher) and HF (high frequency content higher). Statistically significant differences were not found between the two RTN spectra. However, the retrospective ranking of the three sound conditions indicated that spectrum HF was the most adverse for sleep. Smith et al. (7) found that ground-borne noise from railway tunnels having high emphasis above 100 Hz led to greater elevations of heart rate and arousal probability than similar noise having high emphasis below 100 Hz. Smith et al. found objective evidence and we found retrospective subjective evidence. It is, thus, possible that high frequency RTN could be more adverse for sleep than low frequency RTN. More research is needed in this field.

Table 1. The results of objective sleep quality measures.

	Condition			
	LF	*HF*	*Q*	*p*
Variable	M (SD)	M (SD)	M (SD)	
Sleep latency [min]	14 (13)	13 (10)	13 (11)	>0.1
WASO duration [min]	19 (15)	18 (13)	15 (16)	>0.1
No. of arousals	49 (23)	54 (24)	47 (24)	>0.1
N1 duration [min]	29 (14)	32 (17)	27 (13)	>0.1
N2 duration [min]	228 (28)	225 (28)	218 (43)	>0.1
SWS duration [min]	86 (30)	89 (25)	97 (27)	0.01
REM duration [min]	104 (24)	104 (24)	111 (27)	>0.1

M= mean, SD = standard deviation, SWS= Slow wave sleep,
REM= rapid eye movement sleep, WASO=wake after sleep onset

Table 2. The results of subjective sleep quality measures. Means (M) and standard deviations (SD).

	Sound condition			
	LF	HF	Q	*p*
Subjective variable	M (SD)	M (SD)	M (SD)	
Satisfaction with sleep [a]	0.1 (1.1)	0.3 (1.0)	1.0 (1.0)	0.02
Subjective sleep latency [b]	2.1 (1.1)	1.9 (1.1)	1.5 (0.9)	0.01
Subjective sleep difficulties [b]	2.2 (1.0)	2.1 (1.1)	1.6 (1.0)	0.01
Subjective recovery [b]	3.2 (1.0)	3.2 (0.9)	3.5 (1.2)	0.29

[a] Response range: -2 Very dissatisfied, +2 Very satisfied

[b] Response range: 1 Not at all, 5 Very much

Table 3. The disturbance caused by different environmental factors on sleep.

		Sound condition		
	1st night	LF	HF	Q
Item	M (SD)	M (SD)	M (SD)	M (SD)
*Road traffic sound****	1.2 (0.5)	2.5 (1.2)	2.8 (1.1)	1.1 (0.2)
Silence	1.9 (1.3)	1.0 (0.0)	1.0 (0.0)	1.2 (0.5)
Cold	1.9 (0.9)	1.4 (0.7)	1.6 (0.9)	1.3 (0.7)
Hot	1.8 (1.0)	1.4 (0.7)	1.3 (0.6)	1.2 (0.5)
Bed quality	1.1 (0.3)	1.1 (0.3)	1.1 (0.5)	1.1 (0.5)
Apparatus on my body	2.8 (1.0)	1.1 (0.3)	1.2 (0.5)	1.2 (0.5)
Darkness	1.5 (1.2)	1.1 (0.4)	1.1 (0.2)	1.2 (0.6)
Unfamiliar place	2.5 (1.2)	1.3 (0.5)	1.3 (0.6)	1.4 (0.7)
Monitoring camera	1.5 (0.9)	1.3 (0.7)	1.1 (0.5)	1.2 (0.5)

*** Significant difference between *sound conditions* LF, HF, and Q ($p<0.001$).

ACKNOWLEDGEMENTS

This study was a part of ÄKK project (2012-2014) mainly funded by Tekes (Grant 2296/31/2011).

REFERENCES

1. World Health Organization. Night Noise Guidelines for Europe; Regional Office for Europe: Copenhagen, Denmark, 2009.
2. Nilsson ME. A-weighted sound pressure level as an indicator of short-term loudness or annoyance of road-traffic sound, J Sound Vib 2007;302:1-2 197-207.
3. Hongisto V, Oliva D, Rekola L. Subjective and objective rating of spectrally different pseudorandom noises – Implications for Speech Masking Design. J Acoust Soc Am 2015;137(3):1344-1355.
4. Torija AJ, Flindell IH. Differences in subjective loudness and annoyance depending on the road traffic noise spectrum. J Acoust Soc Am 2014;135(1):1-4.
5. Torija AJ, Flindell IH. The subjective effect of low frequency content in road traffic noise. J. Acoust. Soc. Am. 2015;137(1):189-198.
6. ISO (2013). ISO 717-1:2013 Acoustics. Rating of sound insulation in buildings and of building elements. Part 1: Airborne sound insulation, International Organization for Standardization, Geneva, Switzerland.
7. Smith MG, Ögren M, Morsing JA, Persson Waye K. Effects of ground-borne noise from railway tunnels on sleep: A polysomnographic study. Build Environ 2019;149:288-296.