14th ICBEN 2023 18 - 22 JUNE BELGRADE

14th ICBEN Congress on Noise as a Public Health Problem

Motorcycle Noise Study Baden-Württemberg, Part I: Long-term noise annoyance in residents living alongside busy motorcycle routes in the southwest of Germany

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ABSTRACT

Especially in places attractive to tourists, nice weather provokes high numbers of motorcycles on the roads. Thereby the local population is often exposed to high noise levels. Only a few studies have investigated the impact of motorcycle noise on residents so far. A two-part study was conducted assessing the long-term responses (study part I) and acute reactions to motorcycle noise (study part II). Five sites with busy motorcycle routes in Baden-Württemberg, in the southwest of Germany, were selected. First, residents in the exposed areas were invited to participate in a questionnaire survey. Second, a version of the experience sampling method was applied to assess residents' acute perceptions of and reactions to motorcycle traffic. Long-term noise levels were calculated according to the German road traffic noise calculation model RLS 19. This paper presents the study design and the results of part I of the Motorcycle Noise Study Baden-Württemberg on the long-term responses to traffic noise on busy motorcycle routes. In total, 493 subjects participated in the long-term questionnaire survey. Differences in exposure-response relationships for the percentage highly annoyed (%HA_V) were found, indicating higher annoyance due to motorcycle noise than other road traffic noise sources.

Keywords (3-6): Noise, Road traffic, Motorcycle, Annoyance

INTRODUCTION

Road traffic noise is one of the most widespread environmental noise sources. Robust evidence of the harmful health effects of road traffic noise exists. Amongst the health outcomes of road traffic noise are high annoyance[1], sleep disturbance[2], cardio-vascular diseases[3], as well as depression[4], and cognitive impairment in children[5]. However, less evidence from socio-acoustic field studies exists for noise responses and health effects due to noise from specific types of vehicles, such as lorries or motorcycles. Nevertheless, the number of complaints about motorcycle noise has increased especially in more rural places attractive to tourists. In these places, in warmer seasons, nice weather provokes high numbers of motorcycles on the roads. Thereby the local population is often exposed to high noise levels.

A literature analysis on responses due to motorcycle noise revealed 780 papers, of which nine papers describing eight studies were further included and examined[6-15]. A further conference paper was added to the literature analysis dealing with a laboratory study on noise annoyance caused by mopeds and other traffic sources[15].

Regarding the noise effects studied, most studies refer to noise annoyance assessed according to recommendations from the International Commission on Biological Effects of Noise (ICBEN)[16]. Some studies also investigated the impact of motorcycle noise on the disturbance of activities during daytime and sleep disturbance[7,9,10]. In an Austrian field study on the effects of motorcycle noise in Tyrol, the annoyance due to motorcycle noise related to the average summer Sunday sound level $L_{d,SuSy}$ at daytime (13 hours) was found to be considerably higher compared to noise annoyance due to other road traffic noise sources[10]. The difference is equivalent to a shift of more than 30 dB, leading the authors to the conclusion that a malus of about 5 dB for motorcycle noise, as proposed by other authors[11,15] would be an estimation set too low.

Annoyance and disturbances due to motorcycle noise turn out to be higher, in particular at routes in attractive – mostly rural – areas in warmer seasons in the evening and night as well as on Sundays and holidays[9,10]. Therefore, it is argued that seasonal sound level metrics are a better predictor for annoyance and disturbances than annually averaged sound levels[9,11].

Psycho-acoustic studies hint to sound characteristics that could explain the motorcycle noise annoyance[8,12,14]. These are, in particular, the motorcycle sound's loudness, roughness, and sharpness. The driving behaviour of motorcyclists plays an important role here. High noise levels are specially produced by driving manoeuvres such as starting from traffic lights at maximum acceleration, changing to a lower gear at high speeds, or driving in sports mode with an open exhaust flap if the vehicle allows for manual activation of the exhaust flap or active sound generation[13,14]. For residents, high revolutions while accelerating, fast and aggressive riding, groups of motorcycles, and low frequencies ('humming') are essential disturbing characteristics of motorcycling[10].

In order to assess the impact of motorcycle noise on residents living along scenic routes in Germany, a two-part socio-acoustic study was carried out in five sites with busy motorcycle routes in Baden-Württemberg in the southwest of Germany. The focus of the first study part was on long-term responses to motorcycle noise, i.e., annoyance and disturbance, compared to responses to other road traffic noise sources. In the second study part, among others, short-term (hourly) annoyance due to noise from motorcycles, cars, lorries, and coaches was estimated within an experience sampling survey[17] and related to source-specific hourly sound levels ($L_{Aeq,1h}$). Benz et al.[18] present the second study part in more detail. This paper describes the conduction and main results of the first study part on long-term responses to motorcycle noise.

MATERIALS AND METHODS

Study design

The socio-acoustic study was conducted as an online and postal survey (mixed mode) in five scenic areas along popular motorcycle routes in Baden-Württemberg in the southwest of Germany. This are the places Güglingen, Gaggenau, Gernsbach, Oppenau, and Engen. Figure 1 shows the location of the study sites.

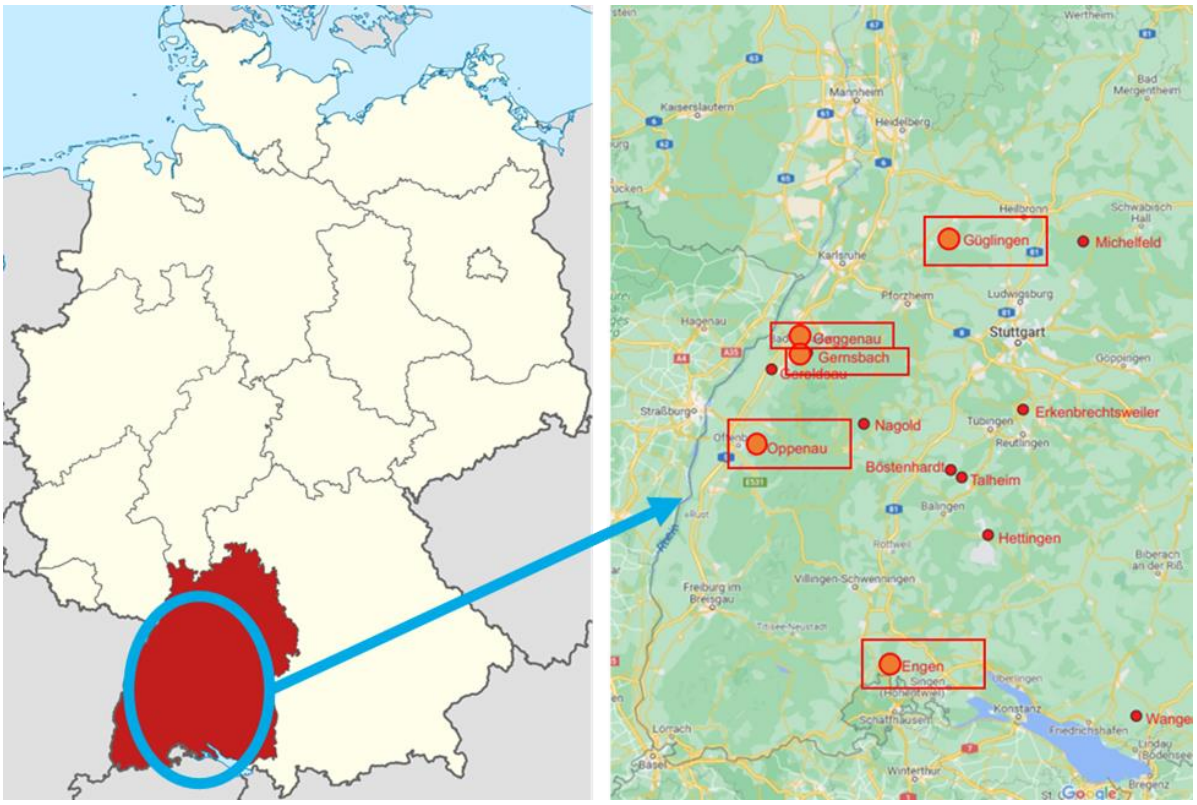

Figure 1: Study sites of the motorcycle noise study in Baden-Württemberg, in the southwest of Germany

Based on official register data, a random sample of adult residents was drawn in each study area. The residents selected for study participation received an invitation letter informing them about the study and about privacy issues and inviting them to participate in the survey. The invitation mailing included a link to the online questionnaire and a paper-pencil version to be filled in and sent back by mail. The participants could decide whether to participate online or use the paper-pencil questionnaire.

Long-term exposure to road traffic noise was assessed based on traffic volume data for the main roads passing through the study sites. Noise levels were assessed for the address of each participant and linked with the survey data for exposure-response analysis.

Road traffic noise exposure

Road traffic noise exposure metrics were assessed with the German calculation model for road traffic noise RLS-19[19] using SoundPLAN 8.2. For the address of each survey participant, the continuous sound level for daytime $L_{Aeq,day}$ (6 am - 10 pm), night-time L_{night} (10 pm - 6 am), and the day-evening-night level L_{den} were estimated. In this paper, results referring to L_{den} and L_{night} are presented.

Questionnaire

The questionnaire includes questions about the following concepts/topics:

- Residential satisfaction: Satisfaction with the residential area and the dwelling (two items regarding satisfaction assessed on a 5-point scale from (1) 'not' to (5) 'very').
- Residential situation: length of residence, house ownership, type of house, availability of balcony, terrace, or garden, hours away from home, window position (single items).
- Place attachment[20-21] (the emotional attachment to the home, neighbourhood, or place of residence): Active place attachment (3 items, α = 0.72), traditional place attachment (3 items, α = 0.75), placelessness (3 items, α = 0.81) with judgments assessed on a 5-point scale from (1) 'not' to (5) 'very'.
- Sensitivity to environmental conditions (single items: noise, odour, weather, environmental stress) assessed on a 5-point scale from (1) 'not' to (5) 'very.'
- Annoyance due to different sources of road traffic noise: cars, lorries, coaches, agricultural traffic, and motorcycles within the past 12 months (assessed with the ICBEN verbal 5-point scale as recommended by ICBEN and ISO/TS 15666[16,22]). Respondents who chose the two upper categories of the verbal scale, 'very' and 'extremely', are defined as being highly annoyed (HA_V according to ISO/TS 15666[22]).
- Time of day, day of the week, and the season when motorcycle noise is mainly annoying.
- Noise annoyance due to characteristics of motorcycle sound (high revolutions while accelerating, fast and aggressive riding, groups of motorcycles, and low frequencies ['humming'], rattle) assessed with the 5-point ICBEN scale[16,22].
- Disturbance of activities in the daytime (communication, relaxation, concentration), sleep disturbance (when falling asleep, during the night sleep, when sleeping in) within the past 12 months. A verbal 5-point scale similar to the annoyance scale was used for the assessment. Those who chose the upper two categories of the 5-point scale for judging their sleep disturbance are regarded as highly sleep disturbed (HSD_V).
- Attitudes towards motorcycle traffic[9]: positive (3 items, α = 0.75), negative (3 items, α = 0.81) with agreement to statements assessed on a 5-point Likert scale.
- Capacity to cope with motorcycle noise (6 items, α = 0.85) with judgments assessed on a 5-point scale from (1) 'not' to (5) 'very'.
- Socio-demographic variables (e.g. age, gender).

Statistical analysis

The software package R, Version 4.2.1 was used for the statistical analysis. Logistic regressions were calculated to estimate the exposure-response relationships for noise annoyance and sleep disturbance due to the noise from different types of vehicles. In the regression models, the criterion variable is the probability of being highly annoyed and highly sleep disturbed, respectively, in per cent ($\%HA_V$, $\%HSD_V$), and the predictor is L_{den} and L_{night}, respectively, as metric for overall road traffic noise exposure. Further, the correlation of variables of road traffic noise annoyance and exposure with other motorcycle noise responses and non-acoustic factors were analysed by calculating Pearson correlation coefficients.

RESULTS

In total, 493 residents participated in the study, 240 of them male, 240 female, 13 participants did not inform about their gender. The age ranged from 18 to 95 years (M = 52.7, SD = 17.2). The sample was exposed to road traffic noise levels of L_{den} from 37 to 74 dB (M = 53.8,

SD = 7.8) and L_{night} from 27 to 65 dB (*M* = 43.1, *SD* = 7.8). Figure 2 depicts the distribution of the road traffic noise levels L_{den} and L_{night} in the sample.

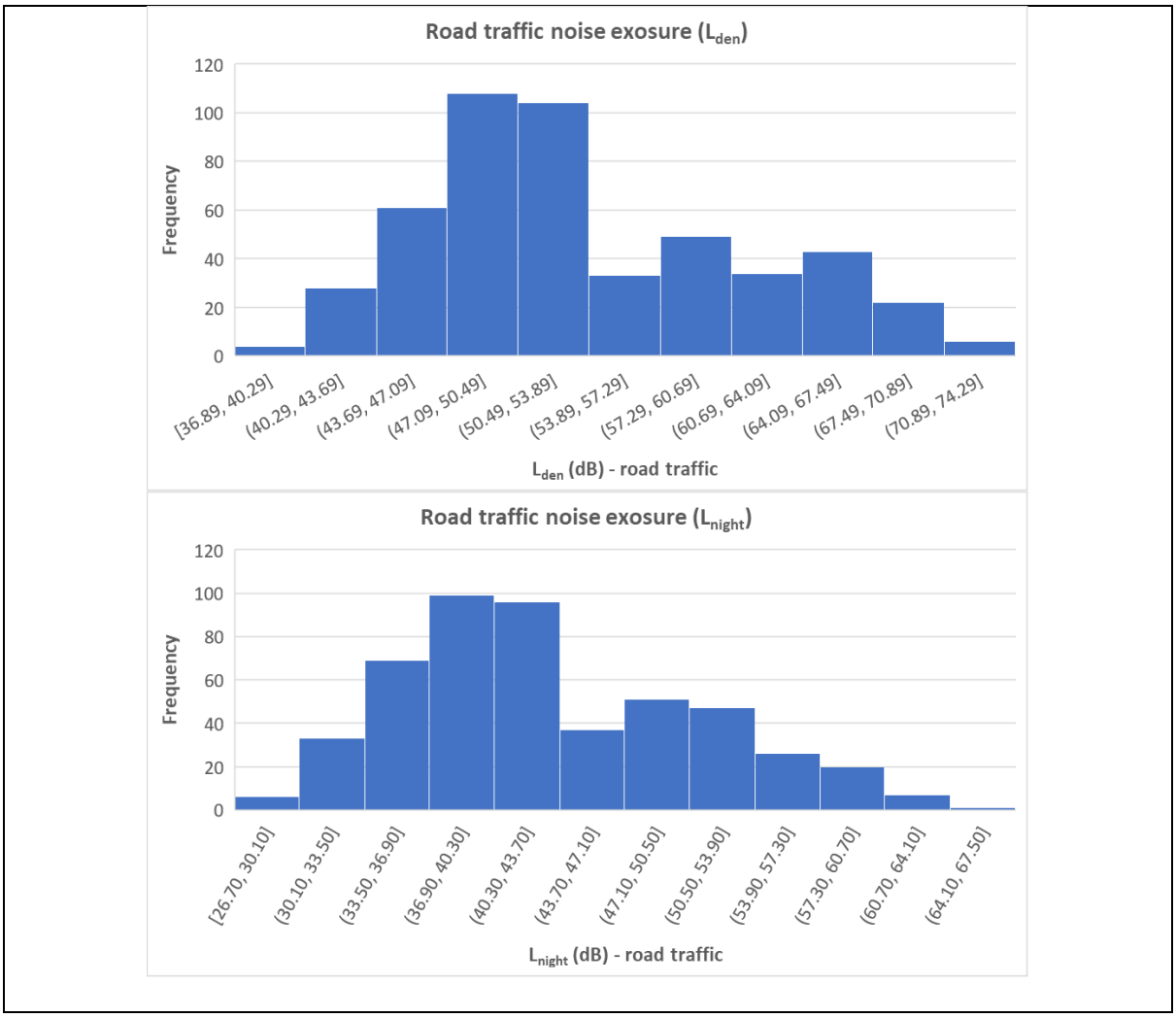

Figure 2: Distribution of the road traffic noise levels L_{den} (top) and L_{night} (bottom) in the sample.

Table 1 shows the annoyance judgments concerning noise from different types of vehicles. Most participants are highly annoyed (HA_V, very and extremely) by motorcycle noise (HA_V = 46.5%), followed by overall road traffic noise (HA_V = 25.1%), lorries (HA_V = 19.3%) and cars (18.4%). Fewer respondents are highly annoyed by noise from agricultural traffic (HA_V = 8.7% and coaches ((HA_V = 6.2%). The ranking order of the noise sources regarding the average noise annoyance is almost similar.

Descriptives for sleep disturbance due to motorcycle noise when falling asleep, during the night, and when sleeping in are shown in Table 2. Motorcycle noise is, in particular, disturbing when falling asleep (HSD_V = 20.3%, *M* = 2.23), followed by sleep disturbance in the early morning when sleeping in (HSD_V =17.2%, *M* = 2.13). In comparison to that, respondents are less disturbed by motorcycle noise during the night (HSD_V = 13.1%, *M* = 1.86).

Table 1: Annoyance due to several sources of road traffic noise

Noise annoyance	*N*	*M*	*SD*	not at all	slightly	moderately	very	extremely	HA_V
				%	%	%	%	%	%
Road overall	486	2.64	1.14	18.7%	28.6	27.6	20.4	4.7	25.1
Car	479	2.45	1.09	23.4%	29.2	29	15.9	2.5	18.4
Lorry	475	2.33	1.20	32.2%	26.7	21.7	14.9	4.4	19.3
Coach	467	1.73	0.98	56.1%	21.8	15.8	4.9	1.3	6.2
Agricult. tr.	482	1.92	1.08	47.5%	24.3	19.5	5.8	2.9	8.7
Motorcycle	488	3.09	1.46	21.7%	15.6	16.2	24.8	21.7	46.5

Table 2: Sleep disturbance due to motorcycle noise

Sleep disturbance	*N*	*M*	*SD*	not at all	slightly	moderately	very	extremely	HSD_V
				%	%	%	%	%	%
fall asleep	486	2.23	1.32	42.4	20.5	16.9	12.7	7.6	20.3
during night	479	1.86	1.20	56.3	19.7	10.9	7.8	5.3	13.1
sleeping in	475	2.13	1.26	43.7	22.9	16.1	11	6.2	17.2

Figure 3 depicts the exposure-response relationship for the source-specific percentage of highly annoyed people ($\%HA_V$, probability of high annoyance in per cent) related to L_{den} for overall road traffic noise. The percentage of highly sleep-disturbed people ($\%HSD_V$, probability of high sleep disturbance in per cent) due to noise from different types of vehicles against the L_{night} is shown in Figure 4.

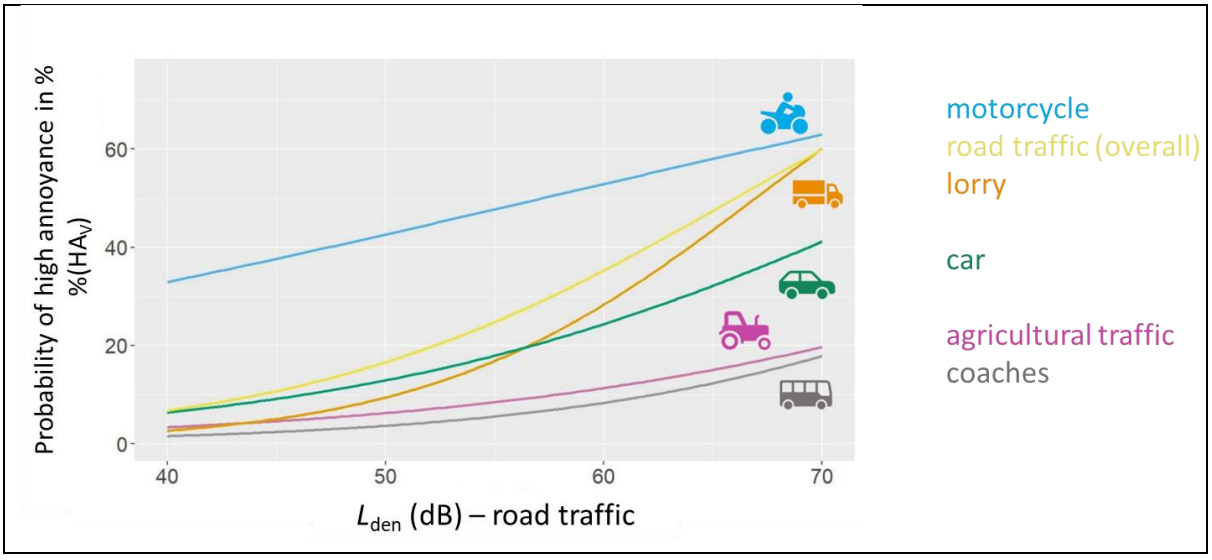

Figure 3: Probability of high annoyance due to sources of road traffic noise in per cent ($\%HA_V$) against L_{den} for overall road traffic noise

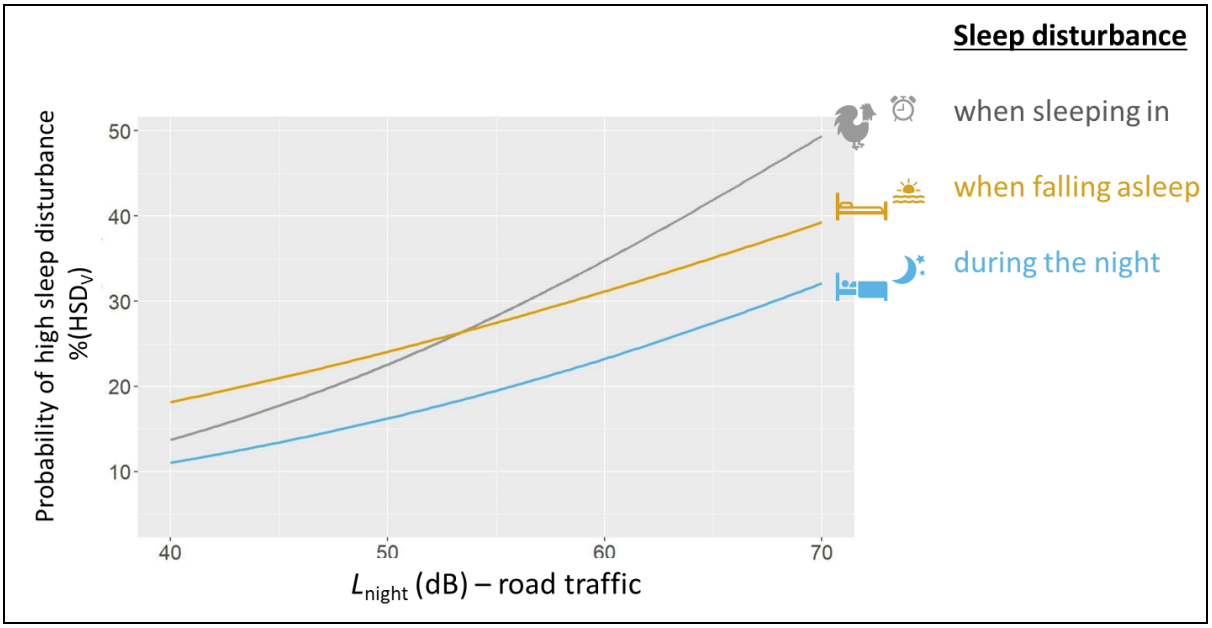

Figure 4: Probability of high sleep disturbance due to sources of road traffic noise in per cent (%HSD_V) against L_{night} for overall road traffic noise

Figure 5 shows the mean annoyance (with standard error) of annoyance due to specific characteristics of the motorcycle noise. It turns out that it is mainly the driving behaviour (high revolutions while accelerating, fast/aggressive riding) and the perception of the resulting sound it produces that annoys the respondents.

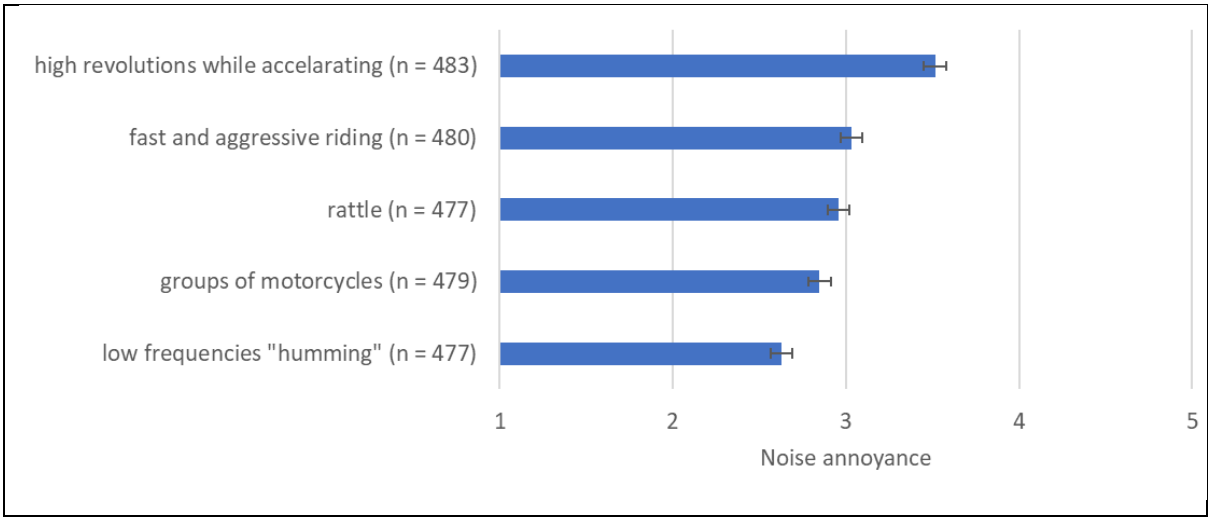

Figure 5: Mean noise annoyance due to characteristics of motorcycle sound

Regarding time, as Table 3 reveals, motorcycle noise mainly annoys in the afternoon and evening, on Sundays and holidays, and in the summer and spring.

Table 3: Time periods when motorcycle noise is most annoying (multiple responses)

Time of day			Day of week			Season		
	N	%		*N*	%		*N*	%
Morning	60	11.4	Mon – Fri	167	33.9	Spring	149	28.8
Noon	66	12.5	Sat	94	19.1	Summer	320	61.9
Afternoon	217	41.1	Sun/holiday	232	47.1	Autumn	41	7.9
Evening	124	23.5				Winter	7	1.4
Night	61	11.6						
Total	528	100.0	Total	493	100.0	Total	517	100.0

Note. $N_{persons}$=493.

Table 4 shows correlations between annoyance due to noise from road traffic vehicle types and the overall road traffic noise levels L_{den} and L_{night} and the correlation of these variables with selected further noise responses and attitudes. The road traffic noise levels correlate higher with noise annoyance due to lorries and overall road traffic noise than with annoyance due to noise from other types of vehicles. The lowest correlations are between motorcycle noise annoyance and road traffic sound levels.

The annoyance judgments referring to the noise of all types of vehicles correlate moderately with activity disturbances in the daytime and sleep disturbance due to motorcycle noise ($0.30 < r < 0.83$). The highest correlations are between motorcycle noise annoyance and the disturbance variables ($0.56 < r < 0.83$). The disturbances due to motorcycle noise correlate relatively low ($r < 0.2$) with the overall road traffic sound levels.

The capacity to cope with motorcycle noise, which can also be regarded as perceived control of the motorcycle noise situations, correlates negatively with annoyance due to motorcycle noise ($r = -0.73$) but also somewhat less strongly with annoyance due to the other road traffic noise sources. That is, the higher the perceived capacity to cope with noise, the lower the annoyance due to motorcycle noise and noise from other types of vehicles. Noise sensitivity correlates positively with the noise annoyance judgments indicating higher annoyance with increasing noise sensitivity. Among these correlations, the highest correlation is found between noise sensitivity and motorcycle noise annoyance ($r = 0.50$).

The attitudes towards motorcycles correlate with motorcycle noise annoyance: the agreement to positive statements correlates negatively, and the agreement to negative statements correlates positively. That is, the more positive and the less negative the attitudes towards motorcycles are, the lower the annoyance due to motorcycle (and other road traffic) noise. The capacity to cope with motorcycle noise, the noise sensitivity, and the attitudes towards motorcycles are not associated with road traffic noise levels hinting at the assumption that these variables moderate the exposure-response relationship of motorcycle noise annoyance. Place attachment of the surveyed residents is not associated with road traffic noise exposure or annoyance due to sources of road traffic noise.

Residential satisfaction, particularly the satisfaction with the residential area, is to a similar degree negatively correlated with the noise annoyance judgments and road traffic noise levels ($-0.31 > r > -0.46$). That result indicates that with increasing noise levels and annoyance, the satisfaction with the residential area (and, to a lesser extent, the satisfaction with the dwelling) decreases. These hints at the assumption that residential satisfaction is a secondary reaction to road traffic noise.

Table 4: Correlations of road traffic noise annoyance and exposure with selected variables (*N*: 452 – 492)

Correlation *r*	Noise annoyance						Road traffic noise levels	
	Road overall	Car	Lorry	Coach	Agricul tural tr.	Motorc ycle	L_{den}	L_{night}
Road traffic noise levels								
L_{den}	0.318	0.279	0.401	0.280	0.243	0.190	1.000	0.995
L_{night}	0.302	0.264	0.399	0.280	0.233	0.163	0.995	1.000
Disturbances due to motorcycle noise …								
...when having a conversations or phone call	0.597	0.533	0.394	0.302	0.307	0.690	0.184	0.161
...while listening to radio/ music or watching television	0.568	0.483	0.370	0.307	0.300	0.669	0.197	0.174
...while reading, thinking or concentrating	0.603	0.499	0.409	0.296	0.299	0.706	0.154	0.133
...while relaxing and taking a rest after work	0.605	0.505	0.376	0.277	0.307	0.749	0.137	0.118
...when socialising at home or when having visitors	0.580	0.493	0.357	0.297	0.290	0.686	0.156	0.132
...when staying and relaxing outdoors	0.667	0.554	0.406	0.255	0.291	0.832	0.135	0.113
...when having conversations outdoors	0.651	0.562	0.407	0.273	0.304	0.807	0.178	0.152
...when falling asleep	0.509	0.491	0.421	0.402	0.355	0.568	0.136	0.134
...at night, during sleep	0.415	0.407	0.360	0.373	0.317	0.434	0.127	0.132
...when sleeping off	0.510	0.484	0.371	0.335	0.353	0.561	0.198	0.187
Capacity to cope with motorcycle noise	-0.548	-0.439	-0.314	-0.203	-0.212	-0.730	-0.086	-0.067
Noise sensitivity	0.442	0.401	0.233	0.187	0.238	0.502	-0.028	-0.036
Pos. attitudes motorcycles	-0.375	-0.285	-0.196	-0.166	-0.176	-0.571	-0.062	-0.046
Neg. attitudes motorcycles	0.463	0.369	0.231	0.147	0.181	0.651	0.002	-0.020
Active place attachment	-0.037	-0.059	-0.026	-0.077	-0.037	-0.006	-0.011	-0.011
Traditional place attachm.	-0.110	-0.132	-0.031	-0.074	-0.070	-0.065	-0.088	-0.079
Placelessness	-0.101	-0.126	-0.040	-0.012	-0.049	-0.071	-0.059	-0.063
Satisfaction residential area	-0.426	-0.457	-0.381	-0.324	-0.313	-0.321	-0.351	-0.341
Satisfaction dwelling	-0.255	-0.251	-0.186	-0.168	-0.226	-0.134	-0.149	-0.142

coefficients highlighted in red/grey: not significant

DISCUSSION

This study on long-term responses to motorcycle noise shows that - in mostly rural - areas alongside scenic routes attractive for motorcycling, the motorcycle noise annoyance is with 46.5 % of the sample being highly annoyed considerably high and higher compared to noise annoyance due to other sources of road traffic noise. Correspondingly, the exposure-response curve for $\%HA_V$ due to motorcycle noise against the L_{den} for road traffic noise is above the $\%HA_V$-curves for other road traffic noise sources. That is in line with results from previous studies on motorcycle noise that, regarding the effects on annoyance, indicate a malus for motorcycle noise in comparison to noise from cars[9-12,15]. Motorcycle noise especially annoys in the afternoon and evening, disturbs when falling asleep, and annoys mainly in warmer seasons (spring, summer) and more at weekends, especially on Sundays and holidays than

on weekdays (Monday - Friday). That corresponds to Lechner et al.[10], who show long-term motorcycle noise annoyance to be stronger associated with seasonal sound levels, such as the continuous sound levels during Sundays in summer, than yearly averaged sound levels. Characteristics of motorcycle sound resulting from aggressive, avoidable driving behaviour, such as driving with high revolutions while accelerating and fast driving, are the main annoying characteristics. That confirms results showing high motorcycle driving speed to be associated with high annoyance[13]. Results are further in line with results from the Austrian motorcycle noise study where the disturbing effect of the same characteristics (except rattle) was asked for nearly the same order of mainly disturbing characteristics than in this study were identified[10].

Like many other previous studies on environmental noise annoyance, this study showed that motorcycle noise disturbs people's activities at home, both during daytime (e.g., disturbance of communication, relaxation, and concentration, indoors and outdoors) and at night-time when falling asleep, during the night, and in the early morning when sleeping in. Several non-acoustic factors are associated with noise annoyance, like the capacity to cope with noise, noise sensitivity, and motorcycle-related attitudes. Again, this aligns with previous research, particularly the recently published socio-acoustic survey on motorcycle noise effects conducted in Tyrol[9-10].

A main limitation of this study is that long-term source-specific sound levels were not available for exposure-response analysis. Only the overall road traffic sound levels L_{den} and L_{night} modelled according to the German road traffic noise calculation model RLS-19[19] could be related to the source-specific noise annoyance and disturbances. Thus, it cannot be conclusively clarified on the basis of the data whether there is a source-specific annoyance effect of motorcycle noise in terms of a malus or whether the higher annoyance compared to annoyance due to noise from other types of vehicles is merely a result of higher exposure (sound levels).

However, the authors of this study were further interested in details about motorcycle noise responses closer to the event, particularly in the diurnal and weekday-related variation in motorcycle noise annoyance and in motorcycle characteristics contributing to the annoyance. Therefore, in the second study part, the hourly annoyance due to motorcycle noise was investigated using the experience-sampling approach with a subsample of the survey participants described in this paper. In this second study part, the road traffic noise was measured in the study areas during the daytime (8 am to 8 pm), and the source-specific hourly sound levels for each vehicle type were estimated for the home address of each participant in parallel to the hourly annoyance assessments. Further details and the results of this second study part is presented by Benz et al.[18].

CONCLUSION

A total of 493 residents living in the southwest of Germany along scenic routes attractive to motorcycling were surveyed with regard to annoyance and disturbances due to motorcycle noise. Motorcycle noise turned out to produce higher annoyance in comparison to noise from other road traffic sources. Sound characteristics that result from high-speed and aggressive driving behaviour belong to the main annoying factors. Motorcycle noise seems to be a seasonal noise problem that is underestimated if yearly averaged sound levels are considered. The annoyance is higher in warmer seasons, particularly in the afternoon and evening and on Sundays and holidays. A preliminary conclusion is that seasonal sound levels might better predict motorcycle noise annoyance and disturbances than sound levels averaged across the whole year. Interventions should focus on single loud events and avoidance of driving behaviour that results in unnecessary and avoidable high sound levels.

Acknowledgements

We want to thank all participants of the Motorcycle Noise Study Baden-Württemberg for their involvement in the study. This study was commissioned and funded by the Ministry of Transport Baden-Württemberg.

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