MADRID
inter.noise 2019
June 16 - 19
NOISE CONTROL FOR A BETTER ENVIRONMENT

The effects of noise reducing pavement and speed reduction on noise responses

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ABSTRACT

Noise reducing pavements and speed reduction can be effective solutions to reduce noise from road traffic. How residents experience such interventions are rarely evaluated. We conducted a socio-acoustic before-after study to investigate changes in noise levels and resident's noise responses after implementation of these two noise abatement measures. A total of 62 people responded to a questionnaire both before and after the interventions (31 in the intervention area and 31 in the control area). In both areas, noise levels from road traffic ranged between $L_{Aeq,\ 24h}$ 53 dB and 64 dB and noise annoyance was high. In the intervention area, noise levels decreased by about 4-5 dB and noise annoyances (general annoyance, annoyance indoor with closed and open window and outdoors) were significantly reduced. Disturbed sleep from vibrations dropped from 42 to 16 %. In the control area, no changes in noise exposure occurred, but noise responses changed somewhat. In general, they increased in the after study. A majority (64 %) in the intervention area were satisfied with the noise abatement measures, but asked for further solutions to improve the noise situation.

Keywords: Road traffic noise, Intervention, Annoyance
I-INCE Classification of Subject Number: 66

1. INTRODUCTION

Low noise road pavements have long been tested in Sweden as a measure to reduce the noise levels from road traffic. Noise reduction and other asphalt-related factors that affect noise characteristics are most often evaluated in these projects [1-5]. However, there are rather few studies that have evaluated how people perceive acoustically the low noise pavements and how it affects health and well-being, such as general annoyance, relaxation, sleep, and outdoor life [6-8]. The results from these studies indicate that this type of asphalt can be of importance for reducing the negative health impacts of noise. In the latest environmental noise guidelines, the World Health Organization (WHO) [9] underlines the importance of reducing noise exposure to counteract the adverse effects on human health and well-being. To reduce noise at the source is considered the most effective measure.

This paper presents results from an intervention study that investigates the effects of noise reducing pavement and speed reduction on resident's noise responses.

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2. METHOD

2.1 Design and Study Area

We conducted a socio-acoustic intervention study before and after noise abatement measures. The intervention area consists of detached houses, most of them built in the 20-30s. Selected houses are located close to a major road in Örebro Sweden. On the west side of the road, there is a noise barrier and on the east side, there is both a noise barrier and an earth berm. The height of the barrier is generally about 3 meters, but the height of the earth berm varies between 1-2 meters. In 2016, traffic volume was about 20 500 vehicles/day of which approximately 5% constituted heavy traffic. The control area has similar conditions as the intervention area. It is located at the same major road and about 4-5 km north of the intervention area. The houses are detached and most of them built between 30-60s. In 2014, traffic volume was about 20 400 vehicles/day of which approximately 7% constituted heavy traffic. On the west side of the road, there is a noise barrier and on the east side, there is both a noise barrier and an earth berm.

2.2 Questionnaire

In May 2017 (the before study) and in May 2018 (the after study), a questionnaire was distributed by mail to all residents between 18 and 80 years of age in the intervention area and in the control area. An introductory letter presented the survey as an investigation on health and well-being in housing environments. Two reminder letters were sent with 10-day intervals to those who did not respond. The first reminder was a card while the other consisted of a reminder letter with a new questionnaire. The questionnaire was based on previous socio-acoustic studies evaluating adverse health effects of traffic noise [8, 10, 11]. Overall, the same questionnaire was used in both study occasions.

2.3 Study Population

In the before study, 40 out of 63 residents (63%) participated in the intervention area and 45 out of 73 (62%) in the control area. These numbers in the after study was 33 out of 58 residentss (57%) and 36 out of 70 (51%), respectively. A total of 62 residents participated in both study occasions (31 in the intervention area and 31 in the control area). The average age in the intervention area was 57 years and in the control area 55 years and the proportion of women was 48 and 52% respectively. The majority was married or *de facto* cohabiting (90 and 90% respectively). In both areas, the proportion of employees was 61% and about a quarter was old-age pensioners.

2.4 Noise Abatement Measures

The road surface in the before situation was represented by 5 years old asphalt concrete having 11 mm maximum aggregate stone size. The Swedish type designation is ABS 11, which in English corresponds to SMA 11. In August 2017, the old pavement was replaced with a new type of pavement where the ballast consisted of steel slag. It had a maximum aggregate size of 8 mm and the layer was 25 mm. When the asphalt contains smaller stones, it gets a smoother road surface, and thus a better noise-reducing effect than conventional asphalt [12]. Tests of steel slag in pavements have shown very good properties in terms of stability, stiffness and durability [3]. Although, the steel slag pavement do not reduce noise as good as other low noise road surfaces, such as double-layer porous asphalt [2], a noise reduction of about 4 dB was expected since the old pavement was damaged and worn-out, in some places down to the first asphalt gravel layer [12]. In the middle of September 2017, the speed limit in the intervention areas was reduced from 70 to 60 km/h.

2.5 Measurement Method

Noise measurements were made with the CPX-method (Close proximity) according to the ISO 11819-2. The method is specially designed to measure road surface noise characteristics and it gives a good picture of the differences in noise levels between different pavements and speeds [12, 13]. Using a measuring carriage with two fitted extra tires, a tire roller in the left wheel track and the other in the right wheel track, the noise levels was measured using two microphones at each of the tires. The two tires are considered as references for the CPX-method and represent passenger car tires and heavy vehicle tires. The measurements were carried out at 50 and 70 km/h.

2.6 Determination of Noise Exposure

Noise levels from road traffic were calculated using the Nordic Prediction Method [14]. Estimations of $L_{Aeq,24h}$ and L_{AFmax} were determined for all selected houses in the two areas. As a basis for the calculations, data available on traffic volume (total and percentage of heavy traffic), the sign-posted speed limit on the current roads, height of noise barriers and earth beams, and digital maps of the areas were used. Table 1 shows that the two study areas before interventions did not differ in estimated noise levels from road traffic.

Table 1. Noise levels from road traffic for the intervention area and the control area before noise abatement measures.

	Intervention area (n=31)		Control area (n=31)	
	$L_{Aeq,24h}$	L_{AFmax}	$L_{Aeq,24h}$	L_{AFmax}
Mean	58.2	64.7	58.2	64.5
SD	2.1	3.2	2.9	4.2
Minimum	54	57	53	56
Maximum	63	71	64	72

2.7 Data Analysis

The McNemar-test was used to test a change in proportions (before and after interventions) for paired data. All tests were two-tailed and a *p*-value below 0.05 was chosen as the threshold for considering a given relationship significant. The statistical analyses were conducted with SPSS Statistics 22.

3. RESULTS

The present paper focus on presenting the effect of the interventions on noise levels, road traffic noise annoyances, sleep, and on perceptions of the outdoor sound environment. The results shown are based on the respondents who participated in both study occasions (intervention area, n=31; control area, n=31).

3.1 Change in Noise Levels in the Intervention Area

A measurement of the road pavement’s noise properties was carried out in June 2017 with the CPX-method. After repaving with the new steel slag asphalt, two measurements were made, in September 2017 and in June 2018. To reduce the amount of data, each curve in Figure 1 shows an arithmetic mean of the two speeds 50 and 70 km/h and the two directions north and south for the reference car tyre P1. The curves show the differences between the old pavement and the new pavement with steel slag, as well as between the two lanes L1 and L2 [12].

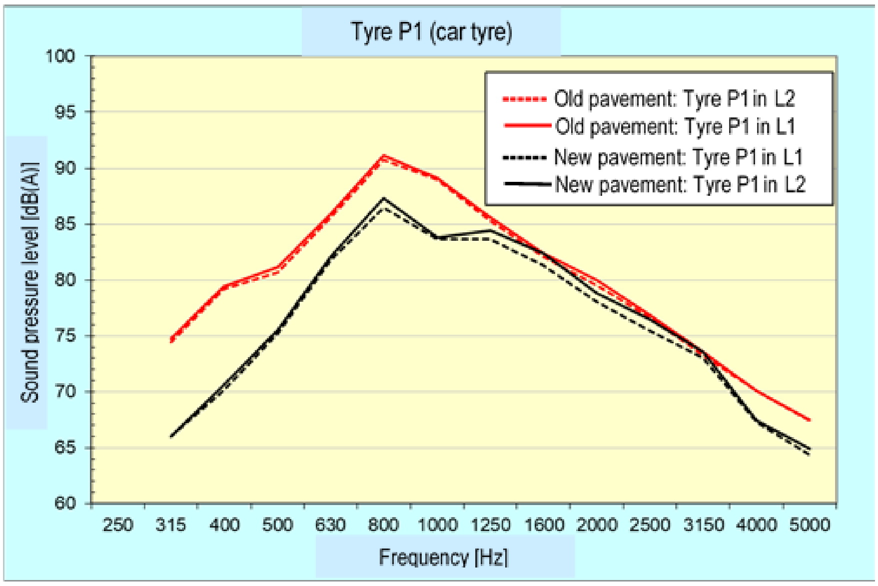

Figure 1. A-weighted frequency spectra for the reference car tyre P1 (car tyre), calculated mean value for the directions north and south and for 50 and 70 km/h. The curves show the differences between the old pavement and the new pavement with steel slag and between the two lanes L1 and L2 [7].

The same measurement for the reference truck tyre is reported in [12]. The measurements show that the noise reduction effect after repaving with the steel slag asphalt decreased relatively much during the first year. In the beginning, the A-weighted noise reduction was just over 3 dB compared to the old pavement – the differences were mainly up to 1000 Hz (see Figure 1) – but in June 2018, the reduction had fallen to about 1 dB. The causes of the deterioration have not yet been clarified [13]. A reduction of the speed from 70 km/h to 60 km/h gives a general reduction of the noise by about 2 dB [15]. Overall, we estimated that noise levels directly after implemented measures (new asphalt and speed reduction) decreased by approximately 4-5 dB in the intervention area. For the control area, we assumed that no changes in traffic occurred between the two study occasions (2017 and 2018) and thus no change in noise levels was expected other than very marginal.

3.2 Noise Annoyance

General noise annoyance due to road traffic in four situations were assessed: (i) when you are in or near your home, (ii) indoors with windows closed, (iii) indoors with windows open, and (iv) outdoors close to the home. Following the ISO specification of annoyance scales [16] the wording was "Thinking about the last 12 months, when you are …(each of the four situations above), how annoyed or disturbed are you by noise from road traffic?" Respondents answered the questions on verbal 5-point category scales ("not at all", "slightly", "moderately", "very", and "very much"). In the present paper, results on annoyance are presented as highly annoyed (HA; response alternatives very annoyed and very much annoyed). Figure 2 shows the proportion of HA in the before study for both study areas together (n=62) in relation to noise exposure from road traffic. As seen in Figure 2, the percentage of HA increases with increasing road traffic noise.

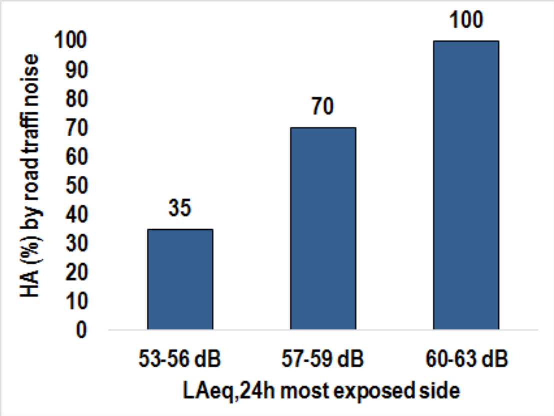

Figure 2. Percentage highly annoyed (HA) residents due to road traffic noise in the before study for the intervention area and the control area together (n=62) in relation to noise exposure.

Figure 3 shows the proportion of HA in different situations for the intervention- and control area separately. After repaving and speed reduction in the intervention area, noise annoyance indoors with closed and open windows as well as outdoors decreased significantly. From 35 to 13% with closed windows ($p<0.05$), from 71 to 45% with open windows ($p<0.05$) and from 74 to 42% when staying outdoors close to the home ($p<0.01$). In the control area, noise annoyance outdoors increased significantly from 35 to 58% ($p<0.05$), otherwise no significant changes occurred.

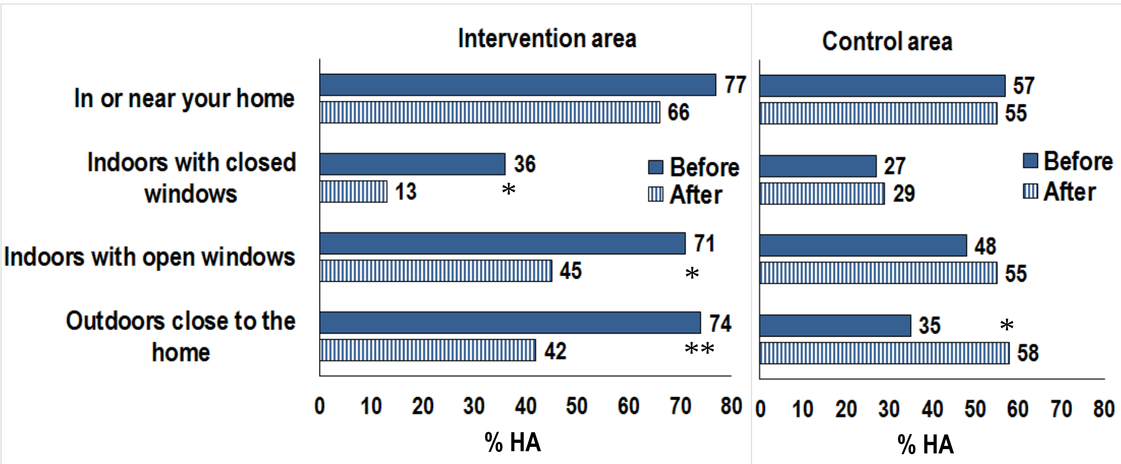

*Figure 3. Percentage highly annoyed (HA) residents due to road traffic noise in different situations for the intervention area (left) and the control area (right) before and after interventions (**p<0.01; *p<0.05).*

3.3 Disturbed Sleep Due to Road Traffic Noise

Sleep disturbances due to road traffic noise with windows closed and open was assessed by two questions regarding (i) how often ("never"=0, "sometimes"=1, and "often"=2) and (ii) to what degree they were disturbed ("slightly disturbing"=2, "moderately disturbing"=3, and "very disturbing"=4). The questions concerning "how often" were phrased: "How often does noise from road traffic disturb" (e.g. sleep quality), while the question concerning "how disturbing" were phrased; "If you have answered sometimes or often, how disturbing or annoying is it?" A disturbance score ranging from 0 to 6 was constructed, in which the value for frequency was added to the value for degree of disturbance. When analyzing the data, a disturbance score above three was used.

Table 2 shows that a large proportion of the residents in the intervention area, 81%, reported that road traffic noise made it difficult to have the bedroom window open as often as they wanted compared to 45% in the control area. There were also many in the intervention area who reported that sleep quality was affected by road traffic noise, 48%, that they had difficulty falling asleep, 45%, and that they were awakened, 39%. In the control area, there were somewhat fewer residents who experienced these sleep disturbances (29-45%). After repaving and speed reduction in the intervention area, the impact of noise on falling asleep, awakenings and sleep quality with closed bedroom window was almost unchanged. However, the difficulty of having the bedroom window open due to noise decreased significantly from 81 to 55% ($p<0.01$). In the control area, the sleep disturbances increased in the after study ($p>0.05$)

Table 2. Sleep disturbances (%) due to road traffic noise before and after noise abatement measures in the intervention- and control area.

	Intervention area (n=31))			Control area (n=31)		
Variables (%)	Before	After	$p^{1)}$	Before	After	$p^{1)}$
	With closed bedroom window					
Difficulties falling asleep	45	42	1.00	32	42	0.38
Wakes up	39	35	1.00	29	39	0.38
Sleep quality	48	42	0.77	29	45	0.06
Not being able to keep bedroom window open	81	55	0.01	45	61	0.12
	With open bedroom window					
Difficulties falling asleep	77	65	0.22	45	55	0.38
Wakes up	74	61	0.22	45	58	0.22
Sleep quality	77	65	0.22	45	55	0.38

[1)]McNemar-test

In both areas, the sleep disturbances increased when the bedroom window was open and there were more residents in the intervention area (about 74-77%) than in the control area (45%) which reported sleep disturbances in the before situation (Table 2). After the noise abatement measures, the proportion with sleep disturbances in the intervention area decreased to 61-65%, but the changes were not significant ($p>0.05$). In the control area, the sleep disturbances increased in the after study ($p>0.05$).

3.4 Disturbed Sleep Due to Vibrations from Road Traffic

With one question we examined how often vibrations from road traffic disturbed sleep with the response alternatives, “rarely/never”, “a few times a month”, “once a week” or “almost every night”. After the noise abatement measures, disturbed sleep from road traffic vibrations, at least once a week or almost every night, decreased significantly from 42 to 16% ($p<0.01$) in the intervention area, see Figure 4. In the control area, disturbed sleep due to vibrations increased in the after study, but not significantly ($p>0.05$).

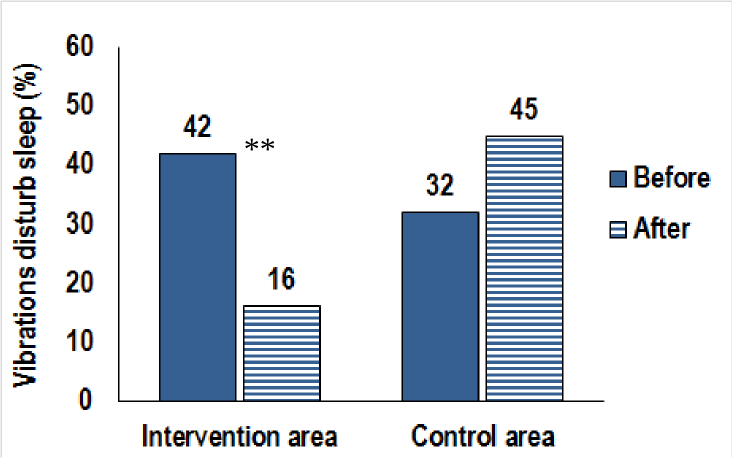

*Figure 4. Disturbed sleep due to vibrations from road traffic (%), at least once a week or almost every night before and after interventions for the intervention area (left) and the control area (right), (**p<0.01; *p<0.05).*

3.5 Perceptions of the Sound Environment

Evaluation of sounds (e.g. loud sounds, sharp sounds, dull sounds) when being outdoors close to the house were assessed with sound quality words on 5-point category scales ranging from "not present" to "dominates". The results are reported in "word clouds" which describes the characteristic of the sound environment based on the how the respondents have assessed the sound words in the questionnaire. Figure 5 shows result from the intervention area before repaving and speed reduction and Figure 6 after the measures. The word cloud shows the sounds experienced very clearly or dominating in the sound environment outdoors. One word is bigger the more people have chosen the answer options. The color of the words is irrelevant.

Figure 5. Sounds that appears very clearly or dominates in the sound environment outdoors close to the house in the intervention area before noise abatement measures.

Figure 6. Sounds that appears very clearly or dominates in the sound environment outdoors close to the house in the intervention area after noise abatement measures.

Before the noise abatement measures, the residents in the intervention area experienced that loud, swishing, sharp, slamming, and harsh sounds were the prominent and dominant sounds in the outdoor environment (Figure 5). After the measures, the sharp and harsh sounds became considerably less prominent, but also the swishing and slamming sounds (Figure 6). The varying sound increased somewhat. The characteristics of the sounds perceived as mainly being in the background were diffuse, muted, dull, and smooth sounds (not shown here). The experience of these background sounds increased after the noise measures, especially the dull sounds.

3.6 Experiences of the Noise Abatement Measures, Attention to Noise Problems and Desired Noise Interventions

The residents in the intervention area were asked how they experienced the noise abatement measures on a scale from very positive to very dissatisfied. A majority, 64% was positive or very positive, while 13% was dissatisfied or very dissatisfied. On an open question, residents described their views of the noise abatement measures and their experiences of the noise problem in and around their home. Many in the intervention area noted a clear improvement in the sound conditions with the new asphalt. However, a majority experienced that the road traffic noise with time had increased. The residents also believed that the speed reduction has been too small, as most people drive too fast. Therefore, one calls for even lower sign-posted speed, as well as speed-reducing measures such as speed cameras. Some people experienced that the tire noise has been dampened somewhat, but it was a number of people who described the motor noise as very disturbing. Especially when the vehicles were accelerating or stopping at the traffic lights. Many also mentioned that the noise barrier and the earth beam needs improvement. Many found the amount of traffic as a big problem and that traffic and noise levels have increased constantly.

4. CONCLUSIONS

In September 2017, the noise abatement measures were estimated to have reduced noise levels by about 4 to 5 dB. The new steel asphalt contributed about 3 dB mainly due to smaller particle size and a smoother surface and the speed reduction contributed about 1 to 2 dB, depending on whether the speed reduction was followed or not. One year later (June 2018), measurements showed that the new asphalt's noise-reducing effect had decreased and that the reduction had fallen to only about 1 dB. What lies behind this is unclear and difficult to explain since the steel slag asphalt should have particularly good properties in stability and durability [3]. Despite the fact that the second questionnaire was answered at a time when the noise reduction effect of the road surface had decreased to about 1 dB, some positive changes still took place among the residents in the intervention area.

The before study showed that many of the residents in the two areas were highly annoyed by the road traffic noise and a clear connection could be seen between increasing noise levels and increasing annoyance. After the noise abatement measures, significant reductions in the prevalence of annoyances was seen in the intervention area, from 36 to 13% with windows closed, from 71 to 45% with windows open and from 74 to 42% when staying outdoors near the house. The results are consistent with previous studies that have evaluated noise-reducing asphalt [6-8, 17].

A large proportion of the residents in the two areas stated that noise from road traffic disturbed sleep, despite closed bedroom windows. With window open, sleep disturbances became even more extensive. The noise abatement measures only resulted in a slight reduction in sleep disturbances in the intervention area. The most likely reason why the sleep disturbance did not change in the after-study is that the maximum sound levels and the number of sound events are of great importance for how sleep is affected by noise [18]. Heavy traffic and accelerating vehicles, especially motorcycles (which were also mentioned by the residents) often give high maximum noise levels, which is less affected by measures such as noise-reducing asphalt and speed reduction. The only major change was that significantly fewer in the intervention area felt that the road traffic noise prevented them from having the bedroom window open. However, the repaving and the speed reduction led to a considerably decrease of sleep disturbance due to road traffic vibrations – a significant reduction from 42 percent to 16%. Studies both in the field and in the laboratory environment have shown that sleep disturbances increase with increasing vibrations caused by train traffic [19-21]. Surface irregularities, such as potholes and cracks can result in ground-borne vibrations [22], so the large reduction in sleep disturbance due to vibration from road traffic is consistent with the replacement of the old and damaged pavement to the new and much smoother one.

The repaving and the speed reduction also led to a changed perception of the sound environment outdoors. The strong, swishing, sharp and slamming sounds that appeared very clearly or dominated the sound environment became less prominent after the interventions. The diffuse, muted, dull and smooth sounds that were most prevalent in the background increased after the actions. The experience of the dull sound increased the most. The results are in agreement with previous studies that examined the effects of noise-reducing asphalt on perceptions of the sound environment [8, 23].

Overall, the noise measures had a positive effect with reduced noise annoyances and sleep disturbances from road traffic vibrations. A majority of the residents was also positive about the measures, but they also mentioned that the noise has increased during the year. Since the steel slag asphalt should have a good stability, stiffness and durability [3] than other types of noise-reducing asphalt, expectations were high, that noise reduction should be maintained much longer than it did. In order to clarify what caused the decline of the noise reduction, a thorough evaluation of the composition of the asphalt (e.g. the road surface texture) and how it was laid should be made.

Lowering speed can provide good noise reduction provided it be followed. If the speed is lowered only with a new sign, it often becomes a small real effect. A speed reduction of 10 km has shown to reduce the average speed by about 2-5 km/h [15]. For vehicle drivers to follow the new speed, it is usually required that the road environment is reshaped so that it corresponds to the lower speed, that other damping measures are introduced, such as speed cameras, or to provide comprehensive information on the purpose of the speed reduction [15]. The major road in the present study is wide with two files in each direction, which invites for higher speeds. The residents also experienced that most people drive too fast and do not hold the new speed limit.

Despite reduced annoyances and disturbances following the noise abatement measures, the road traffic noise still affects many of the residents in the intervention area. Among the residents in the control area, the noise responses increased overall in the after study. Explanations for this result may be that they have become more aware of the noise at the second study occasion or that they respond tactically with the hope that negative responses could lead to noise-reducing measures also for them. It was also very clear that the residents in both areas wanted more noise measures for an improved noise situation.

5. ACKNOWLEDGEMENTS

This study has been sponsored by Örebro Municipality, Sweden. Many thanks to Jarmo Riihinen, Örebro Municipality, and Ulf Sandberg, Swedish National Road and Transport Research Institute for their contribution in the study.

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