DELIVERABLE 2.1.2[1]

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Work Package WP2	Noise score rating models and annoyance
2.1	Evaluation of outdoor noise in urban recreational areas
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PP	Restricted to other programme participants (including the Commission Services)	
RE	Restrictec to a group specified by the consortium (including the Commission Services)	
CO	Confidential, only for the members of the consortium (including the Commission Services)	

Nature of Deliverable

R	Report	✓
P	Prototype	
D	Demonstrator	
O	Other	

SEVENTH FRAMEWORK PROGRAMME

[1] see List of Deliverables, DoW – Annex I to the contract, p.32
(document 233655_CITYHUSH_AnnexI_DoW_2010-01-31_Corrections.pdf - available on the ftp-server)

TABLE OF CONTENTS

0 EXECUTIVE SUMMARY

0.1 OBJECTIVE OF THE DELIVERABLE

Identification of hot spots in noise maps is currently based on façade levels at residents' home and does not include possible beneficial effects of nearby quiet areas. However, a quiet outdoor environment may be very important since urban residents may travel, work and recreate outdoors during many hours of the day, and outdoor noise may affect their health and wellbeing. In order to develop a noise score rating model that enables an evaluation of the outdoor environment as perceived by pedestrians on the streets and visitors to parks, information is needed on the impact of noise in different urban and recreational areas. Knowledge on the effects of noise in the outdoor environment is limited and pertains to very specific situations (e.g. national parks in the USA, aircraft overflights) so that it cannot be applied directly to the impact of predominantly road traffic related noise in the urban outdoor environment. The objective of the present deliverable is to validate the preliminary noise score rating model for outdoor noise, which was given in deliverable 2.1.1, based on field study outcomes.

0.2 DESCRIPTION OF THE WORK PERFORMED SINCE THE BEGINNING OF THE PROJECT

As a starting point, an overview was made of information on the effects of noise in the outdoor environment. Based on this information and an analysis of the effects to be expected in urban (street, park) areas, a tentative noise score rating model for pedestrians and visitors of parks was given in deliverable 2.1.1. Subsequently, a field study was designed to investigate the effect of noise in a realistic outdoor environment. Subjects residing and walking in an urban natural recreational area were assigned to either a noisy or a relatively quiet condition. Measures involved self-report measures such as annoyance, mood state and perceived restoration. Furthermore, physiological parameters (heart rate, blood pressure and autonomic nervous system activity) were measured to assess possible restorative effects of the environment. Also, noise exposure was individually assessed to enable the establishment of both instantaneous and aggregated relationships between exposure and human (e.g. annoyance) response. For the further exploration of the evaluation of outdoor noise by pedestrians on the streets and visitors to parks, close collaboration was established between the present WP and WP 3.5 (Definition of a noise & annoyance standard for motorcycles in the urban environment). The latter involved a field study in which visitors of urban natural environments (parks) and pedestrians in urban non-natural environments (streets) were questioned on their evaluation of the noise situation.

0.3 EXPECTED FINAL RESULTS

The field study results provide information on the evaluation of noise in an urban natural environment and on the possible role of noise in restorative effects of a natural environment. On the basis of observed relationships in the field, the above mentioned tentative environmental noise rating model for pedestrians and visitors of parks was evaluated and improved.

0.4 POTENTIAL IMPACT AND USE[2]

In the context of the EU Environmental Noise Directive, it is important to be able to assess the impact of environmental noise in the outdoor situation on residents. The END promotes the preservation and creation of quiet areas, both in urban and in rural areas, and stresses the need for supplementary noise indicators for quiet areas. So far, the assessment of the impact of noise on residents is based solely on façade levels of dwellings as obtained from the noise maps. Therefore, measures directed towards a more quiet outdoor situation, in so far as they are not reflected in façade levels, will not show up in health assessment indicators. Using the intended noise score rating model for the outdoors, the expected effect of urban quiet areas on residents and visitors of parks may be quantified.

0.5 PARTNERS INVOLVED AND THEIR CONTRIBUTION

TNO is involved in reviewing the literature on the impact of outdoor noise on residents and visitors of parks and in developing the tentative outdoor noise score rating model. TNO has subsequently designed a field study to validate the outdoor noise score rating model. Furthermore, the results of the field study in Athens within WP3.5 (performed by TT&E in collaboration with TNO), were used to validate the model. ACL is responsible for feeding the model with factors that are important from the viewpoint of the CityHush case studies, while ACCON is responsible for the integration of the final validated noise score model in the noise prediction software tool CadnaA (Datakustik GmbH).

0.6 CONCLUSIONS

Based on current knowledge and additional field study results, a noise score rating model for pedestrians and visitors of parks was designed, taking into account the function of the area. In this rating model, indicators for outdoor noise can be combined with information about the number of people making use of the area and the function of the area to predict the overall annoyance response, i.e. the percentage (or number) of visitors that will be expected to be annoyed by noise in a given area.

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2 *including the socio-economic impact and the wider societal implications of the project so far*

1 STATE OF EVIDENCE ON EFFECTS OF NOISE IN THE OUTDOOR ENVIRONMENT

The impact of transportation noise on human health has primarily been studied in the home environment, with the facade exposure level as a determinant. However, urban residents may travel, work and recreate outdoors during many hours of the day, and outdoor noise may affect their health and wellbeing. More specifically, many people intermittently seek relaxation or restoration in a natural environment, often in urban recreational areas in the vicinity of their dwelling. In comparison to knowledge on the community response to noise at the dwelling, relatively little is known about the response to noise in outdoor situations. A summary of the available information from field studies is given below.

1.1 AIRCRAFT NOISE IN WILDERNESS AREAS

The evaluation of noise in the outdoor environment is addressed in a limited number of studies, most of which investigated the impact of aircraft noise in natural areas. Tarrant et al. (1995) reported that, apart from inducing annoyance, aircraft noise in natural areas disturbed feelings of solitude and tranquility. Fidell et al. (1996) found that exposure to high noise level overflights (LAmax 68-98 dB) induced annoyance among visitors of US wilderness parks, but was not related to their enjoyment of visits nor to their intention to return. However, due to the uncertainty of the actual noise exposure of visitors and the number of overflights they experienced, it was not possible on the basis of these data to derive a relationship between the degree of annoyance and the LAmax of overflights or LAeq over visit time. Anderson et al. (1993; 2011), based on data from ten sites in four US national parks, derived exposure-response relationships between aircraft LAeq during a short hike and two effect measures: the percentage of visitors reporting annoyance (moderate or more), and the percentage of visitors reporting interference with natural quiet (moderate or more). For instance, at levels of 50 dB around 40% of the visitors are expected to be annoyed and 55% of the visitors are expected to report interference with natural quiet. Also, the (energy) percentage of the total LAeq due to helicopters and that due to fixed-wing propeller aircraft contributed to the annoyance and interference response. Although the percentage of time aircraft can be heard was also related to the effect measures, this did not have predictive value in addition to LAeq. Non-acoustic variables influencing the annoyance and interference response were the percentage of first-time visitors (20-to-35 dB less sensitive to aircraft noise than those who had visited before) and the percentage of visitors who regarded natural quiet as important (10-to-50 dB more sensitive to aircraft noise than visitors who did not). Also, separate relationships were derived for the much lower annoyance and interference response of visitors at scenic overlooks (35-to-70 dB less sensitive to aircraft noise than visitors on a short hike). Comparison of the observed relationship between aircraft LAeq and outdoor annoyance with the EU-curve for aircraft noise annoyance at home (Miedema and Oudshoorn, 2001) suggests that the outdoor curve is much less steep, with higher annoyance in the lower exposure range (Figure 1; NB while the EU-curve is based on Lden at the façade, it is assumed here that on average this is similar to LAeq during daytime). One reason for this may be that aircraft events at these lower levels are not always heard in the home situation due to insulation of the façade, or that they are masked by background noise in urban settings.

1.2 AIRCRAFT NOISE IN LOCAL RECREATIONAL AREAS

In a partially controlled field study in a local recreational area near Fornebu airport in Oslo, Norway, Aasvang & Engdahl (2004) found a high correlation between noise exposure (ASEL), immediate annoyance response and acceptability response for single noise events. The percentage of aircraft noise events judged as "not acceptable" could be described as a function of the sound exposure level of single noise events, with a sound exposure level of approximately 65 dB corresponding to 10% "not acceptable" ratings, and a level of 80 dB corresponding to 50% "not acceptable" ratings. Although visitors reporting to be rather or highly annoyed on average judged a higher percentage of noises as ''not acceptable'' than those reporting to be slightly annoyed, no significant correlation was found between immediate annoyance response or percentage of ''not acceptable'' judgements and visitor's total annoyance. Therefore, the (expected) annoyance response to individual aircraft events does not seem to be an adequate predictor of the total annoyance response.

In a related field study in two local recreational areas near Oslo airport before and after the relocation of the airport from one area to the other (Krog & Engdahl, 2004), it was found that the relocation resulted in an increase of annoyance at the new site and a decrease of annoyance at the old site. Aircraft LAeq, ASEL and the percentage of time aircraft were audible all significantly predicted aircraft noise annoyance (in separate analyses). No exposure-response relationships were derived, but the percentage of visitors reporting to be not, slightly, rather or very annoyed at each LAeq exposure category were displayed in separate figures for the two sites (with measurements before and after relocation mixed). No or only slight annoyance was reported below an LAeq of 40 dB, while an LAeq between 40-50 dB corresponded to about 20% (rather or very) annoyed visitors in the area where noise had increased, but hardly any annoyance in the area where noise had decreased. An LAeq of 50-55 dB corresponded to about 30% annoyed visitors in both areas, increasing to about 55% with an LAeq of 65-70 dB and to 70% with an LAeq of 70 dB or higher (see Figure 1). Also, it was found that several contextual factors highly influenced the degree of annoyance experienced at a given exposure level, such as the survey being before or after a change in levels due to the relocation (more annoyance after an increase, less annoyance after a decrease in LAeq), the duration of the visit (more annoyance with longer visit), the reason for visiting (more annoyance when reason is the acoustic nature experience and mental relaxation), and the area being the visitor's primary recreational area (more annoyance). Figure 1 shows that, particularly in the low exposure range, lower annoyance was found than expected on the basis of the exposure-response relationship for aircraft noise in national parks derived by Anderson et al. (2011). It has to be kept in mind that the expectation regarding quietness of the visitors of national parks from which Anderson et al. (2011) gathered their data may have differed from that of visitors of local recreational areas, or from that of residents in the urban living environment. The findings of Krog & Engdahl (2004) suggest that the curve by Anderson et al. (2011) for aircraft noise annoyance in wilderness areas may not be applicable to urban recreational areas. Instead, the results appear to be more similar to the EU aircraft noise exposure-response relationship for residents at home (Miedema & Oudshoorn, 2001).

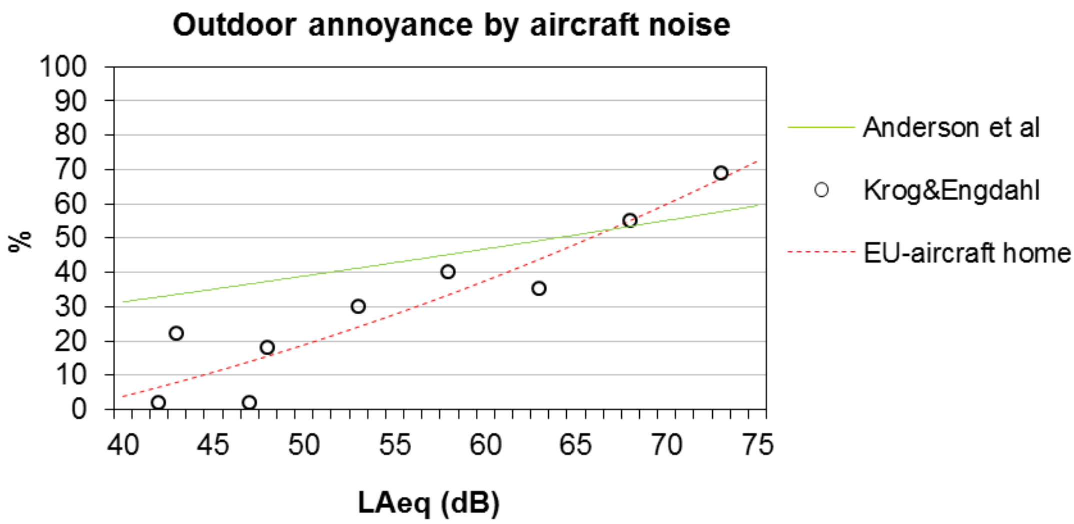

Figure 1 Observed relationships between aircraft noise (LAeq) and % annoyance, in outdoor recreational areas (Anderson, 2011; Krog & Engdahl, 2004) and for residents at home (Miedema & Oudhoorn, 2001).

1.3 ROAD TRAFFIC NOISE IN RECREATIONAL AREAS

While the above relationships are based on studies investigating the response to aircraft noise, a survey that was done in three natural recreational areas in the Netherlands (Goossen et al., 2001) looked at the relation between manmade noise in general (mainly road traffic noise) and visitors' evaluation of the acoustic situation. It was found that among several noise indicators (LAeq, LA95, LA5, number of manmade noise events), LAeq showed the highest correlation with the evaluation of the acoustic environment, although at one of the sites LA95 (as an indicator of background noise) was a better predictor. It was concluded that an LAeq of 40 dB or lower is evaluated by most visitors as sufficiently quiet, whereas levels above 50 dB strongly reduce their positive evaluation. A similar conclusion was reached by Nilsson & Berglund (2006), who found that the Swedish criterion that 80% of the park visitors should perceive the sound environment as good was only met when the traffic noise exposure (LAeq, 15 min) in suburban and city parks during daytime was below 50 dB. However, a field study in 3 Italian urban parks showed that the majority of visitors liked the parks very much, despite LAeq levels over 50 dB, stressing the role of other environmental factors or the contrast with noisier surroundings (Brambilla & Maffei, 2006). Similarly, noise levels up to 60 dB Lday were found at 'quiet' urban places indicated by residents of Amsterdam (Booi & van den Berg, 2012). Nilsson et al. (2007) showed that LAeq predicted the perceived soundscape quality and annoyance due to road traffic noise in 16 city parks, and that the explained variance was raised a little when LA50 was used as a predictor instead. Over and above the effect of the overall sound level, an indicator for the low-frequency component (LCeq-LAeq) was associated with a slight increase in annoyance, and the identification of technological and of nature sounds contributed (in opposite ways) to the perceived soundscape quality and annoyance. This is in line with other indications that, next to the loudness of specific sounds, also the physical characteristics and the perceived appropriateness of sounds in outdoor environments are factors that influence their evaluation (Kariel, 1990).

1.4 APPROPRIATE NOISE INDICATORS FOR OUTDOOR NOISE

In the studies cited above, several noise indicators were used to predict annoyance or the perceived soundscape quality as primary indicators. Apart from LAeq measures, the background noise level (LA95) and the level exceeded 50% of the time (LA50) have been shown to be relevant predictors of annoyance or the evaluation of the acoustic situation, and it is currently not clear what is the best predictor. In fact, different outdoor urban environments may require different annoyance predictors, with the focus here being on outdoor situations in urban recreational areas, with noise contributions from road traffic (distant and local) and other noise sources (natural sources, outdoor equipment, etc.). In the studies cited above, the LAeq level was the indicator that most consistently correlated with annoyance. Because of the consistency with environmental noise policy and the exposure-response relationships for annoyance at the dwelling, LAeq (or Lde/$Lday_{16h}$) would be a first choice for a primary noise indicator in the noise score rating model for the outdoors. In addition, an indicator of the low frequency components of the noise (e.g. LCeq-LAeq) may be considered. Furthermore, additional indicators of the temporal distribution of noise should be considered, such as number of events or the difference between peak and background noise levels (e.g. LA10-LA90). As far as possible, the influence of the above noise characteristics were investigated in the field study described in Chapter 2,

1.5 APPROPRIATE RESPONSE MEASURE FOR OUTDOOR NOISE

While most studies addressed annoyance as the main subjective response to outdoor noise, effects of outdoor noise were also found on the degree of interference with natural quiet and on the evaluation of the acoustic environment, which seem equally relevant in protecting the quality of recreational areas. In addition, there are indications for physiological and mental restorative effects of a natural environment (e.g. Hartig et al., 2003), although the role of noise is largely unknown. It would be highly valuable to investigate whether outdoor noise not only leads to a more negative acoustic evaluation, but also influences mood or physiological stress parameters such as heart rate and blood pressure while visiting a natural environment.

1.6 THE INFLUENCE OF FUNCTION OF THE AREA AND OTHER CONTEXTUAL FACTORS

Main motives reported for visiting urban green areas are to relax, to escape from the city and to observe and listen to nature (Chiesura, 2004). Still, the function of urban green areas may differ from that of some of the recreational areas in the previous studies, which will have implications for the expected annoyance by noise. Furthermore, while the evidence above concerns the expected effect of noise in (urban and non-urban) natural areas, there is even less data on the effects of noise on pedestrians in a built environment. Since restorative effects have been found of a natural as opposed to a built environment (Hartig et al., 2003; Bodin and Hartig, 2003), and also the expectation regarding quietness may be higher in natural areas, the disturbing effect at a given noise level is expected to be higher in a natural than in a built environment. Furthermore, several other contextual factors observed in the studies above need more exploration, such as the duration of the visit (+), the perceived appropriateness of sounds (-), the percentage of first-time visitors (-), the percentage of visitors regarding natural quiet as important (+), and the area being the visitor's primary recreational area (+)(+ denotes an increase in annoyance, - denotes a decrease in annoyance). Some of these factors were also included in the field study.

2 RESPONSE TO NOISE IN AN URBAN RECREATIONAL AREA: FIELD STUDY

Many people intermittently seek relaxation or restoration in a natural environment, often in urban recreational areas in the vicinity of their dwelling. There are indications for a positive influence of a natural environment on restoration from stress and attentional fatigue (Ulrich et al., 1991; Kaplan, 1995; Hartig et al., 2003; Bodin and Hartig, 2003; Netherlands Health Council, 2004) and for a role of green space as a buffer between stressful life events and health (van den Berg et al, 2010). On average, residents living in relatively green neighborhoods report better general health than others (de Vries, Verheij & Groenewegen, 2003), and the availability of green is related to lower mortality (Mitchell & Popham, 2008), even when confounding variables such as age and socio-economic status are corrected for. Apart from one laboratory study, showing indications that physiological restoration after a stress task was facilitated by nature sounds (Alvarsson et al., 2010), the role of noise in possible restorative effects of natural areas is largely unclear. Still, several studies have shown that aircraft noise is perceived as annoying by visitors of natural areas, or that it interferes with the experience of natural quiet (Tarrant et al., 1995; Fidell et al., 1996; Aasvang & Engdahl, 2004; Krog & Engdahl, 2004; Anderson et al., 2011). Also, road traffic noise appears to reduce the perceived quality of the acoustic environment in recreational areas (Goossen et al., 2001, Nilsson et al., 2006; 2007). It is not clear, however, whether this more negative evaluation is associated with a reduction in physiological and mental restoration while visiting a natural environment. The aim of the present study is to investigate in a realistic natural setting the influence of road traffic noise on the evaluation of the area, mood state and physiological stress parameters such as heart rate (variability) and blood pressure. These effects were investigated in a group of 52 healthy volunteers who walked in either a noisy or a relatively quiet green urban recreational area.

2.1 METHODS

Sample

The sample consisted of 52 healthy volunteers, 23 women and 29 men with age ranging between 19 and 64 years, recruited by advertisements in supermarkets, in university buildings and in a local newspaper. They received a remuneration of 40 Euro for their participation. Exclusion criteria were self-reported hypertension, hearing problems, pollen allergy, excessive smoking or drinking, obesity (BMI ≥30), and medication affecting cardiovascular function or mood. Participants were randomly attributed (although matched as much as possible according to age and gender) to one of two conditions: a '(relatively) Quiet' (n=26) or a '(relatively) Noisy' walking route (n=26).

Noise measurement and equipment

The experimenter measured the sound levels during the walk using a hand held sound level meter (Rion NA-28), walking 10 m ahead of the participant and marking important noise events by writing down the type of event and time of occurrence. The data were stored as broadband levels and 1/3-octave band spectra of the A-weighted equivalent sound level over successive intervals of 1 second (LAeq,1s). In addition, the full sound signals were recorded and stored as wav-files for listening to the recordings afterwards. Post-processing of the data resulted in the following single value indicators[3] for each walk:

- LAeq A-weighted equivalent sound level
- LA50 the value of LAeq,1s that was exceeded 50% of the time
- <LA50,1m> the logarithmic average of LA50 levels over successive 1 minute intervals[4]
- LA95 the value of LAeq,1s that was exceeded 95% of the time
- LA10-LA90 10% minus 90% exceedance level, measure of the variation of sound level
- Nev the number of noise events derived from sound level traces, see Annex B

Physiological measurement and equipment

For intermittent measurement in rest of systolic and diastolic blood pressure (SBP, DBP), a portable device was used (Omron, type M6 comfort). For the continuous measurement of heart rate and heart rate variability, the Vrije Universiteit Ambulatory Monitoring System (VU-AMS, version 4.6) was used. This recognizes the R-wave of the ECG by a level detector with automatic level adjustment, while a counter read and reset at each R-wave peak records the sequential R-wave to R-wave time intervals to extract the raw interbeat-interval (IBI) data in milliseconds (ms). From the IBI's, the average IBI and heart rate variability (RMSSD: root mean square of successive differences), both expected to be higher in rest, can be calculated for each specified period.

Questionnaires

Two sets of questionnaires were filled in by the subjects, one at the start of the experiment and one at the end. The first set contained a shortened version (32 items) of the Profile of Mood States (POMS; McNair et al., 1971; Wald & Mellenbergh, 1990) and the Exercise-induced Feeling Inventory (EFI; Gauvin & Rejeski,1993) to assess subjects' baseline values before the experimental condition, as well as the Everyday Problem Checklist (Vingerhoets & van Tilburg, 1994) and the Utrecht Coping List (UCL; Schreurs et al., 1993) to assess potential differences between subjects in their need for restoration and their coping style. The second set of questionnaires contained a retest of the POMS and the EFI at the end of the experimental condition, and the Perceived Restorativeness Scale (PRS, Hartig et al., 1997) to assess the degree to which subjects evaluated the area as facilitating restoration. Finally, questions were asked about subjects' evaluation of the noise situation, including perceived quietness and perceived soundscape quality on 0-10 point scale, perceived loudness, annoyance and interference of natural quiet by several noise sources on a 0-10 point scale, and subjects' noise sensitivity on a 0-10 point scale.

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[3] It was concluded that the center-of-gravity frequency is not useful indicator for this study (see Annex A).

[4] This was calculated as an indicator of the (average) continuous noise level, while events were detected as moments when LAeq,1s exceeded LA50,1m by 3 dB for at least 3 sec (see Annex B).

Procedure

Participants were told that the study addressed the role of the environment in physical activity, and would involve physiological measurements as well as self-report measures while walking in a natural environment. Subjects participated individually and were invited to come to one of TNO's buildings in Delft, where the measurement devices were first attached, the first set of questionnaires was filled in, and then baseline measurements of the physiology (HR, RMSSD, SBP, DBP) were recorded. Subsequently, the experimental condition was determined randomly, and the experimenter and the participant drove by car to the nearby urban recreational area ("Delftse Hout"). One of the routes (Route 2, see Figure 2) was closer to highway A13 than the other, resulting in higher average noise levels than in the other route (Route 1), where the highway was not only further away but also partly shielded by a building. Apart from their difference in noise exposure, the routes were chosen on the basis of their similarity with regard to many other aspects (length, number of expected other visitors, visual attractiveness, presence of green and water). The experimenter led the subjects at a slow pace along one of these predetermined routes by walking about 10 m ahead of the participant, not allowing conversation between them. After about 5 min into the walk, the experimenter instructed the subject to sit down on a bench and relax for 5 min in order to record physiological measures in rest. Then the walk proceeded for about 15 min, after which the subject was again instructed to sit down and relax for 5 min to record physiology in rest. Subsequently, the subject filled in the second set of questionnaires, and was driven back to TNO's building where the measurement devices were removed and the subject was fully informed on the objectives of the study. The procedure was approved by the TNO Institutional Review Board (TCRP) for non-invasive human studies.

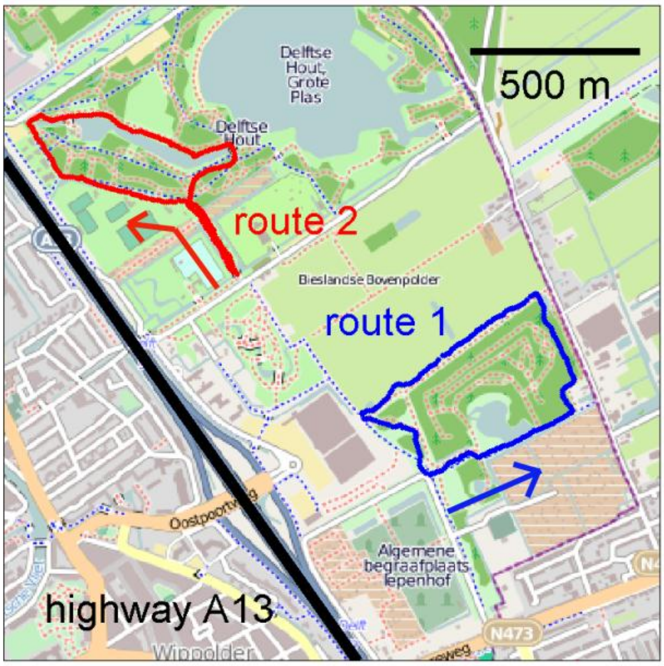


Figure 2 Walking routes 1 and 2 near highway A13.

2.2 RESULTS

Descriptives

Gender was more or less equally divided over conditions, and there was no difference in mean age of subjects between conditions (see Table 1). Although subjects walking the relatively quiet route showed slightly higher noise sensitivity scores (6.8 vs. 6.0), this difference was not significant ($t(49)=1.11$). Furthermore, there were no significant differences between conditions in baseline scores on the Profile of Mood States (POMS) and the Exercise-induced Feeling Inventory (EFI) (see Table 6 on page 16), nor on subjects' scores on the Everyday Problem Checklist and the Utrecht Coping List (UCL).

	Gender (N)			Age (years)				Noise Sensitivity	
Route	Male	Female	Total	Min	Max	Mean (sd)	N	Mean (sd)	N
(Relatively) Quiet	14	12	26	20	58	29 (9.4)	26	6.8 (2.7)	25
(Relatively) Noisy	15	11	26	19	64	29 (12.5)	26	6.0 (2.2)	26
Total	29	23	52	19	64	29 (11.0)	52	6.4 (2.5)	51

Table 1 Descriptives of subjects in the relatively quiet and noisy condition.

Characterization of the acoustic environment

Figure 3 shows the distribution of individual noise exposures in six acoustic indicators during the walk over the 2 conditions (Route 1 is (relatively) Quiet, Route 2 is (relatively) Noisy), with average values given in the legends. The values of the six indicators are given for all persons in the table presented in annex C, together with meteorological parameters. The average value of LAeq is 2.6 dB higher for route 2 than for route 1. For LA50 the difference is 3.4 dB, for <LA50,1m> the difference is 3.9 dB, and for LA95 the difference is 4.7 dB. It should be noted that these are the mean exposure levels for the duration of the visit, and that differences between routes up to 10 dB (LA50) are found at some points during the walk, reflecting differences in the temporal pattern (see Annex A). While mean exposure levels are significantly higher in the noisy condition with respect to the relatively quiet condition ($p < 0.01$), it is clear that there is also considerable overlap in exposure levels between the conditions. Differences in noise level within condition partly reflect differences in meteorological conditions such as wind direction and wind speed (see Annex A) and probably also differences in traffic volumes on the highway A13. Therefore, in all analyses below, not only the influence of condition is tested, but also the influence of individual exposure levels, which show larger variation.

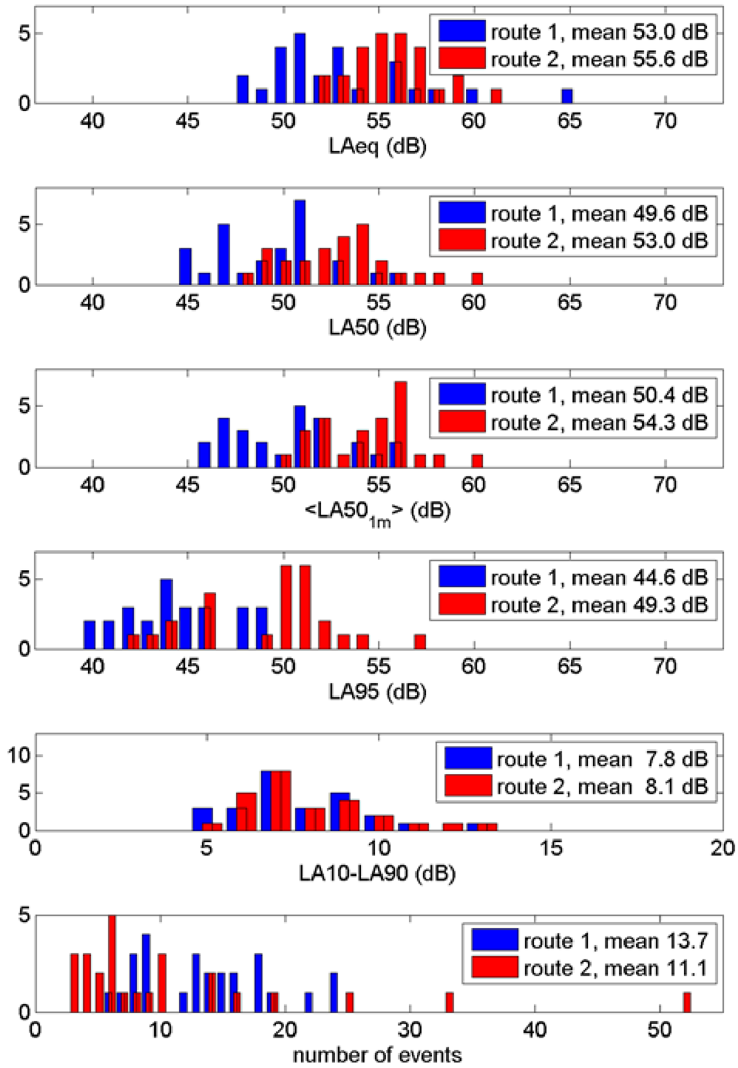


Figure 3 Distribution of individual noise exposure in six acoustic indicators per route.

It has to be kept in mind that these noise levels partly reflect sound from the highway, which was heard continuously, but also various (local) sound sources, such as sounds from local vehicles (automobile, truck, moped, scooter, bicycle, lawn mower, airplane, helicopter), sounds from animals (particularly bird song, but also dogs, frogs, horses), and sounds from people passing by (walking, running, or roller skating). Also wind gusts occurred frequently, and generated sound by moving leaves from trees. In addition, noise generated by the experimenter was non negligible; rustling of paper and in particular footsteps on a gravel path on route 1 generated 'self noise'. Sounds from these sources may have partly blurred the differences in noise levels between routes. There were no significant differences between conditions in the number of events, although it was not possible to characterize the type of all events (e.g. traffic, animals, people, self noise), which may have differed between conditions. Still, there were no significant differences between noisy and quiet condition in the number of subjects who reported having heard local road traffic (16 vs. 17), agriculture related activities (6 vs. 8), nature sounds (25 vs. 26) and people sounds (25 vs. 23). However, more subjects reported having heard powered two-wheelers in the relatively noisy condition than in the relatively quiet condition (13 vs. 6).

Evaluation of the acoustic environment

Subjects' perceived quietness, perceived soundscape quality, and annoyance due to highway noise as well as interference of highway noise with natural quiet on a 0-10 point scale are shown as a function of condition in Figure 4 and Table 2. Using a t-test to test for differences between conditions, perceived quietness showed a marginally significant trend ($t(49) = 1.99$; $p = 0.053$), but perceived soundscape quality was not significantly higher in the relatively quiet versus the relatively noisy condition ($t(50) = 1.48$; n.s.). Annoyance due to highway noise was significantly higher in the noisy condition than in the quiet condition ($t(50) = -3.25$; $p < 0.01$), and a similar effect was found for interference of natural quiet due to highway noise ($t(47) = -2.71$; $p < 0.01$).

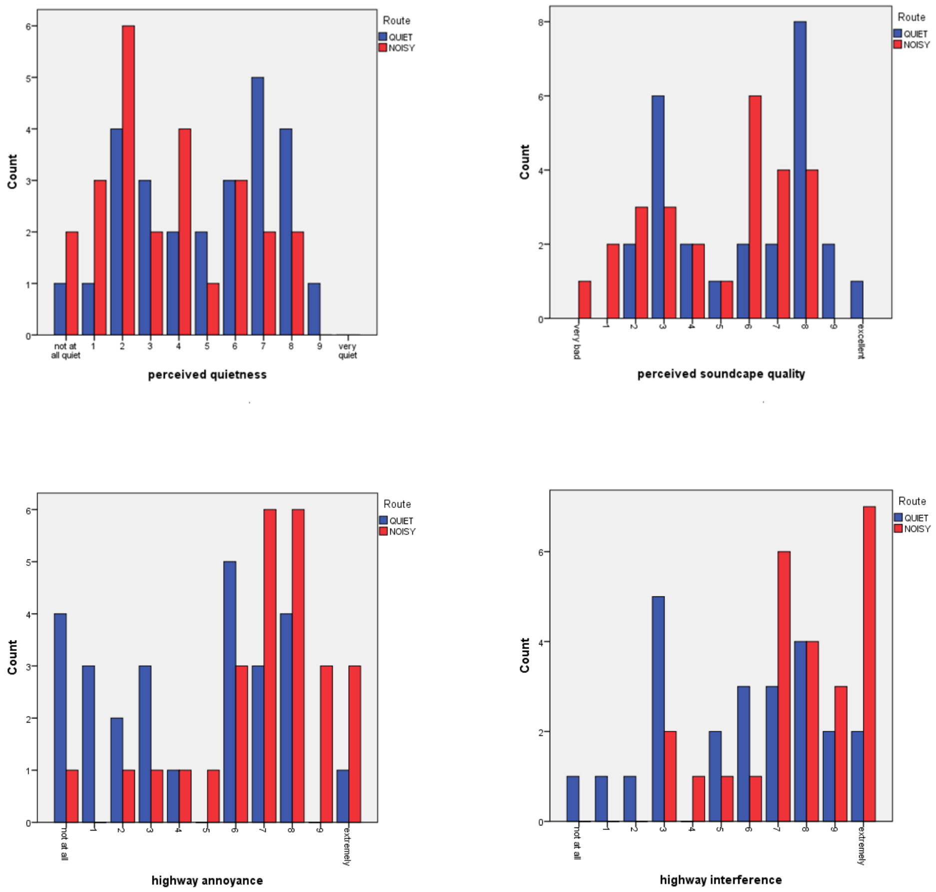


Figure 4 Distribution of Perceived quietness, Soundscape quality, Annoyance and Interference per route.

	Route	N	Min	Max	Mean (sd)
Perceived quietness	Quiet	26	0	9	5.00 (2.58)
	Noisy	25	0	8	3.60 (2.45)
Perceived soundscape quality	Quiet	26	2	10	5.88 (2.55)
	Noisy	26	0	8	4.85 (2.49)
Highway annoyance	Quiet	26	0	10	4.35 (3.14)
	Noisy	26	0	10	6.88 (2.46)
Highway interference	Quiet	24	0	10	5.71 (2.88)
	Noisy	25	3	10	7.68 (2.17)

Table 2 Evaluation of the acoustic environment in the relatively quiet vs. noisy condition.

In addition to an effect of condition, the role of several other factors that may influence the evaluation of the acoustic environment was explored in a stepwise forward regression analysis. Route was entered in the first step, while other variables were entered subsequently (with criteria P-in = 0.05 and P-out = 0.10). The second step contained the individual acoustic indicators (LAeq, LA50, <LA50,1m> LA95, LA10-LA90 and Nev). Of these, LA95 show highest correlations (i.e. partial correlations controlling for Route) with each of the four evaluation measures, whereas the other indicators did not explain additional variance and were not entered into the model. In the third step, the following individual characteristics were tested: age (and age^2), gender, noise sensitivity, scores on the UCL and Everyday Problems Checklist, perceived quietness at home, perceived importance of natural quiet and the perceived frequency and loudness during the walk of sounds from nature, people, local traffic and powered two-wheelers. As shown in Table 3, perceived quietness and soundscape quality were lower in those subjects who were noise sensitive and in those who perceived their home situation as quiet, and higher in those who perceived the sounds from people during the walk as louder. Highway annoyance and interference were primarily influenced by the noise level as defined by LA95 (of the variables tested in the model), although the interference with natural quiet was higher when subjects perceived the enjoyment of natural quiet as an important goal of visiting a recreational area.

Model	Predictors	Perceived quietness	Perceived sound quality	Highway annoyance	Highway interference
1	Route (Noisy vs. Quiet)	-0.273	-0.205	* 0.418	* 0.368
2	Route	-0.066	0.064	0.221	0.061
	LA95	*-0.344	*-0.447	* 0.327	* 0.509
3	Route	*-0.355	-0.211	0.221	0.138
	LA95	-0.041	-0.160	* 0.327	* 0.365
	Noise sensitivity	*-0.375	*-0.327	-	-
	People loudness	* 0.316	* 0.408	-	-
	Perceived quietness at home	*-0.402	*-0.308	-	-
	Importance of natural quiet	-	-	-	* 0.328

*Table 3 Regression models with predictors (beta's; *=p<0.05) of the evaluation of the acoustic environment.*

Perceived restorativeness of the environment

The subscales of the Perceived Restorativeness Scale (PRS), which aimed to assess the degree to which subjects evaluated the area on different aspects that are considered important for attentional restoration (Hartig et al, 1997), are shown as a function of condition in Table 4. None of the subscales was significantly influenced by Route.

	Route	N	Min	Max	Mean (sd)
PRS Being away	Quiet	26	8	30	20.35 (5.82)
	Noisy	26	10	28	19.08 (4.72)
PRS Fascination	Quiet	26	10	48	29.12 (10.59)
	Noisy	26	13	45	29.92 (9.63)
PRS Coherence	Quiet	26	9	23	18.27 (3.34)
	Noisy	26	8	23	17.04 (4.32)
PRS Compatibility	Quiet	26	15	54	31.04 (11.08)
	Noisy	26	17	47	33.04 (6.53)

Table 4 Perceived Restorativeness Scale (PRS) scores in the relatively quiet vs. noisy condition.

Model	Predictors	PRS Being away	PRS Fascination	PRS Coherence	PRS Compatibility
1	Route (Noisy vs. Quiet)	-0.121	0.041	- 0.160	0.111
2	Route	-0.118	0.099	-0.169	0.102
	Age	* 0.303	* 0.275	-	-
	Noise sensitivity	-	* 0.354	-	-
	Frequency local traffic sound	-	-	*-0.303	-
	Importance of natural quiet	-	-	-	* 0.303

*Table 5 Regression models with predictors (beta's; *=p<0.05) of the Perceived Restorativeness Scale (PRS).*

In a stepwise forward regression analysis (see Table 5), the same predictor variables as in the analysis above on the evaluation of the acoustic environment were tested for their contribution in the model. Neither Route nor individual noise exposure as defined by the six acoustic indicators influenced any of the subscales of the PRS. However, the factors 'Being away' (experiencing distance from demands of daily life) and 'Fascination' (effortless attention attracted by aesthetically pleasing stimuli) showed an increase with increasing Age, and 'Fascination' was also higher with increased Noise sensitivity. 'Coherence' (sense of connectedness induced by the ease with which one can structure and organize a scene) was lower with higher perceived frequency of local traffic sounds, while 'Compatibility' (match between personal goals and environmental demands or supports) was higher when subjects perceived the enjoyment of natural quiet as an important goal of visiting a recreational area.

Mood state measures

While all POMS scores showed a significant reduction from pretest to postwalk (see Table 6 and Figure 5 and 6), no significant interaction with condition was found, meaning that this reduction was not influenced by the relatively quiet versus the relatively noisy walking environment. Likewise, EFI scores showed a significant effect from pretest to postwalk (an increase in Revitalization and Tranquility, and a reduction in Positive engagement and Physical exhaustion), but no interaction with condition. Furthermore, a stepwise forward regression analysis with the same predictor variables as above (on the evaluation of the acoustic environment and PRS) was done on the POMS or EFI change scores (postwalk minus pretest). None of the change scores was significantly predicted by individual noise indicators ((LAeq, LA50, <LA50,1m> LA95, LA10-LA90 and Nev), nor by any of the other predictor variables.

			Pretest		Postwalk	
POMS	Route	N	Mean	(sd)	Mean	(sd)
Depression	Quiet	26	4.15	(2.13)	3.38	(1.81)
	Noisy	25	5.08	(2.34)	3.40	(1.76)
Anger	Quiet	26	8.12	(2.32)	6.96	(3.08)
	Noisy	25	8.88	(2.01)	6.92	(2.00)
Fatigue	Quiet	26	1.27	(1.31)	0.69	(1.16)
	Noisy	25	1.64	(2.23)	0.60	(1.00)
Vigor	Quiet	26	3.65	(1.35)	3.23	(1.24)
	Noisy	25	3.60	(1.32)	2.92	(1.22)
Tension	Quiet	26	1.92	(2.00)	1.12	(1.42)
	Noisy	25	2.28	(1.81)	0.80	(1.26)
EFI						
Positive engagement	Quiet	26	7.62	(2.62)	6.88	(2.93)
	Noisy	26	7.27	(1.99)	6.69	(2.00)
Revitalization	Quiet	26	5.23	(2.49)	6.08	(2.92)
	Noisy	26	5.38	(2.33)	6.15	(1.87)
Tranquility	Quiet	26	6.46	(2.18)	7.88	(2.66)
	Noisy	26	6.54	(2.20)	8.23	(1.77)
Physical exhaustion	Quiet	26	2.65	(2.30)	1.35	(1.74)
	Noisy	26	3.38	(2.59)	1.58	(1.75)

Table 6 Mood state measures at pretest and postwalk in the relatively quiet vs. noisy condition.

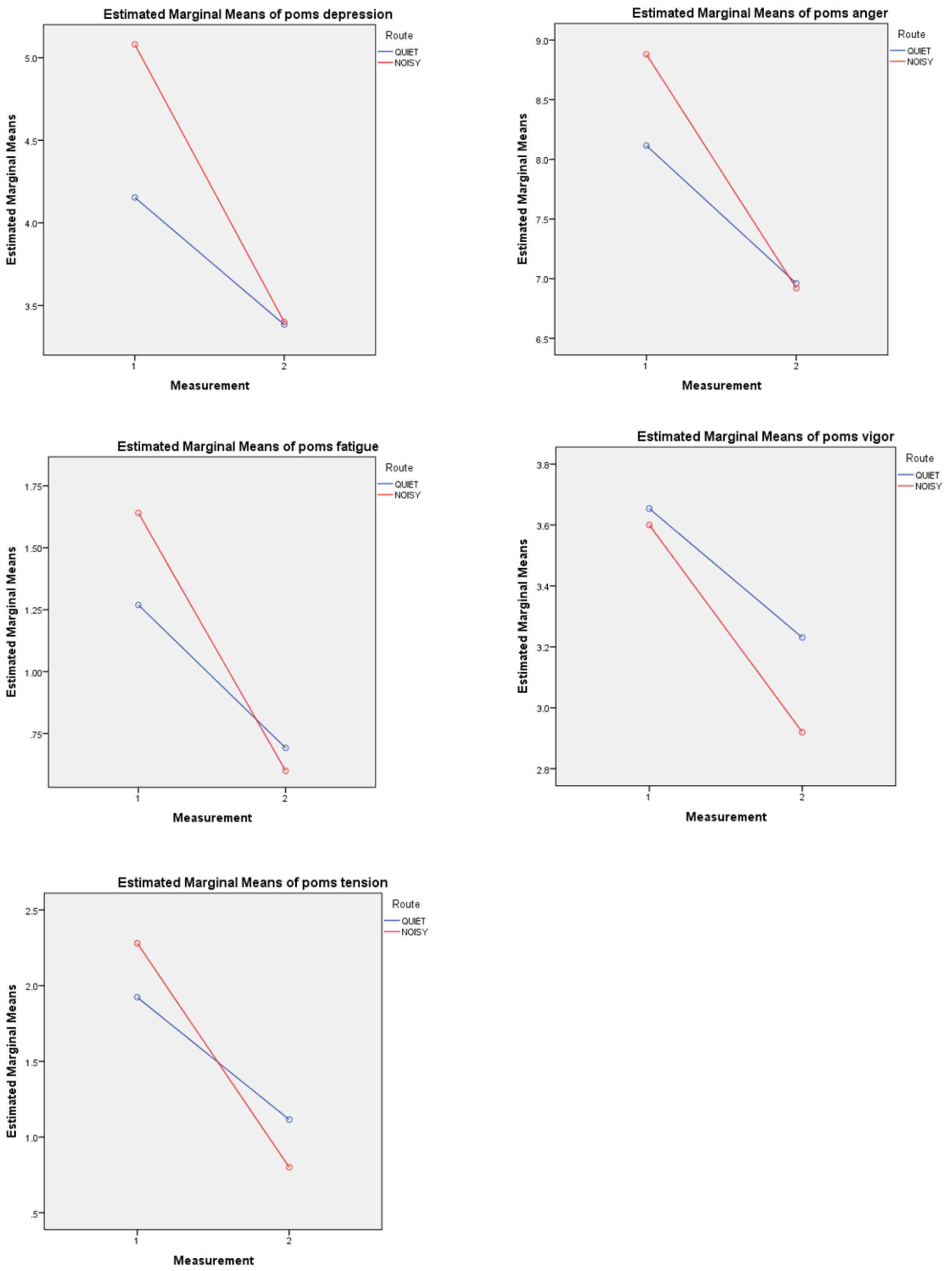


Figure 5 Mean POMS Depression, Anger, Fatigue, Vigor and Tension scores (postwalk vs. pretest) per route.

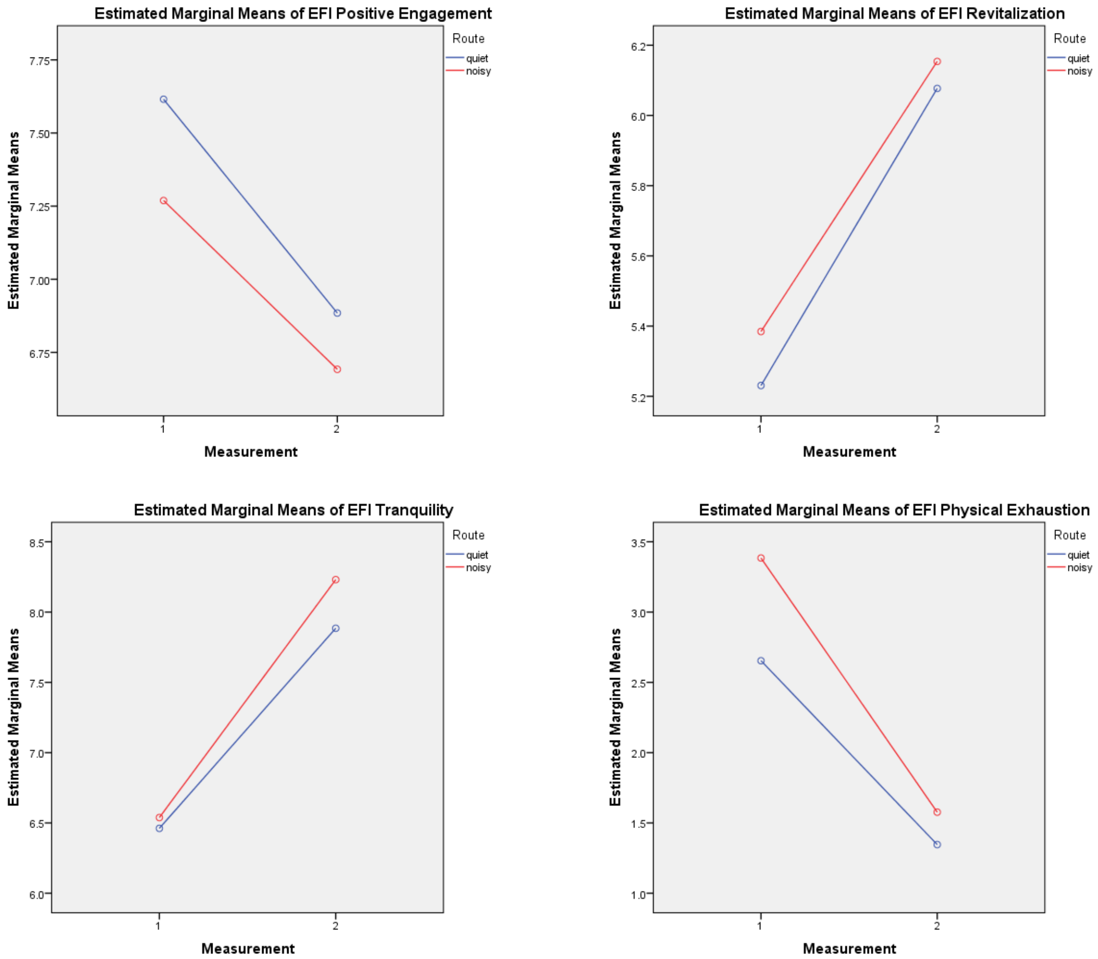


Figure 6 Mean EFI Positive engagement, Revitalization, Tranquility and Physical exhaustion scores (postwalk vs. pretest) per route.

Physiological measures

When comparing the 3 subsequent physiological measurements in rest (pretest, prewalk and postwalk) in a repeated measures analysis, Helmert contrasts revealed significantly higher values during pre- and postwalk measurements with respect to pretest for SBP, DBP, IBI and RMSSD, and a reduction in DBP from prewalk to postwalk (see Table 7 and Figure 7). However, no significant condition effect or interactions with condition were found, meaning that these differences over time were not influenced by the relatively quiet versus the noisy walking environment.

			Pretest		Prewalk		Walk		Postwalk	
	Route	N	Mean	(sd)	Mean	(sd)	Mean	(sd)	Mean	(sd)
SBP	Quiet	26	118	(15)	120	(19)			123	(15)
(in mm Hg)	Noisy	26	115	(15)	119	(17)			120	(15)
DBP	Quiet	26	76	(9)	83	(15)			80	(8)
(in mm Hg)	Noisy	26	72	(10)	80	(7)			76	(8)
IBI	Quiet	25	797	(105)	826	(105)	613	(68)	847	(114)
(in ms)	Noisy	26	772	(84)	821	(101)	626	(72)	840	(97)
RMSSD	Quiet	25	43	(22)	54	(36)	25	(26)	52	(33)
(in ms)	Noisy	26	36	(19)	48	(31)	16	(6)	50	(36)

Table 7 Physiological measures at different times in the relatively quiet vs. noisy condition.

To explore the role of several other factors that may have influenced physiological measures, the following covariates and their interaction with measurement time were entered in the model: LA95, age (and age^2), gender, and noise sensitivity. Of these, SBP was found to be influenced by LA95 (increase in SBP; $F(1,44) = 8.8$; $p < 0.01$), gender (higher SBP in males; $F(1,44) = 21.2$; $p < 0.01$)) and noise sensitivity (lower SBP in noise sensitive subjects; $F(1,44) = 6.7$; $p < 0.05$), and DBP only by gender (higher DBP in males, $F(1,44) = 8.6$; $p < 0.01$). No interaction effects with measurement time were found. On IBI and RMSSD, no effect of any of the covariates was found, and no interaction with measurement time, but a marginally significant reduction in IBI was found with higher LA95 ($F(1,43) = 3.0$; $p = 0.089$, n.s.). However, it should be noted that only overall effects were found of LA95 (on SBP and IBI) and noise sensitivity (on SBP) and no interaction with measurement time (pretest, prewalk, postwalk). A post-hoc analysis shows that LA95 negatively correlates with IBI at pretest (Pearson $R = -0.28$; $p < 0.05$), not with RMSSD, and positively (although only significant when testing within condition) with SBP at pretest (Pearson $R = 0.19$; n.s.; Pearson partial $R = 0.32$; $p < 0.05$). Thus, it cannot be concluded that the effects of LA95 reflect causal effects of noise exposure during the walk, since they may be due to individual differences in physiological measures at pretest.

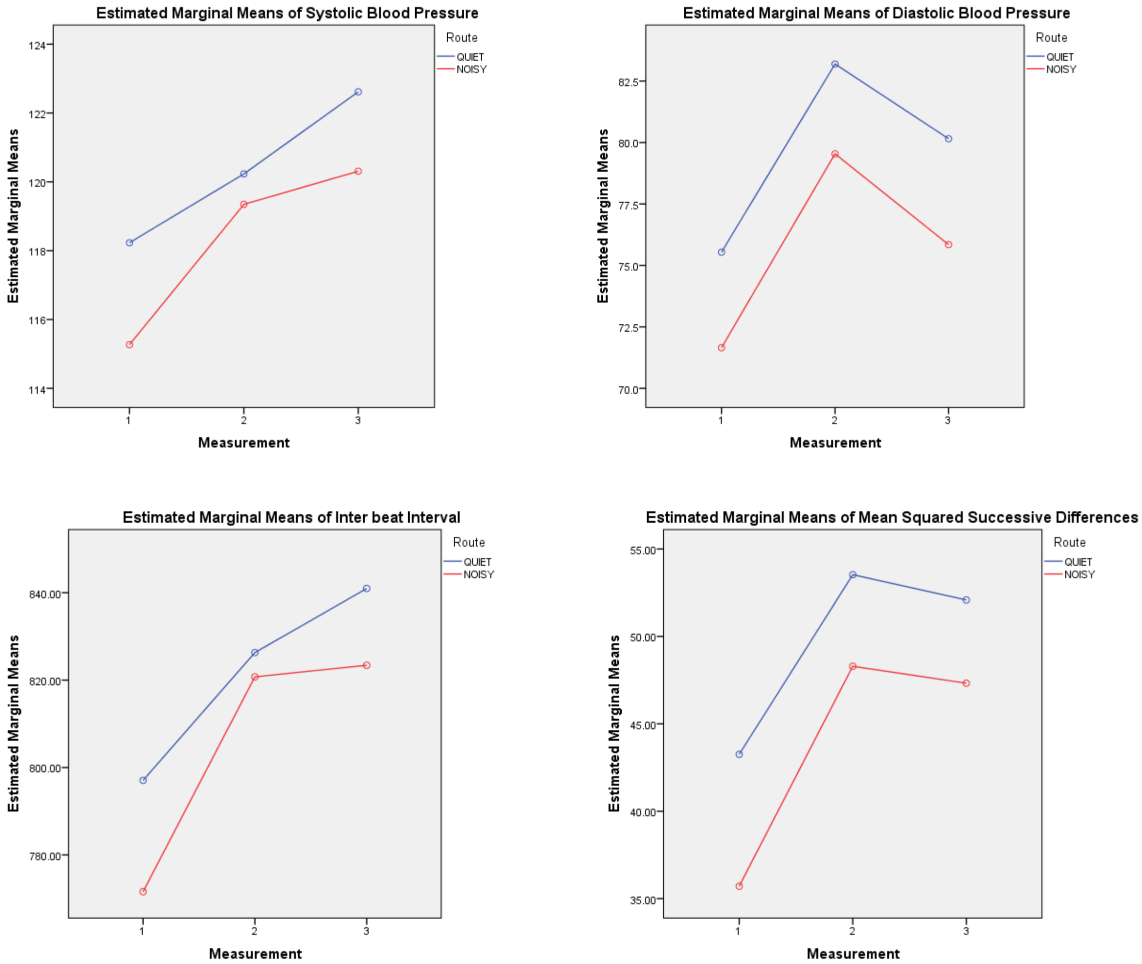
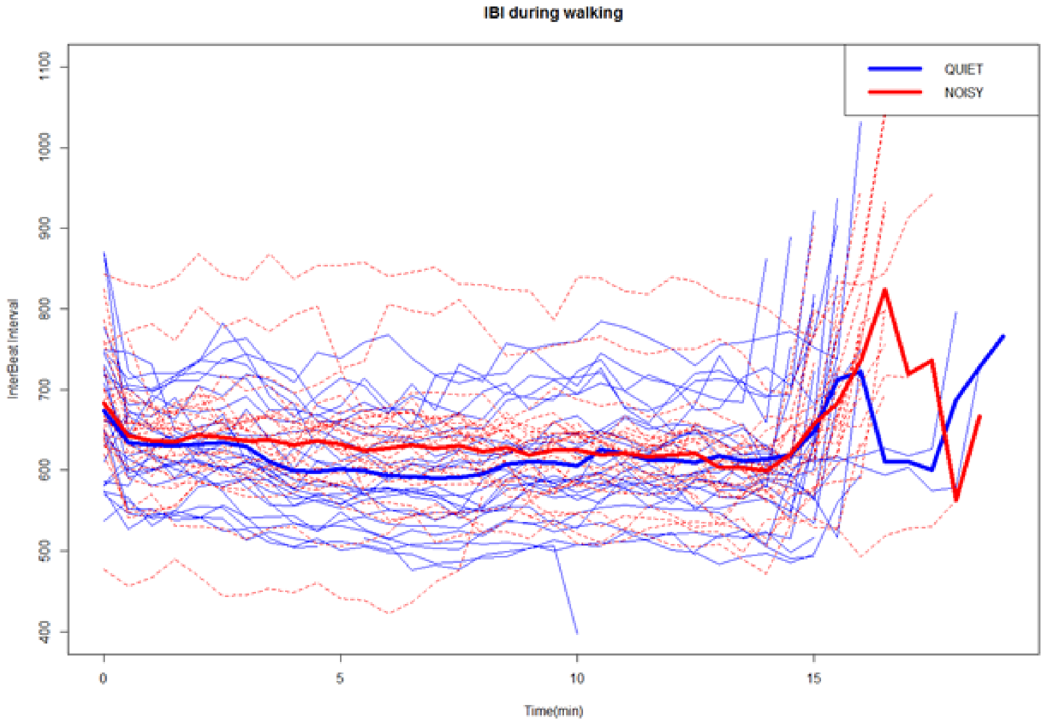


Figure 7 Mean SBP, DBP, IBI and RMSSD for measurements in rest (pretest, prewalk and postwalk) per route.

When comparing average IBI and RMSSD during the walk between different conditions, no effect was found on IBI, but a slightly higher RMSSD was found in the relatively quiet versus the noisy condition ($F(1,49) = 3.2$; $p = 0.079$, n.s.). When covariates (LA95, age, age2, gender, and noise sensitivity) were entered into the model, no effect of these was found on RMSSD, but IBI showed an effect of gender with highest values in males ($F(1,43) = 5.97$; $p < 0.05$), and higher LA95 tended to be associated with lower IBI ($F(1,43) = 3.0$; $p = 0.089$, n.s.). As was discussed in the previous paragraph, the latter effect may reflect individual differences in IBI existing at pretest.

Figure 8 shows no indications for any differential effects over time as a result of the differential time pattern in the noise exposure between conditions (see Figure A2 in Annex A). Therefore, looking into the momentary relationships between (continuous) noise levels and physiological measures is not warranted. While it could be worthwhile to investigate instantaneous responses to certain identified events causing a peak in the noise level, such as powered two-wheelers or other vehicles passing by, this is outside the scope of the present report.



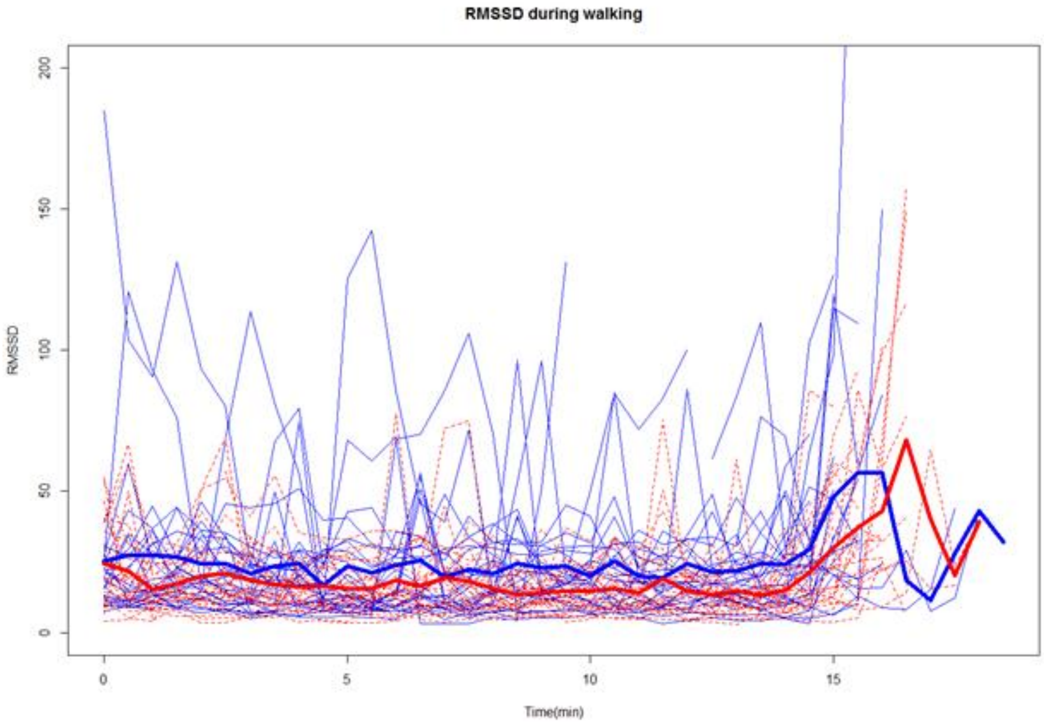


Figure 8 IBI and RMSSD during the walk for each subject (thin lines) and the average per route (bold lines). Note that the lines at the end of the time scale are based on fewer subjects due to differences in the exact duration of the walk, and may reflect effects of sitting down on the bench.

2.3 CONCLUSION

Results of the field study on the evaluation of the acoustic environment in an urban recreational area show that highway noise, especially in the relatively noisy condition, induced annoyance and interference with natural quiet. Also, higher noise levels were associated with higher annoyance and interference due to highway noise, lower perceived quietness and a reduction in perceived soundscape quality. Other factors influencing the acoustic evaluation were noise sensitivity (negative effect), perceived quietness at home (negative effect), loudness of people (positive effect) and the perceived importance of natural quiet (negative effect). Besides these effects on subjective measures, no significant effects of noise condition were found, perhaps due to a lack of contrast between conditions in noise exposure. While postwalk mood state measures showed positive effects with respect to pretest, this was not influenced by noise condition, nor by individual noise exposure. Likewise, heart rate decreased and heart rate variability increased with respect to pretest, and diastolic blood pressure decreased from prewalk to postwalk, but no significant differences were found between noise conditions. However, systolic blood pressure in rest was found to be higher at higher individual noise exposure. Furthermore, although not significant, small indications were found for reduced heart rate variability during the walk in the relatively noisy condition in comparison to the quiet condition, increased heart rate during the walk with higher individual noise level, and higher heart rate and lower heart rate variability in rest with higher individual noise level. Although in the direction of the hypothesized noise-induced deterioration of physiological restoration, it should be noted that these effects may have been due to individual differences already existing at pretest, since no interactions were found with measurement time.

The lower heart rate and higher heart rate variability in the outdoor setting with respect to the pretest, as well as the improved mood state after the walk, suggest restorative effects of being in the recreational area. This is in line with indications from previous studies for restorative effects of a natural environment, although the present study was specifically designed to test effects of a relatively quiet versus a noisy environment and no conclusions can be drawn with regard to other possible requirements of a restorative environment (e.g. natural versus built, outdoor versus indoor, physical activity). While noise condition did not significantly influence physiological or mental restoration, the evaluation of the acoustic environment, which was clearly affected by noise exposure, may indirectly lead to reduced restoration. A more negative acoustic evaluation may affect the perceived attractiveness of a recreational area and thereby the inclination to visit. Particularly when the area is the primary recreational area in the vicinity of the home, residents may refrain from visiting regularly, leading to less opportunities for restoration.

The factors that were found to influence the evaluation of the acoustic environment in addition to the noise level shed some more light on who will be expected to benefit from a more quiet outdoor environment. Subjects regarding themselves as noise sensitive were more negative on the quietness and the soundscape quality, and those who regarded the enjoyment of natural quiet as an important goal of visiting a recreational area reported more interference of highway noise with natural quiet. In this regard, it is also interesting that lower perceived quietness in the home situation was associated with higher perceived quietness and soundscape quality in the recreational area. This suggests that. in urban areas where people are exposed to high levels of noise at home, the presence of *relatively* quiet areas may serve an important recreational function, providing an escape from the higher noise levels at home. Further analyses on the relationship between noise levels and evaluation of the acoustic environment (see Chapter 3) provide information on generally acceptable levels of transportation noise in urban recreational areas, and on the expected percentage of visitors experiencing annoyance or interference.

3 NOISE RATING MODEL FOR THE OUTDOORS - IMPLICATIONS

As described in Chapter 1, only few field studies have quantified the effects of environmental noise on people in outdoor situations such as parks. In the CityHush project, two new field studies have been performed:

1) The field study in an urban park in Delft, as described in Chapter 2.
2) The field study in Athens, in both natural (parks) and non-natural environments (streets), as described in Deliverable 3.5.2 of the CityHush project.

In this chapter, first the results from the field study in Delft are used to derive exposure-response relations (ERF's) for effects of road traffic noise from a nearby highway, including an ERF for annoyance. Next a comparison will be made with results from the Athens study, and it is shown that the ERF for annoyance might be different for the case of non-natural outdoor environments. Further, a comparison will be made with the field data described in Chapter 1 regarding effects of aircraft and road traffic noise on annoyance and soundscape quality in outdoor situations.

3.1 ACOUSTIC ENVIRONMENT IN OUTDOOR URBAN RECREATIONAL AREAS

In outdoor urban recreational areas such as parks, a wide variety of sounds and noises occurs in general. For an annoyance model, it is not practical to distinguish many different recreational areas, therefore we aim for a model that applies to some kind of average recreational area.

In many outdoor urban areas, road traffic is a dominating noise source. In a recreational area such as a park, two types of traffic noise may be distinguished:

1) noise caused by local traffic in the park
2) noise from more distant traffic on roads near the park.

As a consequence, considerable differences in sound level and sound level fluctuations occur in practice. Local noise sources such as mopeds cause high peaks in noise level, while distant traffic causes a more continuous noise signal. In addition, various types of other sounds may occur in a park, both unpleasant sounds (noise) and pleasant sounds. Pleasant sounds include natural sounds from birds or rustling of trees by the wind. Unpleasant sounds include outdoor equipment such as lawn mowers for example.

In the Delft study, the urban recreational area was located near a busy highway, and in this case the acoustic environment (or soundscape) was dominated by road traffic noise from the highway (see Figure 9). Although also questions were asked on quietness and soundscape quality, the noise score rating questions focused in particular on annoyance caused by traffic noise from the highway. However, we will assume here that the results apply to the more general urban park situation where road traffic noise from surrounding roads (either highways or smaller roads) propagates into the park and causes varying degrees of annoyance among park visitors.

There is a wide variety of large and small urban parks in Europe, with various acoustic environments. For example, in some parks local mopeds may cause noise peaks (and annoyance), while in other parks mopeds are not allowed. We assume that the noise score rating model (or ERF) for annoyance caused by road traffic noise, as described in the next sections, applies to an *average urban park*.

Later in this chapter we will also consider results from the Athens field study, and we will argue that a different ERF applies to non-natural outdoor areas such as a street. People walking along a street are expected to respond differently to road traffic noise than people in a park do. More in general, the function of an urban area may play an important role in noise annoyance, as described in Section 1.6.

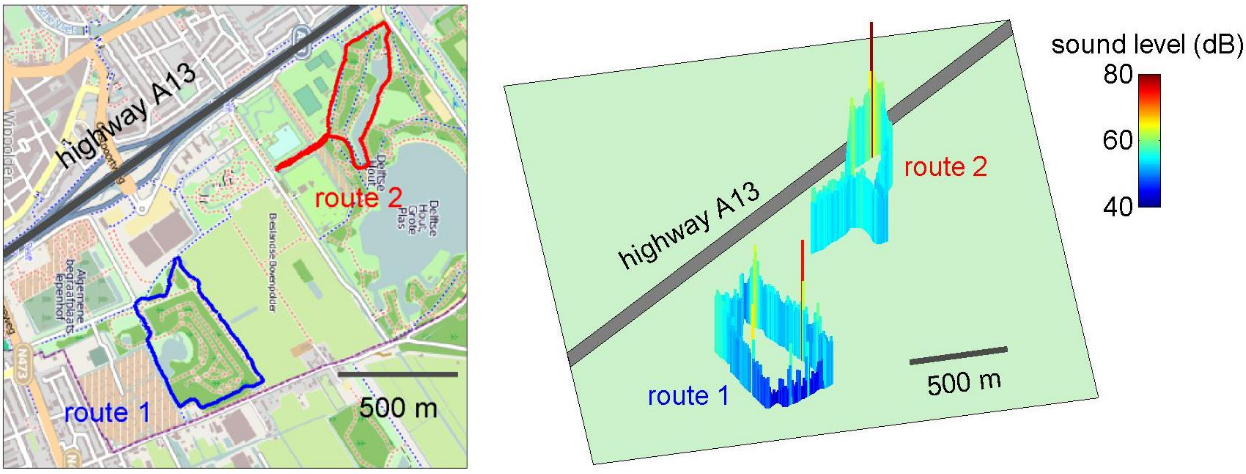


Figure 9 Illustration of routes 1 and 2 in the urban park in Delft near highway A13. The figure on the right shows a three-dimensional view of the varying sound level along the walks. The high peaks up to 80 dB correspond to local vehicles such as mopeds. The sound level is lowest along the section of route 1 at largest distance from the highway, which confirms that highway dominates the acoustic environment in the area.

3.2 NOISE INDICATOR FOR ERF

As described in the previous section, the acoustic environment in outdoor urban recreational areas is often a complex mixture of sounds from various sources. In particular in situations with major *local* sources, large spatial and temporal variations of the sound level occur.

For the noise score rating model (or ERF), the noise exposure of people in outdoor situations should be represented by a single number. Different types of noise indicators may be employed for this representation, such as (see Sections 1.4 and 2.1):

- LAeq A-weighted equivalent sound level,
- LA50 the value of A-weighted sound level that is exceeded 50% of the time,
- LA95 the value of A-weighted sound level that is exceeded 95% of the time.

These levels may be determined for a specific subject's visit in the outdoor situation, for example a period of an hour spent in a park, or for a specific (area of a) park, in which case a longer period may be chosen as representative.

An important question is whether the noise indicator should represent *all* noise or *only* road traffic noise. The latter is preferred when aiming for an ERF for road traffic noise annoyance, although it appears difficult to extract only road traffic noise from measured noise exposure in field studies, as described below. When aiming for the prediction of a more general evaluation of outdoor noise such as soundscape quality, an indicator representing all noise may be more appropriate.

We distinguish two elements of noise response prediction in outdoor urban recreational areas:

1) The derivation of an ERF from a field study, in this case the Delft field study (Section 3.3).
2) The application of the ERF in model studies for European cities (Section 3.6).

In element 1), the noise exposure of individual subjects in the field study may be determined in principle either by measurement or by model calculation. Model calculations are less accurate than measurements in most field-experiment situations, since the presence and location of noise sources (including traffic on roads near the park) are subject to considerable uncertainties during a field experiment.

As a consequence, for the Delft field study we decided to measure the individual noise exposure. The sound signal for the Delft park visitors was measured continuously during the walk through the park. In addition to road traffic noise from the nearby highway, there were various types of local sound sources. It was not possible to extract from the measurements the separate highway noise contribution. However, a model calculation of highway noise in the Delft park configuration (see Annex D) showed that the noise exposure was dominated by the highway, and that calculated highway noise levels agreed rather closely with measured levels of LA50 over the park visit. Levels of LAeq were a few dB higher than LA50, while LA95 was a few dB lower than LA50 (see Annex A). We conclude that LA50 is a useful indicator of (non-local) road traffic noise. High noise peaks caused by local sources such as mopeds do not affect LA50.

The situation is different for element 2) indicated above: application of the ERF in model calculations for parks in European cities. For these model calculations, no information is available about local sound sources in the parks. Only information is available about traffic on roads in the neighbourhood of the parks. Therefore, the best we can do is to calculate some kind of average road traffic noise level, and assume that this level is an approximation of the average road traffic noise exposure of a park visitor. The most appropriate averaging period may vary with the time of the year and with the geographical location in Europe, but a good and simple choice is to use the period from 7:00 to 23:00, i.e. the day and evening period. The LAeq over this period is referred to as Lde, where d stands for day and e for evening (an alternative notation is Lday,16h). Please note that the 5 dB penalty for the evening that is employed for the Lden level is *not* applied for the Lde level, although in principle such a penalty may be applied should evidence become available for a higher importance of the evening period.

Considering the above, one might conclude that for the derivation of the ERF (element 1) we should use the LA50, since this level represents the highway noise primarily. On the other hand, there are also arguments for using LAeq or LA95:

- LAeq is the most common noise indicator in the field of human response to environmental noise.
- In the Delft study it was found that LA95 showed the highest correlation with subjects' responses, although the absolute level underestimates the contribution of highway noise.

Therefore we decided to use LA50, LAeq, and LA95 when deriving ERF's from the Delft study. The best choice of the noise indicator depends on the type of response that is considered.

- For *direct* effects of road traffic noise (annoyance and interference by highway noise), the LA50 level appears the most natural noise indicator.
- For more general effects of outdoor noise (perceived quietness, perceived soundscape quality), the LAeq level may be a better indicator.

3.3 ERF'S DERIVED FROM DELFT FIELD STUDY

Using the same method that was previously used for the derivation of annoyance from transportation noise in the home situation (Miedema & Oudshoorn, 2001), ERF's were derived for the response to noise outdoors. The analysis was done on the individual data, using individual exposure and the annoyance score recoded into a 0-100 point score of each individual subject. The annoyance category boundary quantifications were computed for each annoyance score. For scales with 11 categories the boundaries are as follows: 0-9-18-27-36-45-55-62-73-82-91-100.

The model fitted is (using individual index i and study index j):

$A_{ij} = \beta_0 + \beta_1 L + \varepsilon_{ij}$ [1]

The model predicts the annoyance score on a 100-point scale (or rather the category boundaries) for each respondent as a function of the exposure level. By using the 100-point score as a continuous dependent variable (divided into intervals) instead of a dichotomized high annoyance cutoff point, all the information of the data distribution is used. After fitting the regression the annoyance score on a 100-point scale may be predicted from the regression coefficients. However, for policy the probability to exceed a certain annoyance score at a given noise level *L* may be more important than the mean annoyance score. For any value of the exposure variable, the expected percentage at least a little annoyed (A28; % with annoyance score ≥ 28), the percentage at least annoyed (A50; % with annoyance score ≥ 50) and the percentage highly annoyed (A72; % with annoyance score ≥ 72) can be estimated from the regression coefficients b_0 and b_1 and variance s^2 by using equation [6] from Miedema and Oudshoorn (2001). The same method was applied to the other response measures.

Figures 10 to 12 show ERF's derived from the results of the field study in Delft, for:

- (A) Annoyance by road traffic noise from the highway,
- (I) Interference of natural quiet by road traffic noise from the highway,
- (Q) Perceived quietness,
- (S) Perceived soundscape quality.

Each graph shows three curves, corresponding to expected percentage of scores above 28, 50, and 72 on the scale for annoyance (A), interference (I), perceived quietness (Q) and soundscape quality (S), respectively (corresponding values at integer sound level values are given in Tables 8 to 10). For example, quantity A50 is the percentage of subjects with a noise annoyance score of 50 (5 on the 0-10 point scale) or higher. The sound levels along the horizontal axes correspond to the individual noise exposures, as represented by the LAeq level (Figure 10), LA50 level (Figure 11), and LA95 (Figure 12). Figure 10 shows for example that over the exposure interval of LAeq from 50 dB to 60 dB (the approximate range in the field study):

- A50 increases from about 40% to 80%,
- I50 increases from about 60% to 90%,
- Q50 decreases from about 50% to 20%,
- S50 decreases from about 70% to 40%.

Figure 10 shows that above an LAeq level (all sounds) of around 50 dB, less than half of the visitors will perceive the area as quiet, and less than 70% will perceive the soundscape as good. Figure 11 shows that above an LA50 level (best representation of LAeq of the highway noise) of around 50 dB, more than half of the visitors will report annoyance and more than 70% will report interference by highway noise. The results shown in Figures 10-12 complement earlier findings on outdoor annoyance and perceived soundscape quality (see next section) that levels above 50 dB may strongly reduce positive evaluation the acoustic situation of a recreational area. This has implications for urban planning, indicating the need for a restriction of transportation noise in outdoor urban recreational areas.

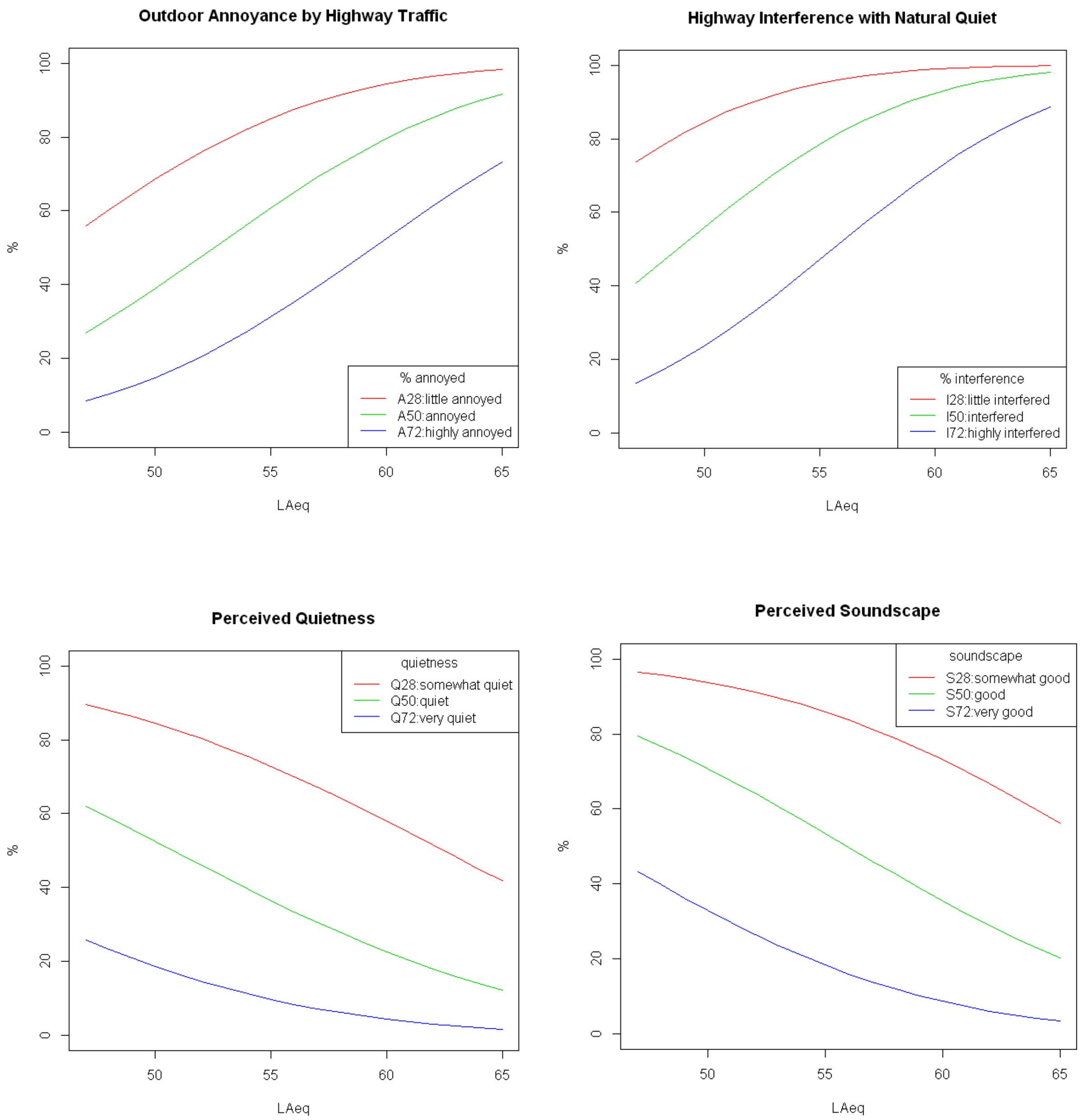


Figure 10 Percentiles of four response measures (Annoyance, Interference with natural quiet, Perceived quietness, and Perceived soundscape) as a function of LAeq.

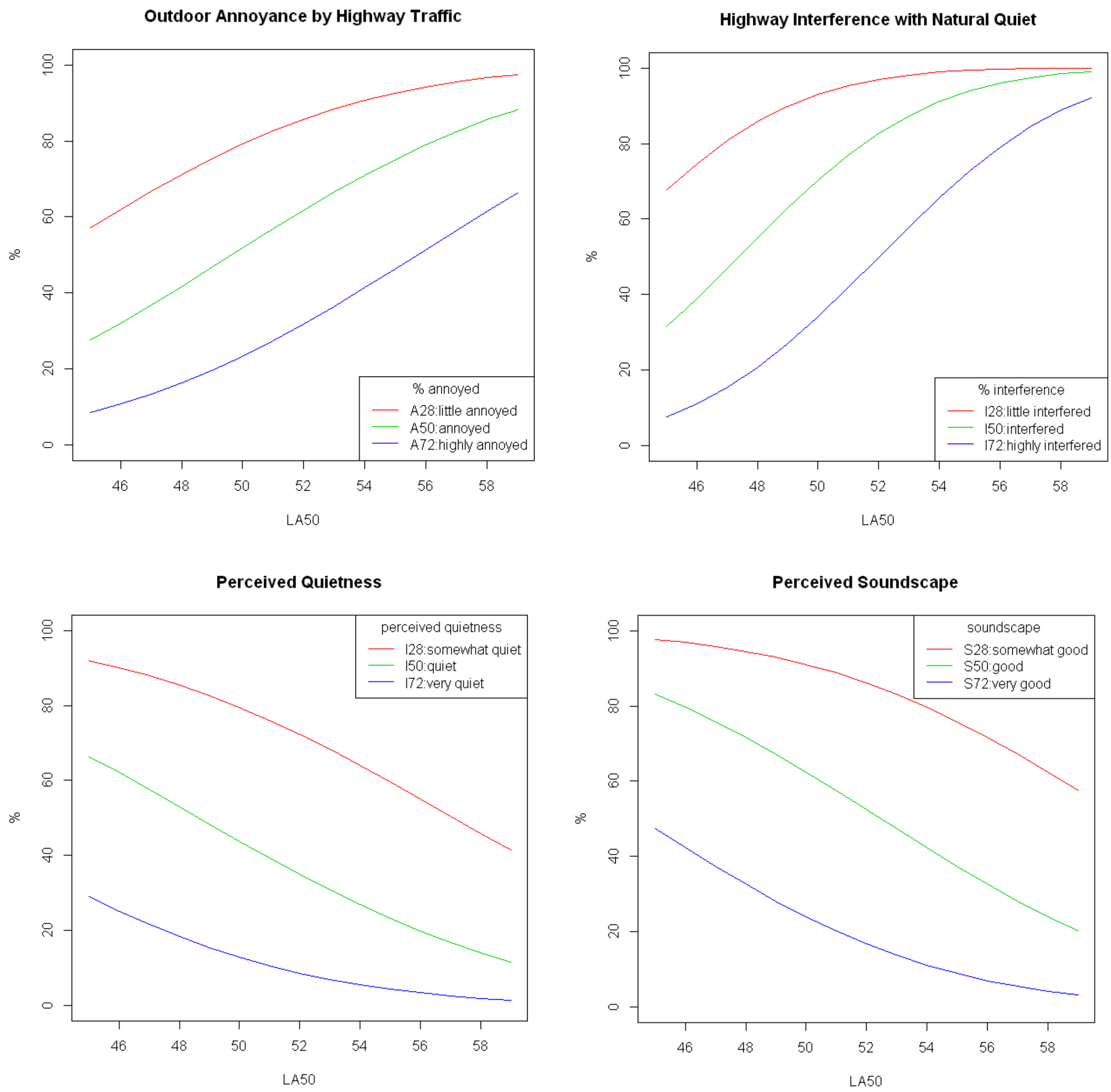


Figure 11 Percentiles of four response measures (Annoyance, Interference with natural quiet, Perceived quietness, and Perceived soundscape) as a function of LA50.

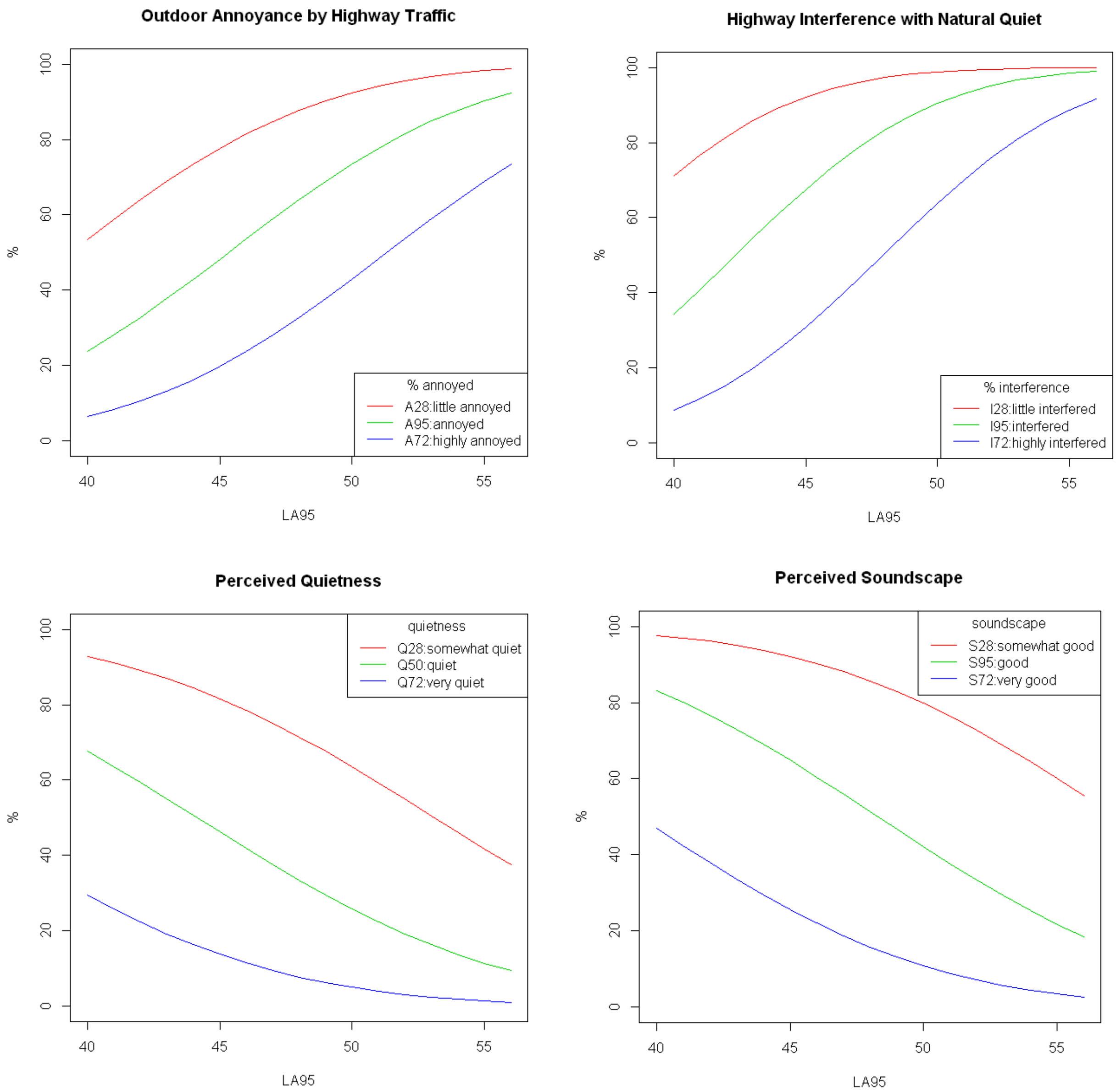


Figure 12 Percentiles of four response measures (Annoyance, Interference with natural quiet, Perceived quietness, and Perceived soundscape) as a function of LA95.

LAeq	A28	A50	A72	I28	I50	I72	Q28	Q50	Q72	S28	S50	S72
47	55.97	27.04	8.48	73.68	40.86	13.66	89.58	62.02	25.91	96.48	79.42	43.34
48	60.29	30.82	10.33	77.68	45.89	16.65	88.03	58.89	23.35	95.71	76.71	39.76
49	64.49	34.82	12.46	81.31	50.99	20.04	86.33	55.70	20.93	94.81	73.81	36.27
50	68.52	38.99	14.88	84.55	56.07	23.82	84.47	52.47	18.67	93.75	70.74	32.89
51	72.34	43.29	17.60	87.40	61.05	27.95	82.45	49.23	16.57	92.54	67.51	29.64
52	75.91	47.67	20.60	89.85	65.85	32.41	80.27	45.99	14.62	91.16	64.14	26.55
53	79.22	52.09	23.90	91.94	70.42	37.13	77.93	42.77	12.84	89.60	60.66	23.63
54	82.25	56.47	27.46	93.69	74.68	42.06	75.45	39.61	11.21	87.85	57.09	20.89
55	84.98	60.78	31.27	95.12	78.59	47.11	72.82	36.51	9.73	85.89	53.46	18.36
56	87.41	64.96	35.29	96.29	82.13	52.21	70.05	33.50	8.41	83.74	49.80	16.02
57	89.56	68.97	39.47	97.21	85.27	57.27	67.17	30.59	7.22	81.38	46.15	13.89
58	91.43	72.76	43.79	97.94	88.02	62.22	64.18	27.80	6.17	78.82	42.53	11.96
59	93.03	76.31	48.18	98.49	90.39	66.97	61.10	25.13	5.24	76.07	38.96	10.22
60	94.39	79.58	52.59	98.92	92.39	71.47	57.94	22.61	4.42	73.13	35.49	8.68
61	95.54	82.57	56.97	99.23	94.06	75.65	54.74	20.24	3.71	70.02	32.14	7.32
62	96.49	85.27	61.27	99.47	95.43	79.47	51.51	18.03	3.10	66.76	28.93	6.13
63	97.26	87.67	65.43	99.63	96.53	82.92	48.26	15.97	2.57	63.36	25.87	5.09
64	97.89	89.79	69.41	99.75	97.40	85.97	45.03	14.07	2.12	59.86	22.99	4.20
65	98.39	91.62	73.18	99.83	98.08	88.62	41.83	12.34	1.74	56.27	20.30	3.44

Table 8 Numerical values of ERF's shown in Figure 10.

LA50	A28	A50	A72	I28	I50	I72	Q28	Q50	Q72	S28	S50	S72
45	57.04	27.66	8.64	67.78	31.51	7.72	91.95	66.42	28.99	97.62	83.08	47.37
46	61.97	32.07	10.82	74.68	39.04	11.10	90.07	62.11	25.17	96.80	79.66	42.32
47	66.71	36.75	13.38	80.72	46.99	15.42	87.90	57.64	21.62	95.77	75.85	37.39
48	71.19	41.64	16.32	85.78	55.07	20.74	85.42	53.06	18.39	94.49	71.69	32.65
49	75.37	46.65	19.65	89.86	62.95	27.01	82.61	48.45	15.47	92.91	67.21	28.18
50	79.20	51.73	23.36	93.01	70.31	34.10	79.48	43.86	12.88	91.01	62.47	24.03
51	82.66	56.77	27.43	95.35	76.92	41.81	76.03	39.35	10.61	88.75	57.54	20.24
52	85.72	61.70	31.83	97.01	82.62	49.85	72.30	34.98	8.64	86.11	52.48	16.83
53	88.40	66.46	36.49	98.15	87.33	57.89	68.29	30.80	6.96	83.09	47.38	13.81
54	90.70	70.96	41.37	98.89	91.07	65.62	64.07	26.85	5.54	79.66	42.33	11.18
55	92.64	75.16	46.38	99.36	93.92	72.74	59.66	23.18	4.36	75.86	37.39	8.94
56	94.26	79.01	51.45	99.65	96.00	79.04	55.13	19.80	3.39	71.70	32.66	7.04
57	95.58	82.48	56.50	99.81	97.46	84.40	50.53	16.74	2.61	67.22	28.19	5.47
58	96.65	85.57	61.44	99.90	98.45	88.76	45.92	14.01	1.98	62.48	24.04	4.20
59	97.49	88.27	66.21	99.95	99.09	92.17	41.36	11.59	1.49	57.55	20.24	3.17

Table 9 Numerical values of ERF's shown in Figure 11, with the selected ERF for annoyance printed in red.

LA95	A28	A50	A72	I28	I50	I72	Q28	Q50	Q72	S28	S50	S72
40	53.53	23.69	6.41	71.07	34.39	8.71	92.72	67.70	29.58	97.71	83.19	47.04
41	58.83	28.03	8.27	76.63	40.89	11.75	91.05	63.62	25.87	97.00	80.11	42.45
42	63.96	32.72	10.51	81.55	47.65	15.47	89.12	59.39	22.42	96.12	76.71	37.96
43	68.86	37.70	13.17	85.76	54.47	19.91	86.91	55.04	19.24	95.04	73.01	33.63
44	73.44	42.90	16.26	89.27	61.17	25.03	84.41	50.62	16.35	93.73	69.04	29.51
45	77.66	48.23	19.78	92.11	67.55	30.78	81.61	46.21	13.76	92.17	64.84	25.63
46	81.46	53.58	23.72	94.34	73.45	37.04	78.51	41.83	11.47	90.33	60.45	22.04
47	84.83	58.87	28.07	96.04	78.75	43.67	75.13	37.56	9.46	88.19	55.91	18.75
48	87.77	64.01	32.76	97.30	83.38	50.48	71.49	33.43	7.73	85.73	51.30	15.79
49	90.29	68.90	37.75	98.20	87.30	57.28	67.61	29.50	6.24	82.95	46.68	13.15
50	92.40	73.48	42.95	98.84	90.53	63.86	63.53	25.79	4.99	79.85	42.09	10.84
51	94.14	77.69	48.27	99.27	93.10	70.06	59.29	22.34	3.95	76.43	37.61	8.83
52	95.56	81.49	53.63	99.55	95.10	75.73	54.94	19.17	3.09	72.71	33.30	7.11
53	96.68	84.86	58.92	99.73	96.61	80.76	50.52	16.29	2.39	68.72	29.19	5.66
54	97.56	87.80	64.05	99.84	97.71	85.09	46.11	13.71	1.83	64.50	25.34	4.46
55	98.23	90.31	68.94	99.91	98.50	88.72	41.73	11.42	1.39	60.09	21.77	3.47
56	98.74	92.42	73.52	99.95	99.04	91.67	37.46	9.42	1.04	55.55	18.51	2.67

Table 10 Numerical values of ERF's shown in Figure 12.

3.4 COMPARISON WITH OTHER STUDIES

In Figure 13 we have reproduced the ERF's for annoyance (A50) for the different noise indicators (LAeq, LA50 and LA95) from Figures 10-12 (Janssen et al) and we have included

- results from the Athens field study in CityHush D3.5.2, by Paviotti and Vogiatzis (P&V),
- results for aircraft noise annoyance in US national parks (Anderson et al, see Section 1.1).

For the Athens study, results are given for different LAeq exposure intervals (2.5 dB wide), which were measured for pedestrians or park visitors at one of four different urban locations during the short time they were interviewed. The four data points in the range from 50 dB to 60 dB roughly correspond to urban park situations in Athens, one site in a park at 100 m from a heavy traffic road and one site with a heavy traffic road at 100-200 m and screened by a low wall, more or less similar to the Delft park situation. The other data points in the range from 60 dB to 75 dB roughly correspond to non-natural locations in Athens, one site next to a minor road with light traffic and one next to a road with heavy traffic. The annoyance response was derived by averaging responses to three questions: one on the annoyance induced by the acoustic environment, one on the perceived quietness (reversed), and one on perceived soundscape quality (reversed). Subsequently, the percentage annoyed (A50) was calculated for each 2.5 dB interval. The blue line represents a linear interpolation fit to the data points, including a small correction for possibly enhanced annoyance by mopeds at two sites. Since the LAeq in the Athens study was measured, as in the field study in Delft, it included all noises and not just road traffic noise. Therefore, the response at a given LAeq from road traffic noise may be somewhat higher (curve shift to the left) than predicted from the overall LAeq, especially in park situations, where other sounds than road traffic noise may be more prevalent than alongside a road.

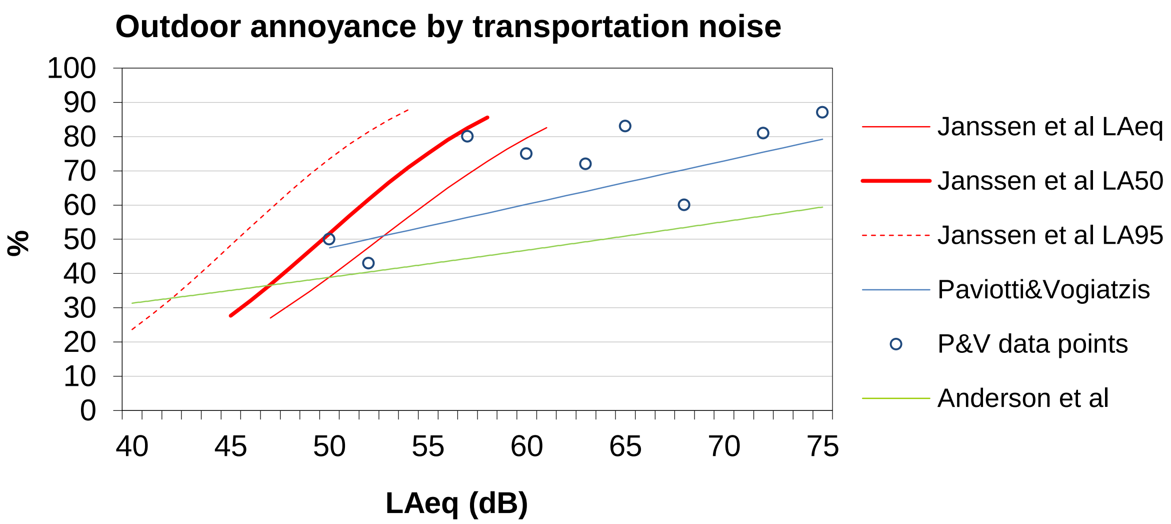


Figure 13 Expected percentage annoyed (A50) by transportation noise as a function of LAeq based on results from the present study (Janssen et al, 2011), in comparison to earlier findings by Paviotti & Vogiatzis (2011) and Anderson et al. (2011). Also included are ERF's from the present study as a function of LA50 (more representative of LAeq of highway noise) and LA95 (best predictor of annoyance).

We draw three conclusions from figure 13.

1. There is good agreement for noise annoyance in park situations with road traffic noise as the main source between the Delft study (LAeq/LA50) and the Athens study (data points between 50 dB and 60 dB LAeq). Therefore, we propose that the Delft LA50 curve in Figure 13 (thick red line, numerical values **printed in red in Table 9**) may be used as ERF for **road traffic noise annoyance in urban green recreational areas**.
2. For **road traffic noise annoyance in *general* outdoor urban areas** (both natural and non-natural areas), the line from the Athens study (blue line, given by **A50 = 1.27LAeq-16**) appears to be a better representation of the ERF across a larger range of LAeq. For levels above 60 dB, the Athens data suggest that road traffic noise annoyance of people in non-natural outdoor situations (people walking along a street) is lower than would follow from extrapolating the curve of people in a park (thick red line), and does not rise as sharp with exposure level.
3. Data from Anderson et al. (2011) show that **aircraft noise annoyance in US national parks** at a given LAeq is considerably lower than road traffic noise annoyance in the Delft and Athens park situations (except at low exposure levels). This is surprising, since for annoyance at home by aircraft noise and road traffic noise, the trend is opposite: at equal façade level Lden, aircraft noise is more annoying than road traffic noise. The reason for the opposite behavior for outdoor annoyance is not clear. Perhaps it is not so much the difference in noise source, but rather the difference in outdoor area (US national park versus urban park in Delft or Athens) that plays a role in explaining the different annoyance response.

In addition to the comparison of studies on outdoor annoyance, a comparison of the present data with other field study findings is given below with regard to the findings on interference with natural quiet, perceived quietness and soundscape quality:

- Interference with natural quiet was also studied by Anderson et al. (2011), whose curve for outdoor annoyance by aircraft noise was less steep than ours, crossing our ERF at an LAeq around 50 dB (just like their aircraft noise annoyance curve).
- Goossen et al. (2001) concluded that an LAeq of 40 dB is evaluated by most visitors of natural recreational areas as sufficiently quiet, whereas levels above 50 dB strongly reduce their positive evaluation. This is consistent with our finding that above an LAeq of 50 dB less than half of the visitors will perceive the acoustic situation as quiet.
- Nilsson and Berglund (2006) showed that in city parks with LAeq levels between 50 and 60 dB around 60% of visitors perceived the soundscape as good, while only in suburban green areas (with levels around 45 dB) more than 80% of the visitors perceived the soundscape as good. This agrees well with our finding that at an LAeq of 55 dB around 60% of the visitors are expected to perceive the soundscape as good, while only levels below 47 dB would allow for 80% of the visitors to perceive the soundscape as good.

3.5 INDOOR ANNOYANCE MODEL VERSUS OUTDOOR ANNOYANCE MODEL

Our preliminary noise rating model for the outdoors was based on the resemblance between findings from Krog & Engdahl (2004) on annoyance by aircraft noise in local recreational areas and the aircraft noise annoyance ERF for residents at home (see Section 1.2, Figure 1). The assumption was that outdoor annoyance in urban green areas would not follow the outdoor annoyance curve for national parks by Anderson et al (2011), but would be more similar to the curve for residents in urban areas. However, the annoyance model (or ERF) for road traffic noise in outdoor green urban areas presented In the previous section highly differs from the road traffic annoyance model for residents. The model predicts for an LA50 level of 54 dB (or an LAeq level of 57 dB) an annoyance response (A50) of 70%, for example. For comparison, indoor annoyance at the same sound level is much lower: for a façade level Lden of 55 dB the annoyance response at home is about 20%. This large numerical difference presumably originates from two basic differences between an outdoor annoyance model and an indoor annoyance model, which are explained below and indicated in Table 11.

Type of annoyance

An indoor annoyance model represents long-term average annoyance, for example annoyance over a period of a year. The annoyance surveys that form the basis of an indoor annoyance model contain questions about annoyance in and around the house, judged over the period of a year. The outdoor annoyance model presented in the previous section corresponds to short-term annoyance, i.e. annoyance for the period of a park visit, for example.

Type of exposure indicator

An indoor annoyance model employs a façade level Lden, the yearly averaged noise level as measured outside at the most exposed façade of each dwelling. Consequently, indoor levels are typically 20 dB lower than façade levels Lden. The exposure level for the outdoor annoyance model presented in the previous section corresponds to the LA50 level ‘at the ear’, averaged over the period of a park visit (although in the practical application of the model, the noise exposure during a visitor’s stay in the park will have to be estimated based on a single level Lde for the entire park or Lde levels for separate areas of the park).

	Indoor annoyance model	Outdoor annoyance model
Type of annoyance	Long-term annoyance in and around the house	Short-term annoyance during a park visit, for example
Type of exposure indicator	Long-term average noise level Lden at the most-exposed façade of the dwelling	Short-term average noise level Lde ‘at the ear’

Table 11 Differences between an indoor annoyance model and an outdoor annoyance model.

3.6 APPLICATION OF THE MODEL FOR OUTDOOR ANNOYANCE

The ERF's derived from the Delft field study, which were described in Sections 3.4 and 3.5, may be used for predictions of road traffic noise annoyance in urban parks in European cities. We recommend using the A50 - LA50 relation as ERF. The ERF is represented by the first and third columns in Table 9 (printed in red), and is shown graphically in Figures 11 and 13.

The noise level LA50 represents approximately the exposure to road traffic noise. For practical calculations for an urban park, an engineering noise model is used with input values of average vehicle intensities on roads near the park (and possibly inside the park). The calculated level should correspond to a time period that is relevant to visits of the park, for example the period from 7:00 to 23:00. The sound level averaged over the period 7:00-23:00 is denoted as Lde or Lday,16h. The averaging procedure amounts to using vehicle intensities averaged over the period 7:00-23:00.

Moreover, some kind of spatial averaging over the park must be performed. The simplest approach is to calculate a single level Lde averaged uniformly over the entire park. In that case, the expected percentage of annoyed visitors is simply the corresponding A50 value in Table 9, and the number of annoyed visitors may be calculated from the expected number of visitors. If significant level variations occur within the park and if information is available on the locations that are most frequently visited by people, a more sophisticated spatial averaging procedure may be appropriate, or alternatively the percentage (and number) of annoyed visitors can be derived separately for different areas of the park on the basis of their respective Lde levels.

4 REFERENCES

Aasvang GM, Engdahl B (2004). Subjective response to aircraft noise in an outdoor recreational setting: a combined field and laboratory study. Journal of Sound and Vibration 276: 981-996.

Alvarsson JJ, Wiens S, Nilsson ME (2010). Stress recovery during exposure to nature sound and environmental noise. Int J Environ Res Public Health 7: 1036-1046.

Anderson GS, Rapoza AS, Fleming GG, Miller NP (2011). Aircraft noise dose-response relationships for national parks. Noise Control Eng J 59: 519-540.

Anderson GS, Horonjeff RD, Menge CW, Miller NP, Robert WE, Rossano C, Sanchez G, Baumgartner RM, McDonald C. Dose-response relationships derived from data collected at Grand Canyon, Haleakala and Hawaii Volcanoes National Parks HMMH Report No. 290940.14; NPOA Report No. 93-6, National Park Service, Denver, CO, USA.

Berg A van den, Maas J, Verheij RA, Groenwegen PP (2010). Green space as a buffer between stressfull life events and health. Social Science and Medicine 70: 1201-1210.

Bodin M, Hartig T (2003). Does the outdoor environment matter for physiological restoration gained through running? Psychology of Sports and Exercise 4: 141-153.

Booi H, van den Berg F (2012). Quiet areas and the need for quietness in Amsterdam. Int J Environ Res Public Health 9: 1030-1050.

Chiesura A (2004). The role of urban parks for the sustainable city. Landscape and Urban Planning 68: 129-138.

Wald FD, Mellenbergh GJ (1990). De verkorte versie van de Nederlandse vertaling van de Profile of Mood States (POMS) [The shortened version of the Dutch translation of the Profile of Mood States (POMS)]. Nederlands Tijdschrift voor de Psychologie en haar Grensgebieden 45: 86-90.

Fidell S, Silvati L, Howe R, Pearsons KS, Tabachnick B, Knopf RC, Gramann J, Buchanan T (1996). Effects of aircraft overflights on wilderness recreationists. Journal of the Acoustical Society of America 100: 2909-2918.

Gauvin L, Rejeski WJ (1993). The Exercise-Induced Feeling Inventory: Development and initial validation. Journal of Sport & Exercise Psychology 15: 403-423.

Goossen CM, Langers F, de Vries S (2001). Gelderse stilte? Onderzoek naar de stiltebeleving van recreanten [A study into the degree of quietness experienced by visitors of recreational areas in Gelderland]. Alterra Research Institute for Green Space Report no. 398, Wageningen, the Netherlands.

Hartig T, Evan GW, Jamner LD, Davis DS, Gärling T (2003). Tracking restoration in natural and urban field settings. Journal of Environmental Psychology 23: 109-123.

Hartig T, Kaiser FG, Bowler PA (1997). Further development of a measure of perceived environmental restorativeness. Institute for Housing Research Report nr 5, Uppsala University, Sweden.

Jim CY, Chen WY (2006). Recreation-amenity and contingent valuation of urban green spaces in Guangzhou, China. Landscape and Urban Planning 64: 191-200.

Kaplan R (1995). The restorative benefits of nature: toward an integrative framework. Journal of Environmental Psychology 15: 169-182.

Kariel HG (1990). Factors affecting response to noise in outdoor recreational environments. The Canadian Geographer 34: 142-149.

Krog NH, Engdahl B (2004). Annoyance with aircraft noise in local recreational areas, contingent on changes in exposure and other context variables. Journal of the Acoustical Society of America 116: 323-333.

Krog NH, Engdahl B (2005). Annoyance with aircraft noise in local recreational areas and the recreationists' noise situation at home. Journal of the Acoustical Society of America 117: 221-231.

McNair DM, Lorr M, Droppelman L (1971). Manual: Profile of mood states. San Diego: EDITS/ Educational and Industrial Testing Service Inc.

Miedema HME, Oudshoorn CGM (2001). Annoyance from transportation noise: relationships with exposure metrics DNL and DENL and their confidence intervals. Environmental Health Perspectives 109: 409-416.

Mitchell R, Popham F (2008). Effect of exposure to natural environment on health inequalities: an observational population study. The Lancet 372: 1655-1660.

Netherlands Health Council (2006). Stille gebieden en gezondheid (Quiet areas and health). Health Council, report nr 2006/12, The Hague, The Netherlands.

Nilsson ME, Berglund B (2006). Soundscape quality in suburban green areas and city parks. Acta Acustica united with Acustica 92: 903-911.

Nilsson ME, Botteldooren D, De Coensel B (2007). Acoustic indicators of soundscape quality and noise annoyance in outdoor urban areas. Proceedings of the International Congress on Acoustics (ICA), Madrid, Spain.

Schreurs PJG, van de Willige G, Brosschot JF, Tellegen B, Graus GMH (1993). De Utrechtse Coping Lijst (UCL): Omgaan met problemen en gebeurtenissen [The Utrecht Coping List (UCL): Dealing with problems and events]. Zwets & Zeitlinger b.v., Lisse, the Netherlands.

Takano T, Nakamura K, Watanabe M (2002). Urban residential environments and senior citizens' longevity in megacity areas: the importance of walkable green space. Journal of Epidemiological Community Health 56: 913-918.

Tarrant MA, Haas GE, Manfredo MJ (1995). Factors affecting visitor evaluations of aircraft overflights of wilderness areas. Society and Natural Resources 8: 351-360.

Vingerhoets AJJM, van Tilburg MAL (1994). Alledaagse Problemen Lijst (APL) [Everyday Problem Checklist (ECPL)]. Zwets & Zeitlinger b.v., Lisse, the Netherlands.

Vries S de, Verheij RA, Groenewegen PP, Spreeuwenberg P (2003). Natural environments – healthy environments? An exploratory analysis of the relationship between green space and health, Environment and Planning 35:1717-1731.

Ulrich RS, Simons RF, Losito BD, Fiorito E, Miles MA, Zelson M (1991). Stress recovery during exposure to natural and urban environments. Journal of Environmental Psychology 11: 201-230.

ANNEX A: ANALYSIS OF THE MEASUREMENTS

Statistics of acoustic indicators

Post-processing of the data resulted in the following single value indicators for each walk:

-	LAeq	A-weighted equivalent sound level
-	LA50	the value of LAeq,1s that was exceeded 50% of the time
-	<LA50,1m>	the logarithmic average of LA50 levels over successive 1 minute intervals
-	LA95	the value of LAeq,1s that was exceeded 95% of the time
-	LA10-LA90	10% minus 90% exceedance level, measure of the variation of sound level
-	Nev	the number of noise events derived from sound level traces, see annex B

The number of noise events was derived from the sound levels traces, as explained in annex B. The values of the six indicators are given for all subjects in the table presented in annex C, together with meteorological parameters, and the distribution per route is given in Figure A1.

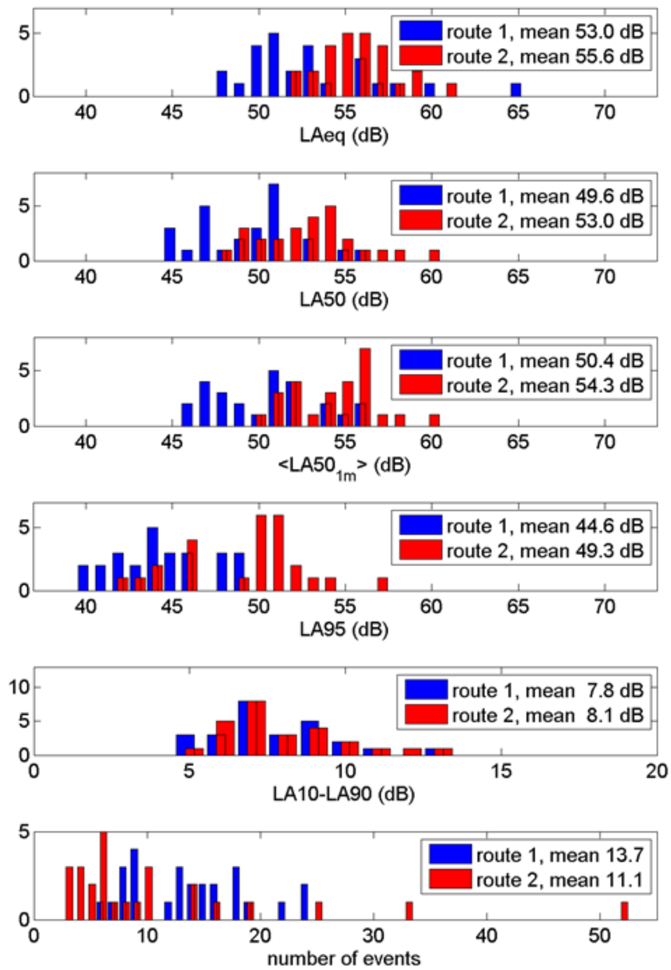


Figure A1 Distribution of individual noise exposure in six acoustic indicators per route.

Variation with time

The variation of the sound level with time during the walk is shown in figure A2. The graphs in the figure show values of LA50 determined over ten successive time intervals. The average lines for routes 1 and 2 are significantly different. For route 1 the level first decreases (the subject is moving away from the highway) while for route 2 the level first increases (the subject is moving closer to highway).

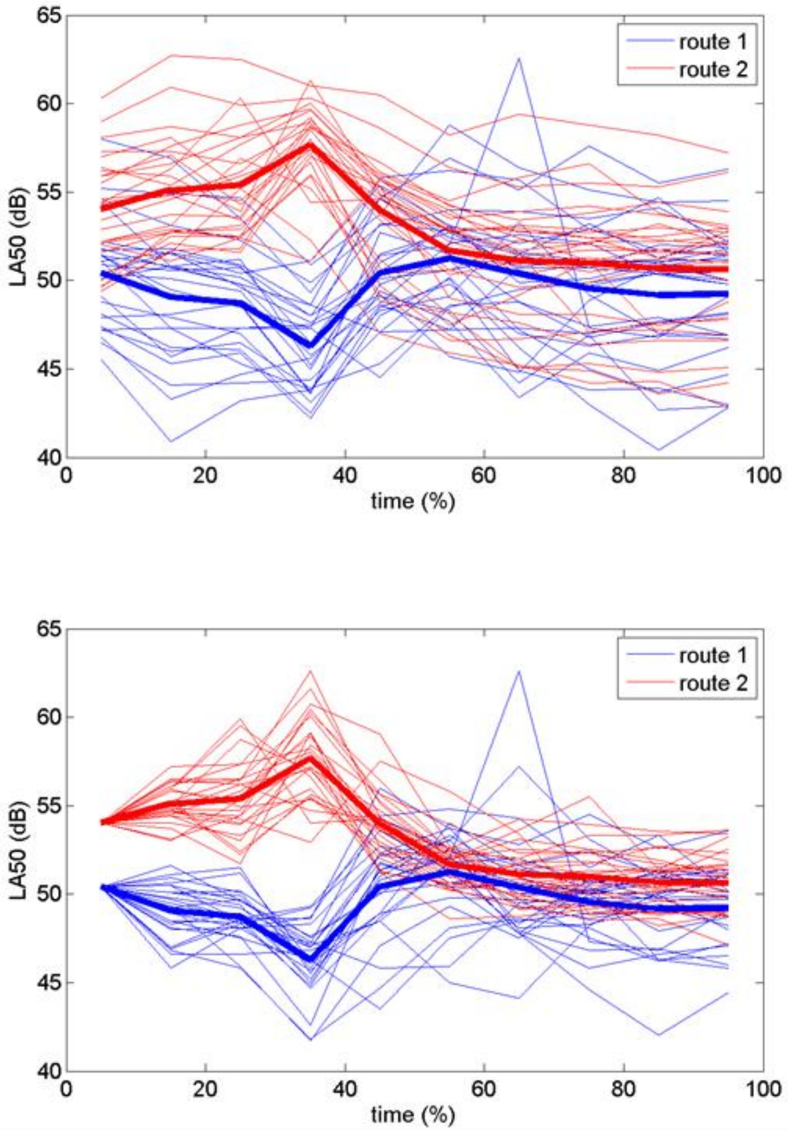


Figure A2 Variation with time of the level LA50 for all walks separately (thin lines) and for the average walk per route (bold lines). The total time of the walk is divided into ten equal parts, and for each part the LA50 level is determined. For the lower graph the traces are shifted such that the first points coincide.

Effect of wind

Figure A3 shows the variation of the level LA50 with wind direction, wind strength, and wind vector component in the direction from the highway to the receiver. The sound level is highest for wind direction SW, in agreement with the geographical orientation of the highway and routes 1 and 2. There were no significant differences between routes in frequency of occurrence of each wind direction, wind strength and wind vector component.

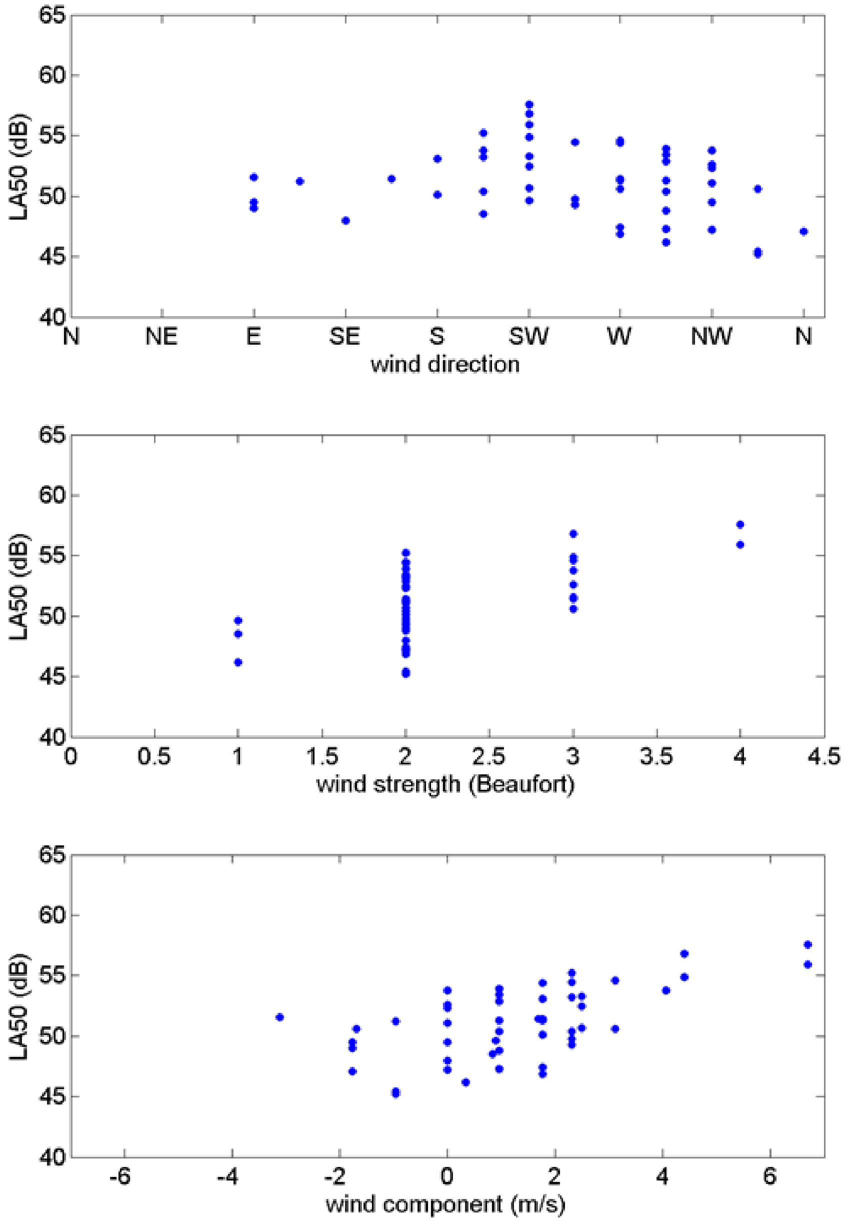


Figure A3 Variation of the level LA50 with wind direction, wind strength, and wind vector component in the direction from the highway to the receiver. The level is highest for wind direction SW (upper graph), in agreement with the geographical orientation of the highway with respect to routes 1 and 2.

Variations of the sound spectrum

In addition to the six acoustic indicators above, we have also investigated the variation of the shape of the spectrum. Traffic noise has a broad spectrum. Bird song shifts the spectrum to higher frequency. We defined the center-of-gravity frequency as $f_{cog} = \sum_j f_j \cdot w(f_j)$, where f_j are the 1/3-octave band frequencies of the spectrum, and the normalized weights w are equal to $10^{L_j/10} / \sum_j 10^{L_j/10}$, where $L_j = L(f_j)$ is the average 1/3-octave band spectrum over the walk. We found values of f_{cog} between 1000 Hz and 2000 Hz for the 52 walks.

During the walk of person 4 there was a lot of bird song (see Figure A4). For this walk a high value was found of 1879 Hz for f_{cog}. The variation of the shape of the spectrum is illustrated in Figure A4.

This suggests that the center-of-gravity frequency might be used as an indicator for the amount of bird song, which might have an effect on the acoustic perception of the environment. However, other local sounds, in particular high-frequency sound generated by footsteps of the researcher on gravel ('self noise') had a similar effect on the spectrum as bird song. Therefore we concluded that the center-of-gravity frequency is *not* a useful quantity for this study.

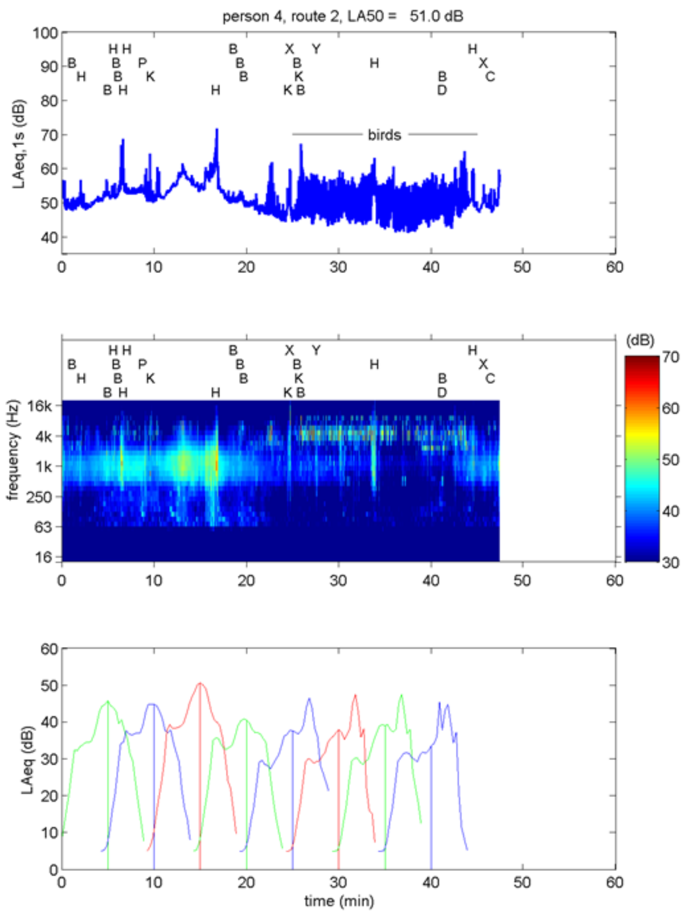


Figure A4 Spectral analysis of the noise signal recorded during the walk of subject 4. During the second half of the walk birds are active, and the spectrum shifts to higher frequency. The lower graph shows the average spectrum over successive intervals of 5 minutes.

ANNEX B: DETECTION AND EXAMPLES OF NOISE EVENTS DURING WALK

In this annex some examples are presented of noise events during the walks. For each walk, two graphs are given:

1) Level-time diagram: A-weighted sound level as a function of time

2) Spectrogram: A-weighted 1/3-octave band spectrum as a function of time.

The time axis consists of successive periods of 1 second, and for each 1 sec period the equivalent A-weighted sound level and the corresponding spectrum is represented.

The titles of the graphs give the following levels:

- LAeq A-weighted equivalent level over the full measurement period
- LA50 the 50% exceedance level corresponding to the full measurement period
- <LA50,1m> the logarithmic average (over the measurement period) of LA50,1m.

Letters in the graphs indicate noise events as written down during the walks. Not all events could be marked, since some events such as birds (B) and wind gusts (W) may have followed each other too rapidly. The meaning of the letters is explained in the list below:

A = automobile / car
T = truck
M = moped
J = boat
L = lawnmower
E = helicopter
S = scooter
P = airplane
C = bicycle
D = dog
F = frog
U = walker (footsteps etc)
H = human voice
R = horse
K = roller skater
B = bird, duck
W = wind / trees / leaves
Y = 'scootmobiel'
N = horn
Z = 'self noise' (paper etc)
Q = gravel
X = 'other'

In addition, automatic detection of events from the sound level traces is illustrated, by black and red dots in the graphs. The detection is based on two acoustic indicators:

- LAeq,1s the 1 second equivalent A-weighted sound level
- LA50,1m the 50% exceedance level, corresponding to a period of 1 minute.

Black dots represent moments that LAeq,1s exceeds LA50,1m by 3 dB, red dots represent moments that LAeq,1s exceeds LA50,1m by 3 dB for at least 3 sec.

Figure B1 and B2 below show the sound traces of a test walk on both routes, a Figure B3 to B6 show examples of sound traces of subjects. Note that the full walks are represented here , i.e. until the subject is back at the starting point. Since the noise exposure after the second bench (a few minutes before the end of the walk) could not affect the response anymore, acoustic quantities used for the analyses in Chapter 2 have been restricted to the time interval until the end of the rest period on the second bench.

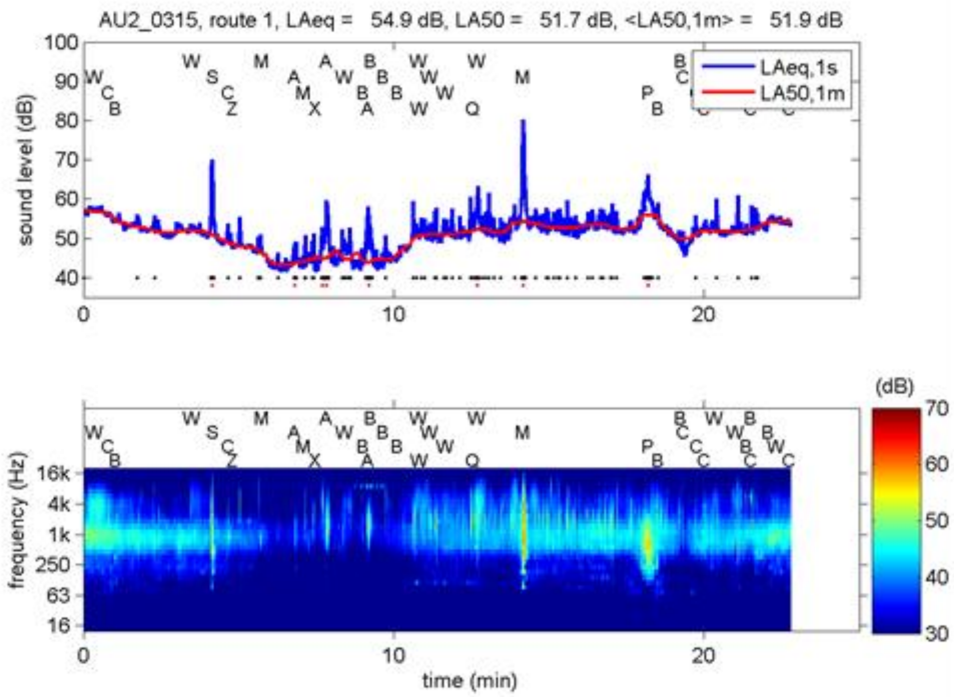


Figure B1 Sound trace for a test walk along route 1 (relatively quiet).

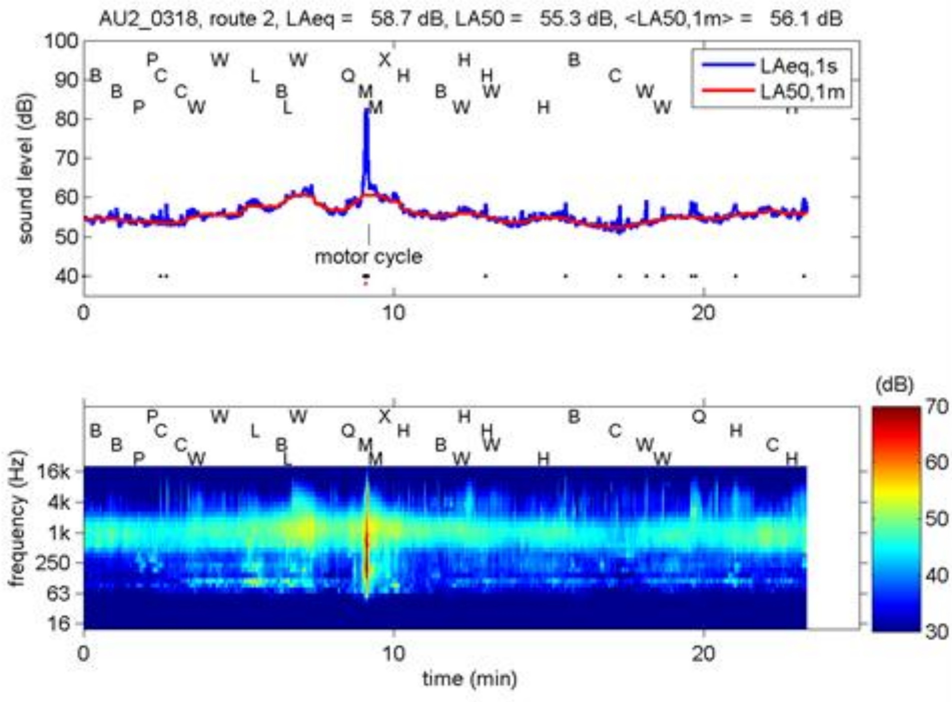


Figure B2 Sound trace for a test walk along route 2 (relatively noisy).

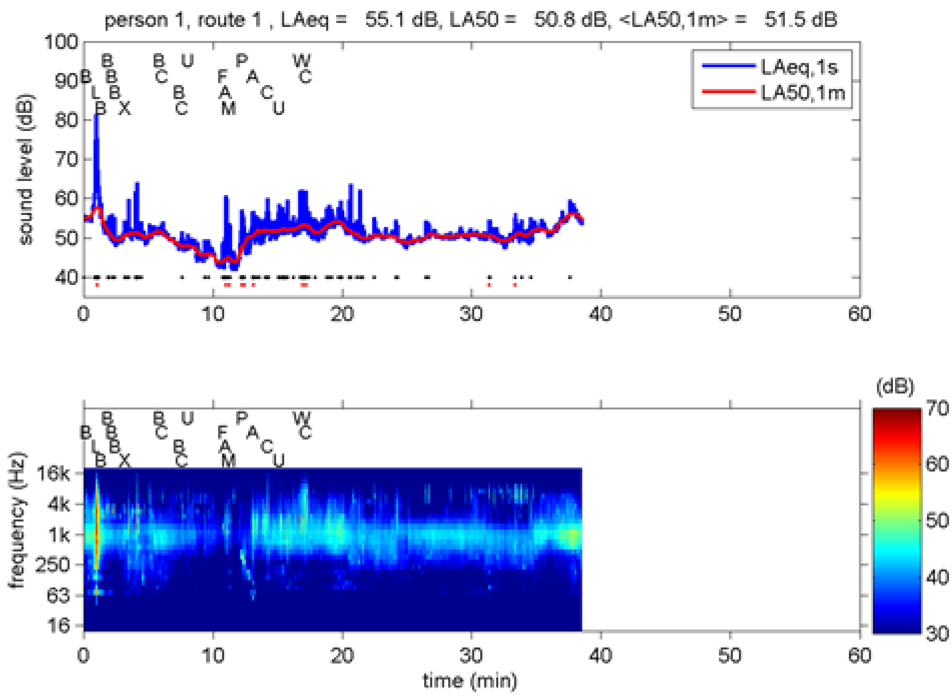


Figure B3 Sound trace for subject 1 along route 1 (relatively quiet) with noise events.

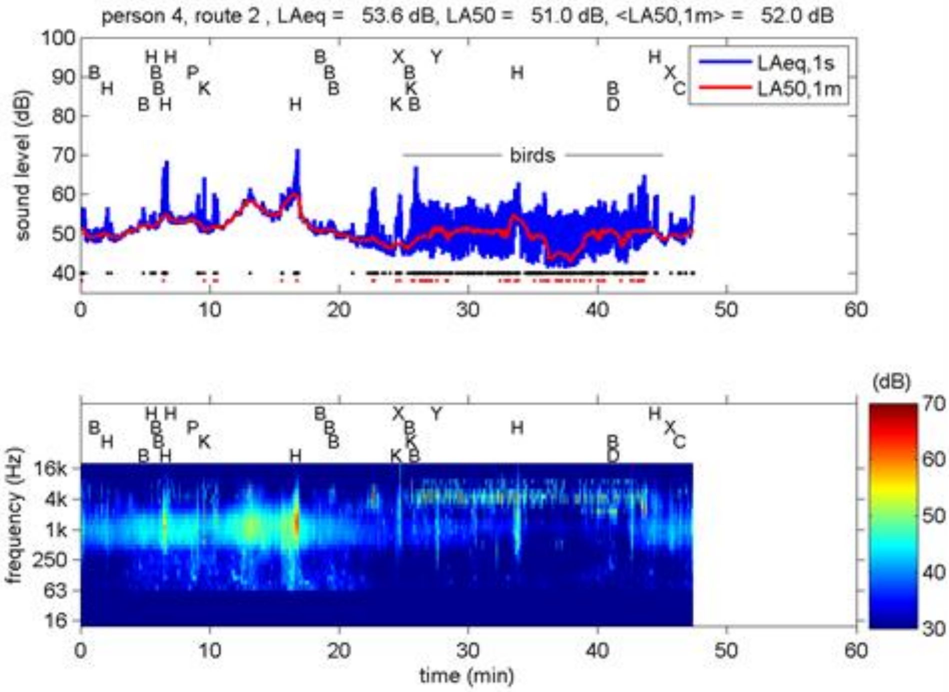


Figure B4 Sound trace for subject 4 along route 2 (relatively noisy) with noise events.

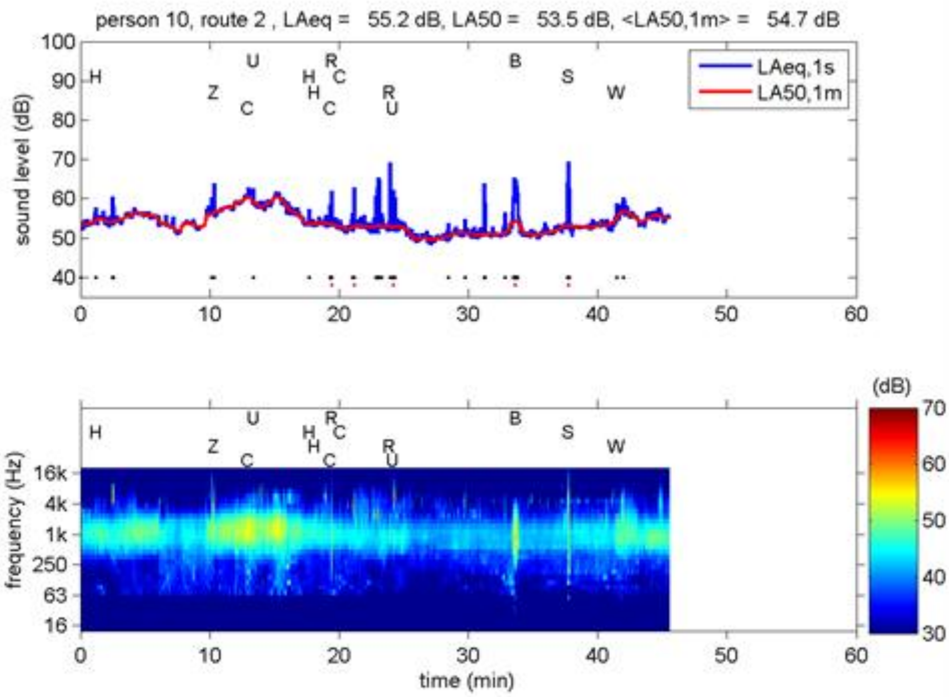


Figure B5 Sound trace for subject 10 along route 2 (relatively noisy) with noise events.

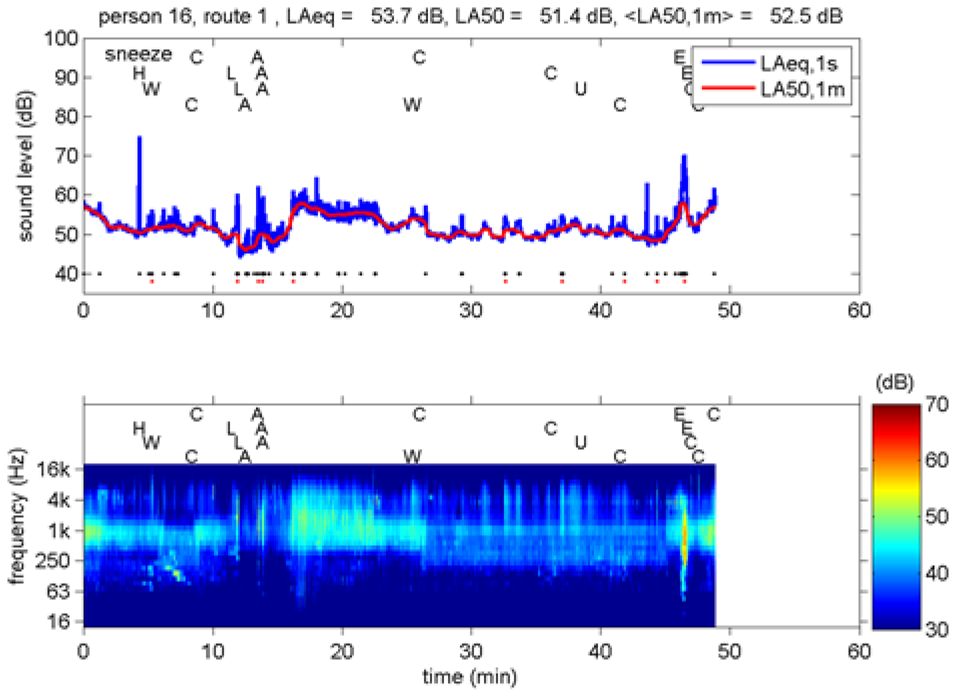


Figure B6 Sound trace for subject 16 along route 1 (relatively quiet) with noise events.

ANNEX C: ACOUSTIC AND METEOROLOGICAL PARAMETERS PER WALK

Subject	Route	LAeq (dB)	LA95 (dB)	LA50 (dB)	LA50,1m (dB)	LA10-LA90 (dB)	Nev	Time (min)	Wind direction (deg)	Wind force (bft)	Wind speed (m/s)	Wind comp (m/s)	Temp (C)
1	1	55.9	44.5	50.7	51.2	8.2	8	27.5	225	2	2.5	2.5	17
2	2	57.2	51.4	54.6	55.6	7.2	7	37.3	270	3	4.4	3.1	15.5
4	2	53.6	44.2	51.2	52.1	11.3	52	42.4	112.5	2	2.5	-1	26.4
5	1	52.9	44.8	50.6	50.6	6.8	15	30.5	270	3	4.4	3.1	18
6	1	52.4	44.9	50.6	51.6	9.9	24	40.2	337.5	3	4.4	-1.7	17.9
9	2	58.9	52.1	56.8	57.3	6.9	4	44.3	225	3	4.4	4.4	19.2
10	2	55.2	50.1	53.3	54.6	7.7	5	40.5	225	2	2.5	2.5	19.3
11	1	51.8	46.2	51.4	51.3	5.3	8	39.1	157.5	3	4.4	1.7	18.2
12	1	54.4	48.7	53.1	53.6	7.1	9	39.8	180	2	2.5	1.8	20.1
13	2	54.4	46.5	50.1	52.4	9.4	9	41.2	180	2	2.5	1.8	20.2
14	1	51.3	42.0	46.9	47.5	7.1	14	41.1	270	2	2.5	1.8	21.4
15	1	55.6	48.1	52.6	54.0	9.1	16	38.9	315	3	4.4	0	15.4
16	1	53.1	48.0	51.3	52.3	7.1	8	44.1	270	2	2.5	1.8	18.2
17	2	56.7	50.3	53.8	56.1	7.7	3	40.6	202.5	3	4.4	4.1	21
18	2	52.6	45.6	49.6	51.5	10	19	45.3	225	1	0.9	0.9	18.9
19	1	51.1	42.5	47.4	47.7	6.1	19	50.5	270	2	2.5	1.8	18.4
20	2	55.1	49.8	52.9	54.6	7.5	8	41.8	292.5	2	2.5	1	16.3
21	2	55.7	51.0	53.8	54.9	6.5	10	42.5	315	3	4.4	0	17.3
22	1	50.9	43.8	49.3	49.4	7.2	9	29.8	247.5	2	2.5	2.3	19.9
23	2	55.6	43.1	49.0	51.6	12.9	25	43.9	90	2	2.5	-1.8	19.9
24	2	54.7	45.7	49.5	51.3	9.4	10	48.9	315	2	2.5	0	16.4
25	2	54.1	50.0	52.3	53.6	6.6	4	43.8	315	2	2.5	0	17.8
26	2	51.9	43.9	49.5	50.9	10.5	14	42.3	90	2	2.5	-1.8	18.9
27	2	51.8	42.4	48.0	50.2	12.2	33	52	135	2	2.5	0	21.9
28	2	56.1	51.0	53.9	54.5	6.3	16	40.6	292.5	2	2.5	1	21.9
29	1	56.1	49.5	54.9	55.4	6.8	7	38.5	225	3	4.4	4.4	19.1
30	2	55.3	50.0	53.2	54.5	7.2	6	50.3	202.5	2	2.5	2.3	18.4
31	1	52.6	46.4	50.4	51.0	5.3	12	46.8	202.5	2	2.5	2.3	18.4
32	2	59.1	54.4	57.6	58.3	6.4	6	46.1	225	4	6.7	6.7	19.2
33	1	57.2	48.6	55.9	56.4	7.9	16	44.1	225	4	6.7	6.7	19.2
34	2	57.1	50.7	53.4	55.9	8.3	6	41.8	292.5	2	2.5	1	19
35	1	51.4	44.0	50.4	50.6	7.1	9	38.6	292.5	2	2.5	1	19
36	2	57.7	50.7	54.5	55.9	8.6	10	40.9	247.5	2	2.5	2.3	19.7
37	1	65.3	44.6	49.8	56.2	13.4	18	39.6	247.5	2	2.5	2.3	19.7
38	2	53.2	48.9	51.1	52.8	6.9	4	50.2	315	2	2.5	0	18.4
39	1	49.7	43.0	47.2	47.4	6.5	13	37.1	315	2	2.5	0	18.4
40	1	59.8	47.6	51.3	52.4	5.9	18	40.1	292.5	2	2.5	1	19.6
43	2	56.1	51.1	54.4	55.6	7.2	3	43.6	270	2	2.5	1.8	16.7
44	1	49.9	41.4	45.2	46.3	8.8	22	39.2	337.5	2	2.5	-1	20.4
45	1	57.8	46.4	51.4	51.6	5.2	9	39.5	270	2	2.5	1.8	16.7
46	1	50.4	43.6	48.8	49.5	7.1	6	38.5	292.5	2	2.5	1	18.4
47	1	51.1	41.5	45.4	46.7	8.8	15	38.7	337.5	2	2.5	-1	19.7
48	1	50.2	42.5	47.1	48.4	9.8	24	42	360	2	2.5	-1.8	20.4
49	1	52.5	43.8	48.5	49.6	8.7	14	26	202.5	1	0.9	0.8	18.2
50	1	48.3	40.0	46.2	46.8	10.7	13	37.9	292.5	1	0.9	0.3	16.6
51	1	49.1	42.8	47.3	47.7	7.8	13	38.6	292.5	2	2.5	1	18
53	2	54.3	50.0	52.5	53.9	7.4	6	42.9	225	2	2.5	2.5	17.4
54	2	56.5	52.7	55.2	56.1	5.5	3	40.6	202.5	2	2.5	2.3	19.7
55	2	54.8	46.1	51.6	52.4	9.3	5	34.1	90	3	4.4	-3.1	19.1

ANNEX D: COMPARISON MEASURED AND CALCULATED SOUND LEVELS

Noise from highway A13 is heard continuously along the trajectories, so cannot be isolated by signal processing. Therefore we concluded that the contribution of A13 highway noise is best determined by calculation. These calculations were compared to the measurements done during a test walk (see Figure D1). We used the Dutch road traffic noise model (SRM2) for this calculation, with the following vehicle intensities: 8000 cars per hour, 800 light trucks per hour, and 800 heavy trucks per hour (based on a few counts performed by us, and an 'official' total intensity of 173 000 vehicles per 24 h). Further, we used a driving speed of 100 km/h, and a porous asphalt road surface.

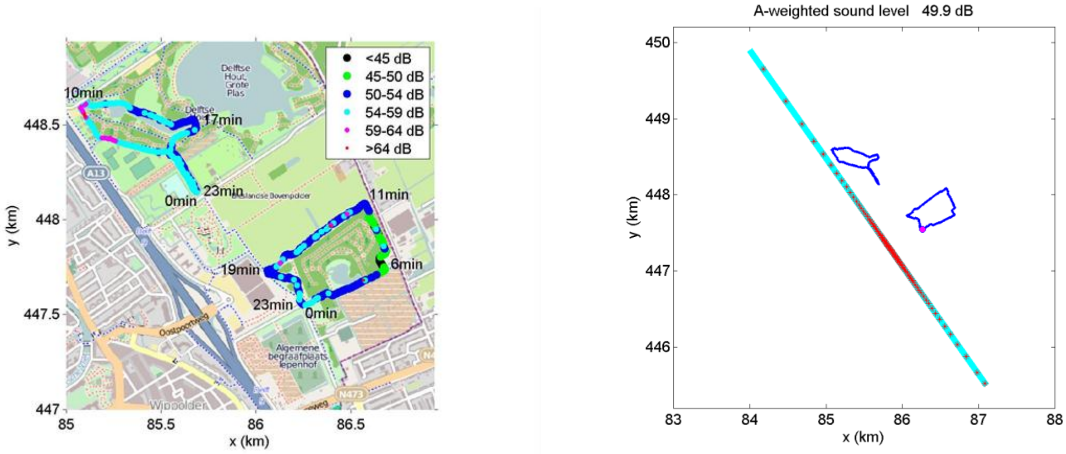


Figure D1 Variation along routes 1 and 2 of the sound level LAeq,1s. Each dot represents an average of five successive values of LAeq,1s measured during a test walk. The right figure shows an Illustration of SRM2 noise calculation for a single point (purple) of route 1. Red dots are source emission points on highway A13.

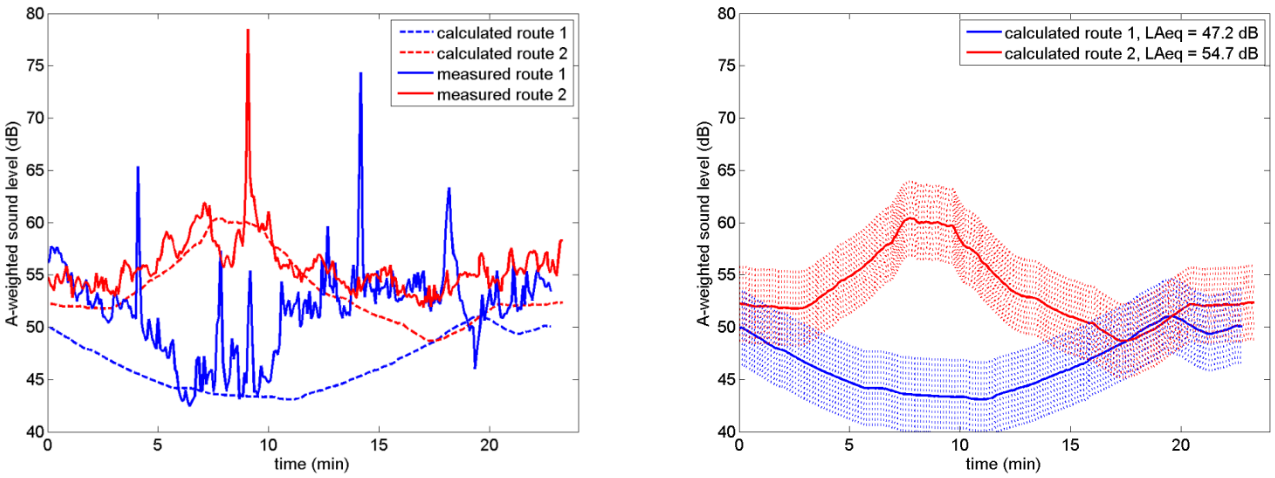


Figure D2 Comparison of measured and calculated levels (left) and calculated levels with +/- 3.5 dB atmospheric fluctuation (right).

Figure D2 shows the calculated sound level as a function of time. For comparison also the measured sound levels from the test walk are shown. The calculated levels should be considered as average levels for the day period. Actual levels deviate from these levels, because of variations of vehicle intensity and variations of atmospheric conditions. The variations due to atmospheric conditions are estimated as ± 3.5 dB, and are illustrated in figure 10. As indicated in the legend of figure D2, we find that the calculated LAeq level is 7.5 dB higher for route 2 than for route 1. Atmospheric variations generate level differences of the order of at least 5 dB.