Assessment of spatial and physical neighborhood characteristics that influence sound quality and herewith well-being and health

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Abstract

Environmental noise and health studies seldom address the positive effect of environments with high acoustic quality. Sound quality, in turn, is influenced by a large number of factors, including the spatial–physical characteristics of a neighborhood. In general, these characteristics cannot be retrieved from existing databases. In this article, we describe the design of an audit instrument and demonstrate its value for gathering information about these characteristics of neighborhoods. The audit instrument used was derived from research in other fields than environmental health. The instrument was tested in 33 neighborhoods in the Dutch cities of Amsterdam, Rotterdam, and Arnhem. In these neighborhoods, more or less homogeneous subareas were identified that were subject of the audit. The results show that the audit approach is suitable to gather neighborhood data that are relevant for the sound quality of neighborhoods. Together with survey data, they provide information that could further the field of soundscape and health. Several suggestions for improvement of the audit instrument were made.

Keywords: Auditing, neighborhoods, noise, soundscapes

INTRODUCTION

In the last decades, the quality of life in many western countries has improved significantly. People live in better houses, the standard of living has increased, and people live longer in better health. The environmental conditions have improved as well: the air quality is much better, several soil pollutions have been cleaned up, and the surface water is much cleaner.[1] A remarkable exception is environmental noise. The annoyance and sleep disturbance caused by noise in western countries, as a result of predominantly road, rail, and air traffic, is still at the same level as several decades ago, and this has been shown to have a negative effect on health and well-being.[2,3]

An important indicator of these effects, especially in urban areas, is the extent to which people are able to recover from environmental stressors such as noise exposure. In the recovering process, both sound levels and meanings of sounds play an important part. For the meaning of sound different taxonomies have been developed, but a very straightforward one differentiates simply between pleasant (wanted) and annoying (unwanted) sounds.[4]

However, as a result of sound (noise) by traffic, neighbors and mechanical devices in urban areas, the variation in sounds (wanted and unwanted) is diminishing. Norms for noise levels cannot prevent that urban areas get covered by a blanket of background noise that masks differences in the levels and the meanings of sound. Consequently, the impact of the use of norms for sound (noise) levels on the quality of life in urban areas is limited. Therefore, the attention in noise and health research has partly shifted from the effects of noise levels to the effects of sound quality. Sound quality refers to levels of sound as well as their meaning.

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How to cite this article: Devilee J, Kempen Ev, Swart W, Kamp Iv, Ameling C. Assessment of spatial and physical neighborhood characteristics that influence sound quality and herewith well-being and health. Noise Health 2017;19:154-64.
Identifying and designing areas with a good sound quality is not an easy task due to the rather large number of factors that can have an influence on it. To get an idea of these relevant variables, at the Dutch National Institute for Public Health and the Environment a literature review has been done\(^5\) as part of the project “towards a sustainable sound environment” (TASTE). Key finding of this review was that areas with good sound quality are not only characterized by acoustic aspects, but also by aspects other than sounds. Kang et al.\(^6\) showed, for example, that the shape of an area affects its sound quality. Salomons et al.\(^7\) demonstrated that characteristics and interruption of facades of buildings have strong effects on propagation and reflection. Van Renterghem et al.\(^8\) provide evidence that boundary materials (street surfaces, bricks, concrete, glazing, etc.) influence the reverberation and attenuation of sounds. Moreover, several studies\(^9-11\) show that vegetation is capable to reduce sound levels by reflecting, refracting, scattering, and absorbing sound.

In addition to the physical characteristics of a place, its visual features also are of importance of the sound quality of a place. A large number of studies\(^12-19\) have shown that vision and hearing are not independent, but reinforce each other in complex ways.

The review\(^5\) showed that, although a significant amount of knowledge about the determinants of sound quality has been developed, a (validated) instrument that enables the measurement of sound quality in urban areas does not exist yet. Consequently, it is not possible to make a link between spending time in urban areas with good sound quality and its effects on human health and well-being. To fill this gap, in the TASTE project, a research design has been developed to study sound quality in urban areas. This design uses different methods and includes a survey to register the perceived sound quality of residents. Details about the design and the results of the survey will be reported elsewhere. To acquire data about the spatial–physical characteristics of neighborhoods a different approach was needed. Most of the attributes of neighborhoods as described above cannot be retrieved from databases or other information systems. Consequently, it was decided that an audit at neighborhood level was needed to gather these data.

In an audit, trained research assistants enter an (urban) area and systematically register the spatial and physical characteristics in a form, laptop, tablet, or smartphone. In this way, information about neighborhoods can be collected that cannot be derived from secondary data or registrations. In this article, we describe the design and demonstrate the feasibility of an audit instrument that registers relevant spatial–physical neighborhood characteristics. For this purpose, a selection of the variables in the audit instrument will be made.

**DESIGN OF THE AUDIT INSTRUMENT**

Although in the last decades, several audit tools have been developed, for example, to study sound characteristics of nature area\(^20-23\) or to study spatial and physical traits of urban areas,\(^24-30\) they are not very common in the field of noise and health. In this type of research, neighborhood characteristics are usually derived from existing databases and registrations. The choice of indicators for the audit instrument presented here [Table 1], was partly based on an evaluation of the literature about these instruments, supplemented with indicators from existing tools.

**SAMPLING OF THE NEIGHBORHOODS**

The audit was tested in 33 neighborhoods in three Dutch cities (Arnhem, Amsterdam, and Rotterdam) that have very different characteristics [Table 2]. Of the three cities, Amsterdam has the most typical urban characteristics. It has the largest number of inhabitants, the largest population density, the highest level of criminality, and the relatively smallest surface area of forest and nature. Rotterdam takes a middle position, whereas Arnhem has clearly the least typical urban characteristics. In fact, the area taken by forest and nature in this city is larger than the built area. We included Arnhem in the sample as it may provide a vivid contrast with Rotterdam and Amsterdam.

**Table 1: Summary of the audit instrument**

| Name of audit component | Indicators included |
|-------------------------|---------------------|
| I. General              | Name of auditors, name of city, date, weather conditions, time, positive, or negative elements in the neighborhood, remarkable issues |
| II. Characteristics of buildings | Type of roads, closedness of building blocks, predominant height of buildings, staggering facades, cultural historic elements, historic, or diversity in architecture |
| III. Playing, meeting, and public facilities | Shops, businesses, meeting places, catering, suitability for playing, suitability for social meetings, litter bins, benches, bus shelters, bike racks, mutual planters or letter boxes, and street lightning |
| IV. Traffic safety      | Speed limits, traffic safety measures, car parking style, and presence of a car park |
| V. Physical characteristics of green areas | Number of visible gardens, size and style of these gardens, trees in the street, type of public green, and type of public blue (water) |
| VI. Pollution, rubbish, decay, and social insecurity | Litter, rubbish, signs of alcohol or drug use, graffiti, broken glass, vandalism, and dog defecation |
| VII. Perception         | Diversity of streetscapes, attractive furnishing of streets, area was properly looked after; during the audit I felt safe, I encountered several disrupting physical elements, the design of the area did not match its function, quality of green and blue areas, and overall impression of the area |
The neighborhoods included in the test were selected according to level of urbanization (variation in), yearly averaged noise levels ($L_{den}$), morphology, and the date of construction. Moreover, we used socioeconomic status (at neighborhood level) as a selection criterion. Representatives of municipal health services in the three cities provided assistance in the selection process. In this way, relevant local information was taken into account. There is a large variety of neighborhoods in terms of the variables mentioned above.

Figure 1 displays the scores of the neighborhoods in our study on these variables by using star plots. In these plots, a set of related variables is presented in a kind of pie chart, in which the radius of a piece of the pie is dependent upon the relative strength of a variable. In these plots, neighborhood characteristics are presented and ordered by the overall impression of an area (see the “Results” section for the construction of this last variable). By providing the plots for all neighborhoods in a particular city a compact description of relevant neighborhood characteristics can be given and a comparison between different neighborhoods can be made. The figure shows for instance that IJburg West is the youngest neighborhood in our study, in which the urbanity is very limited, the socioeconomic status is high and there is a large amount of blue and green. Moreover, there is no variation in noise levels (and background noise levels are low).

As it was not feasible to audit entire neighborhoods, we decided to select to draw a purpose full sample of streets per neighborhood. To this end, we divided the neighborhood in more or less homogenous subareas. Decisions about the homogeneity of neighborhood parts were based on combinations of data in geographical information system (GIS). These data provided an overview of the building period of houses (in classes of 15 years), which is an important indicator in The Netherlands for the morphology of a neighborhood, spatial distribution of noise levels in $L_{den}$ (less than 50 dBA, between 50 and 65 dBA, and larger than 65 dBA) and an overview of logical subareas as a result of physical barriers like roads, railways, waterways, and other obstacles. Subsequently, we constructed a route of two to three streets that was assumed to be representative through each subarea.

![Figure 1: Characteristics of neighborhoods in the study, ordered by overall perception](image-url)
THE AUDITING PROCESS

We instructed 12 research assistants (with a background in planology and/or architecture) to register the features of the selected neighborhoods in a systematic way (auditing). The research assistants were asked to walk the abovementioned predetermined route in the relatively homogeneous parts of neighborhood and to audit the elements they met. For this purpose, they received several small maps with directions that were generated by the GIS system, illustrated in Figure 2. In the lower part of the figure, an overview of the neighborhood is provided in which the numbers indicate the homogeneous areas. In the upper part, the predetermined route has been drawn.

Moreover, the auditors received a detailed map of the municipality and a small notebook to register situations that had not been anticipated in the audit form. The auditors were allowed to contact the researchers by phone or e-mail to solve these unforeseen problems. In addition, auditors were asked to take five photographs during the walk and to include GPS-trackings. This provided the possibility to monitor the quality of the data and gave us some additional visual information about the neighborhoods audited. Two research assistants walked a route together, each recording his own impressions in the audit form. They were allowed to deliberate about scores, but a consensus was not required. The research assistants were recruited locally and each walked routes in one specific city only. Within the city, the routes were divided between assistants themselves. This means the pairs were mostly constant in formation. The resulting correlation structure in the data leads to limited options for the statistical analysis.

STATISTICAL ANALYSIS

To ensure good quality, double data entry according to a codebook was done by two research assistants who had not been involved in the auditing process. Data entry was followed by comparison and correction of
errors. After data cleaning, a dataset with 216 observations was obtained.

The first step in the analysis was to create, using SAS (SAS Institute Inc, Cary, NC, USA), ordinal variables defined in terms of scales (e.g., of 1 to 5) to represent the different aspects or characteristics of a neighborhood. In a second step, correlations between these variables were calculated. The purpose of these correlational analyses was to examine the usefulness and validity of the scale constructs. For the same reasons, means, standard deviations and, when appropriate, frequencies of the ordinal variables have been examined. In a last step, we made star plots to present neighborhood characteristics.

RESULTS

The audits were done by the 12 research assistants in July 2013 [Table 3]. It took them on average 25 min to perform one audit, which was done at office hours between 9.00 and 17.00 h. The number of homogeneous routes ranged between 2 and 10 routes in a neighborhood. There was a variety of the weather conditions, but, in general, the weather was pleasant. Most of the time it was sunny, dry, and the temperature was mild or warm.

Intercoder Consistency

To get an idea about the reliability of the instrument, the fraction of identical scores of auditor pairs on a predetermined route in a homogeneous subarea has been calculated and is shown in Figure 3. A plus symbol in the figure represents a pair of auditors that visited a neighborhood. For example, in the neighborhood zevenkamp, there are four auditor pairs of which the fraction of identical scores is between 90 and 100%. In general holds that the correspondence between auditor pairs is between 70 and 100%, which we interpret as an indication that the measurement instrument is generally reliable and that the scores obtained with it should be replicated in other, independent audits.

| Table 3: Overview of audit characteristics |
|--------------------------------------------|
| **Characteristic**                         | **Entry**                                      |
| Data collection period                     | Between July 2 and 12, 2013                    |
| Time frame                                 | Evenly spread between 9.00 and 17.00          |
| Average duration                           | 25 min                                         |
| Number of neighborhoods                    | 33 (11 in each city)                           |
| Total number of homogeneous routes audited | 216                                            |
| Number of homogeneous routes               | Range: 2–10                                    |
| Weather conditions (multiple answers allowed) | Sunny without clouds (33%)                        |
|                                            | Sunny with clouds (33%)                         |
|                                            | Clouds no sun (30%)                             |
|                                            | Rain (6%)                                       |
|                                            | Thunderstorm (10%)                              |
|                                            | Cold (10%)                                      |
|                                            | Cool (10%)                                      |
|                                            | Warm (33%)                                      |
|                                            | Mild (48%)                                      |

Figure 3: Fraction of identical scores of auditor pairs per predetermined route in a neighborhood.
Definition and Assessment of Summary Variables

As the number of items in the audit is quite large, data reduction is needed to provide indicators to describe the neighborhoods. Consequently, we performed internal consistency analysis on the indicators in the audit instrument [Table 4]. We were able to construct a summary index for economic activity based on four items observing the presence of shops, offices or companies, places to meet, and bars, pubs, and restaurants (3 points scale: 1 = absent, 2 = a few, and 3 = many). This resulted in an index with an internal consistency coefficient, or Cronbach’s $\alpha$, of 0.63. On average, the level of economic activity in the neighborhoods in our study is weak to moderate. The availability of places to meet is the item with the highest score. See the appendix for more characteristics of this scale and others that will be discussed below.

A second index formed pertains to the availability of public facilities, including eight items on “availability of litter bins” and “availability of bicycle racks.” This index has an internal consistency coefficient of 0.66. The facilities most often present according to the auditors were street lightning and litter bins. The presence of public facilities in the neighborhoods is moderate.

A third index represents the “quality of urban environments.” It consists of nine items related to “graffiti”, “litter”, “signs of vandalism”, and has an internal consistency coefficient of 0.73. On average, the negative characteristics in our study neighborhoods are hardly visible to absent. The presence of elements with a strong positive influence scores moderately, whereas the presence of elements with a strong negative influence is weak.

We also constructed an index for the availability of private green (three items: “number of gardens”, “size of gardens”, and “type of garden”), with an internal consistency coefficient of 0.86. As there are a significant number of buildings without a garden, the means in the scale analysis are not very indicative. Studying the frequencies shows that in approximately 35% of the homogeneous parts of neighborhoods, there are no gardens. In the remaining 65%, the categories “less than half of the buildings with gardens”, “more than half of the buildings with gardens,” and “all buildings with gardens” are evenly distributed. In the case of gardens, small and average sized front yards are the dominant type. In the gardens, mixtures between plants and hard surface are the predominant layout. “Predominantly plants, with partly hard surface” makes up 26%, whereas “predominantly hard surface with some plants” makes up 24% of the garden layouts in the homogeneous neighborhood parts.

A fifth analysis was performed to construct an index for “public green and blue.” This index included nine items like “trees in the area,” “small parks,” “ditches,” and “canals,” and had an internal consistency coefficient of 0.47. Although an $\alpha$ of 0.47 is considered too low to conclude on a sufficiently reliable index, there were no opportunities to improve this, and we temporarily allowed for using the sum score nevertheless.

Another two indices have been created for the quality of private green (five items like “general impression,” “maintenance,” “tidyness,” $\alpha = 0.74$), a scale for quality of public blue (four items like “maintenance,” “tidyness,” $\alpha = 0.86$). Statistics suggested that the consistency of the quality of private green could be improved significantly (to $\alpha = 0.87$) by excluding the item about human litter. This suggestion has been taken by heart. Finally, a seven-item index for the overall perception of an area (items like “variety of streetscapes,” “perception of safety,” and “the area looked cared for”), with an internal consistency coefficient of 0.86 was constructed.

Correlations between the Indices

A check of validity and usability of the thus formed indices was done by looking at the correlations between them. A first look at the correlations [Table 5] shows that the quality of urban environments is negatively associated with the presence of economic activities ($r = -0.45$) and public facilities ($r = -0.43$), and positively associated with the presence ($r = 0.36$) and quality ($r = 0.49$) of especially private green. There is a strong correlation between the perceived quality of blue and that of green ($r = 0.70$). The overall impression of a neighborhood has the strongest correlations with the quality of urban environments ($r = 0.63$), the quality of green ($r = 0.73$), and the quality of blue ($r = 0.54$). This implies that a lack of negative urban traits like litter, graffiti, and others is related with a better overall impression of an area. Moreover, it is not the presence of green and blue alone that counts, for the correlations indicate that the quality of green and blue is a very important factor for neighborhood quality.

As it is not possible to create an index for building characteristics, in a second analysis the correlations between audited neighborhood characteristics and features of buildings have been calculated. These correlations, shown in Table 6, reveal some obvious associations, such as the negative association between private green and height of buildings ($r = -0.64$) and the positive association between public facilities and height of buildings ($r = 0.42$). The positive relationship between cultural historic elements, historic character, and economic activity ($r = 0.39$ and 0.43, respectively) are also not unexpected. All correlations represent typical urban traits such as balconies rather than gardens; the presence of public facilities in urban areas and the fact that economic centers often have a long history.

Correlations that are less evident are the association between the quality of urban environments and the variety of buildings. Apparently, there are fewer negative urban traits like presence of litter, dog excrements, and graffiti in neighborhoods with a richer architecture. The correlation of 0.62 between “overall perception” and “variety of
buildings” shows that this aspect of urban environments has more or less the same impact as “quality of green,” “quality of blue,” and “quality of urban environments” [Table 6] on the “overall perception.”

**Star Plots Describing and Comparing Neighborhoods**

To describe and compare neighborhoods with the data obtained in the audit we use star plots again. In the star plots, the perceived neighborhood characteristics as displayed in Table 4 are presented. The plots have been made for each city that participated in the study and have been ordered by overall neighborhood impression. In Figure 4, the star plots for Rotterdam are presented. What the figure illustrates vividly (notice that the overall impression in the first three rows is more or less the same) is that the overall impression of the neighborhood is a result of different mixtures of green, blue, urban environments, public facilities, and economic activities.

The worst overall neighborhood impression was obtained in the Bergpolder neighborhood and the best overall impression was scored in Kralingen-Oost. In Bergpolder, there is hardly any private green, the quality of the (public) green present is very poor, and there is a qualitatively very bad urban environment. However, the quality of blue in this neighborhood is quite good. Furthermore, there is some economic activity, and there are public facilities. For Kralingen-Oost, the neighborhood with the best overall impression, holds that public facilities, economic activities, green, and blue areas and a moderate positive urban environment are all present. Moreover, the quality of both the blue and the green areas is high.

![Star plots for Rotterdam neighborhoods](image-url)

**Figure 4:** Audited neighborhood characteristics in Rotterdam, ordered by overall impression.
The results show vividly that the overall perception of urban areas is dependent upon a mix of perceived urban characteristics. This illustrates that nonnatural elements such as economic activity and the quality of urban environments are also important drivers behind the overall perception. In many studies of urban environments, the importance of the presence of green and blue is stressed. Our results do not dispute this, but show that a variety of functions in urban environments can result in good overall impressions.

Remarkable is that the correlation with objective information from geographic information systems is limited. There are no significant correlations between the perceived overall quality of a neighborhood with objective noise indicators and with objective indicators for green and blue. There is a positive significant correlation, however, between the perceived overall quality of neighborhoods and neighborhood with a high-socioeconomic status ($r = 0.55$; sig 0.01)) and a significant negative correlation with neighborhoods that were built shortly after the Second World War ($r = -0.50$; sig 0.01). These associations make sense as the postwar neighborhoods (1945–1959) in The Netherlands are often of a dubious quality. Moreover, people with a higher income and education usually live in the best neighborhoods.

**DISCUSSION**

This paper describes the development and result of a neighborhood audit tool that can be used to measure physical characteristics of neighborhoods that are usually not registered in existing databases in GIS. In reality green and blue, as distinguished on a map, are often very different from what might be expected. The quality of blue and green cannot be evaluated by means of geographic information systems. Moreover, part of the audit data is not available in datasets. This holds for instance for building variety and the variable “quality of the urban environment.”

### Table 4: Summary of characteristic for the eight scales on neighborhood conditions

| Scale                        | $N$ | No of items | Range of scores | Mean score | Cronbach’s $\alpha$ |
|------------------------------|-----|-------------|-----------------|------------|---------------------|
| Economic activity            | 212 | 4           | 4–12            | 6.35       | 0.61                |
| Public facilities            | 207 | 9           | 9–18            | 11.28      | 0.66                |
| Quality of urban environments| 214 | 9           | 9–38            | 15.79      | 0.73                |
| Private green                | 212 | 3           | 0–10            | 4.32       | 0.85                |
| Public green and blue        | 211 | 9           | 9–32            | 14.58      | 0.47                |
| Quality green                | 216 | 5           | 5–25            | 16.04      | 0.74                |
| Quality blue                 | 212 | 4           | 4–20            | 11.23      | 0.86                |
| Overall perception           | 212 | 7           | 7–35            | 24.34      | 0.86                |

### Table 5: Pearson correlations between audited neighborhood characteristics

| EA   | PF   | QUE  | PG   | PGB  | QG   | QB   | OP  |
|------|------|------|------|------|------|------|-----|
| 1    | 0.34 | −0.45| −0.24| −0.12| −0.39| −0.14| −0.27|
| −0.43| 1    | −0.27| 0.21 | 0.13 | 0.27 | 0.05 |
| 1    | 0.36 | 0.29 | 0.49 | 0.29 | 0.63 |
| 1    | 0.32 | −0.03| 0.28 | 0.12 |
| 1    | 0.40 | 0.31 | 0.22 |
| 1    | 0.07 | 0.73 |
| 1    | 0.54 |

### Table 6: Pearson correlations between characteristics of neighborhood and buildings (both audited)

|                  | Closed | Height | Facade variety | Cultural historic elements | Historic character | Variety of buildings (color, architecture) |
|------------------|--------|--------|----------------|---------------------------|--------------------|-------------------------------------------|
| Economic activity| 0.16   | 0.37   | −0.08          | 0.39                      | 0.43               | −0.10                                      |
| Public facilities| 0.34   | 0.42   | −0.36          | −0.01                     | 0.05               | −0.12                                      |
| Quality of urban environments | −0.21 | −0.26 | 0.32          | 0.01                      | −0.06              | 0.43                                      |
| Private green    | −0.28  | −0.64  | 0.21          | −0.05                     | −0.05              | 0.27                                      |
| Public green and blue | −0.32 | −0.10 | −0.08         | −0.31                     | −0.17              | 0.11                                      |
| Quality green    | −0.07  | 0.00   | 0.06          | −0.03                     | −0.12              | 0.31                                      |
| Quality blue     | −0.06  | 0.31   | −0.16         | 0.06                      | 0.10               | −0.07                                      |
| Overall perception| −0.03 | 0.12   | 0.25          | 0.11                      | 0.05               | 0.62                                      |
To audit homogeneous neighborhood parts, several decisions about the inclusion of neighborhoods and the identification of homogeneous neighborhood parts were needed. This process is not always very straightforward and sometimes required difficult decisions about classification. Nevertheless, we are convinced that it is necessary to use this kind of selective sampling techniques to audit neighborhood characteristics in studies investigating peoples’ perception of the sound quality of their neighborhood. The alternative is to rely fully on average noise levels and other noise indicators in these studies. This ignores the interaction between auditive and visual perception. Moreover, soundwalks could be used to study the sound quality of single routes or places. The disadvantage of the last approach is that soundwalks have strong spatial and temporal restrictions.

This does not mean that no improvements on our audit of urban areas are possible. For future studies, the use of an app to register the physical traits is a realistic option. As it is often difficult to recall noises, apps can be very valuable in this process. In our study, the perception of the sound quality was reported by local residents who were asked about the sound quality in a survey in the selected neighborhoods. Moreover, complementary to the audit of physical traits of urban areas, soundwalks on different parts of the day and on different days of a week may provide additional information about sound quality. For the soundwalks, more or less the same routes as those used in the audits can be used.

The index on public green and blue was by far the weakest and is a point of concern. For future use, this index need improvement. The index on public green and blue was by far the weakest and is a point of concern. For future use, this index need improvement.

Another improvement of the approach might be to assign auditors randomly to homogeneous neighborhood parts. In our approach, selection effects might have occurred; for example, if auditors agree to perform an audit of an area they like or are familiar with. Moreover, the approach can be improved by increasing the number of auditors of a homogeneous subarea. In our study, four to six auditors for such an area were used.

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**Conclusion**

The results above show that it is possible to use audits to gather neighborhood data to complement survey data in studies that aim to study sound quality in neighborhoods. These data are fundamentally different from data that can be retrieved from databases and registrations. The overall perception of urban areas is dependent upon the perceived quality of different components of urban areas, including public facilities and economic activities. There are several opportunities to improve the audit instrument. Nevertheless, this instrument is already very useful auditing the qualities of urban areas.

**Conflicts of interest**

There are no conflicts of interest.

**References**

1. OECD. OECD Better Life Index. Consulted at April 25, 2016 by http://www.oecdbetetrifindex.org/.
2. Weber M. Noise Policy: Sound Policy?. Utrecht: Utrecht University; 2013.
3. Goines L, Hagler L. Noise pollution: a modern plague. South Med J 2007;100:287-99.
4. Brown AL. A review of progress in soundscapes and an approach to soundscape planning. Int J Acoust Vib 2012:17:73-81.
5. van Kempen E, Devilee J, Swart W, van Kamp I. Characterizing urban areas with good sound quality: development of a research protocol. Noise Health 2014;16:380-7.
6. Kang J. Sound propagation in interconnected urban streets: a parametric study. Environ Plann B 2001;28:281-94.
7. Salomons EM, Polinder H, Lohman WJA, Zhou H, Borst HC, Miedema HME. Engineering modeling of traffic noise in shielded areas in cities. J Acoust Soc Am 2009;126:2340-9.
8. van Renterghem T, Hornikx M, Forssen J, Botteldooren D. The potential of building envelope greening to achievequietness. Build Environ 2013:61:34-44.
9. Zhang M, Kang J. Towards the evaluation, description, and creation of soundscapes in urban open spaces. Environ Plann B 2007;34:68-86.
10. Samara T, Tsitsoni T. Road traffic noise reduction by vegetation in the city ring road of a big city. In: Kungolos A, Aravossis K, Karagiannidis A, Samaras P, editors. Proceedings of the International Conference on Environmental Management, Engineering, Planning, and Economics, Skiathos, June 24–28, 2007; 2007, pp. 2591–6.
11. Fan Y, Zhiyi B, Zhujuan Z, Jianli L. The investigation of noise attenuation by plants and the corresponding noise-reducing spectrum. J Environ Health 2010;72:8-15.
12. Ge J, Hokao K. Applying the methods of image evaluation and spatial analysis to study the sound environment of urban street areas. J Environ Psychol 2005;25:455-66.
13. Ge J, Lu J, Morotomi K, Hokao K. Developing soundscapegraphy for the notation of urban soundscape: its concept, method, analysis and application. Acta Acust Acust 2009;95:65-75.
14. Southworth M. The sonic environment of cities. Environ Behav 1969:1:49-70.
15. Carles JL, Bernaldez FG, De Lucio JV. Audiovisual interactions and the soundscape preferences. Landsc Res 1992:17:52-6.
16. Tamura A. Effect of landscaping on the feeling of annoyance of a space. In: Schick A, Klatté M, editors. Contributions to psychological acoustics: Results of the Seventh Oldenburg Symposium on Psychological Acoustics. Oldenburg: Bibliotheks- und Information’s system der Universität Oldenburg; 1997, p. 135-61.
17. Rohrmann B, Bishop I. Subjective responses to computer simulations of urban environments. J Environ Psychol 2002:22:319-31.
18. Pedersen E, Larssan P. The impact of visual factors on noise annoyance among people living in the vicinity of wind turbines. J Environ Psychol 2008:28:379-89.
19. Gidlöf-Gunnarsson A, Öhström E. Attractive “quiet” courtyards: a potential modifier of urban residents’ responses to road traffic noise?. Int J Environ Res Public Health 2010:7:3359-75.
20. Blaauw K. Stiltebeleving in de Weerribben en de Wieden. Utrecht, Netherlands. [Perception of silence in the Weerribben and Wieden nature areas], Network of the 12 provinciale Milieufederaties en de Stichting Natuur en Milieu; 2003.
21. Goossen CM, Langers F, De Vries S. Gelderse stilte? Onderzoek naar stiltebeleving van recreanten [Silence in the Gelderland region? A study on the perception of silence by recreating people]. Wageningen: Alterra; 2001.
22. De Jong RG. Beoordelingsmethoden stiltegebieden. Deelrapport belevingsonderzoek [Assessment method for quiet areas. Sub report perception study]. Leiden: TNO Preventie en Gezondheid; 1998.
APPENDIX

SCALE ANALYSES

Table A1 Economic activity ($\alpha = 0.61$)*

| Item                        | N  | Mean | SD  | $\alpha$ if item deleted |
|-----------------------------|----|------|-----|--------------------------|
| Shops                       | 212| 1.51 | 0.63| 0.46                     |
| Offices or companies        | 212| 1.63 | 0.66| 0.67*                    |
| Places to meet              | 212| 1.80 | 0.66| 0.63                     |
| Bars, pubs, restaurants     | 212| 1.41 | 0.57| 0.38                     |

*1 = absent, 2 = a few, and 3 = many; †Statistics suggested that the summary variable would improve if we excluded the item about the presence of companies and offices. As this item has strong conceptual importance and the number of observations is relatively small, we decided not to do so.

Table A2 Collective facilities ($\alpha = 0.66$)*

| Item                          | N  | Mean  | SD  | $\alpha$ if item deleted |
|-------------------------------|----|-------|-----|--------------------------|
| Litter bins                   | 207| 1.35  | 0.48| 0.59                     |
| Underground litter containers | 207| 1.40  | 0.49| 0.60                     |
| Benches                       | 207| 1.50  | 0.50| 0.60                     |
| Tram or bus shelters          | 207| 1.58  | 0.49| 0.66                     |
| Bicycle racks                 | 207| 1.42  | 0.49| 0.60                     |
| Collective planters           | 207| 1.48  | 0.50| 0.64                     |
| Letter boxes                  | 207| 1.48  | 0.50| 0.62                     |
| Street lightning              | 207| 1.00  | 0.00| 0.67                     |
| Carparks                      | 207| 1.55  | 0.50| 0.70                     |

*1 = present and 2 = absent.

Table A3 Quality of urban environments ($\alpha = 0.73$)+‡

| Item                                      | N  | Mean  | SD  | $\alpha$ if item deleted |
|-------------------------------------------|----|-------|-----|--------------------------|
| Litter (1–4)                              | 214| 2.23  | 0.92| 0.58                     |
| Signs of alcohol use (1–4)                | 214| 1.29  | 0.63| 0.60                     |
| Signs of drugs use (1–4)                  | 214| 1.12  | 0.39| 0.64                     |
| Graffiti (1–4)                            | 214| 1.79  | 0.93| 0.58                     |
| Broken windows (1–4)                      | 214| 1.31  | 0.66| 0.60                     |
| Vandalism (1–4)                           | 214| 1.28  | 0.62| 0.60                     |
| Dog shit (1–4)                            | 214| 1.60  | 0.81| 0.60                     |
| Elements with a strong positive presence (1–5) | 214| 2.97  | 1.14| 0.79‡                    |
| Elements with a strong negative presence (1–5) | 214| 2.20  | 1.09| 0.64                     |

*1 = absent, 2 = hardly visible, 3 = visible, and 4 = very visible; †Scores range between 1 and 5. 1 = no this type of elements are not present; 5 = yes, the perception of the neighborhood is clearly influenced by the presence of this type of elements; ‡The consistency of the scale could have been improved by excluding the item about elements with a strong positive influence on the neighborhood. On basis of the argumentation we used before, we decided not to do so.
Table A4 Private green ($\alpha = 0.85$)*†‡

| Item                                          | N   | Mean | SD  | $\alpha$ if item deleted |
|-----------------------------------------------|-----|------|-----|---------------------------|
| Number of buildings with a garden (0–3)       | 212 | 1.28 | 1.18| 0.81                      |
| Size of these gardens (0–3)                   | 212 | 1.53 | 1.41| 0.75                      |
| Type of layout of the garden (0–4)            | 212 | 1.51 | 1.31| 0.64                      |

$^0 \text{no garden, } 1 = \text{less than half of the houses, } 2 = \text{more than half of the houses, and } 3 = \text{all houses}; ^\dagger 0 = \text{no garden, } 1 = \text{predominantly façade gardens, } 2 = \text{predominantly small front yards, } 3 = \text{predominantly average sized front yards, and } 4 = \text{predominantly large yards}; ^\ddagger 0 = \text{no garden; } 1 = \text{plants; } 2 = \text{predominantly plants, partly hard surface; } 3 = \text{predominantly hard surface, some plants; and } 4 = \text{predominantly hard surface, no plants.}$

Table A5 Public green and blue ($\alpha = 0.47$)*†

| Item                                          | N   | Mean | SD  | $\alpha$ if item deleted |
|-----------------------------------------------|-----|------|-----|---------------------------|
| Trees in the area (1–4)                       | 211 | 1.97 | 0.77| 0.37                      |
| Planters (1–4)                                | 211 | 1.55 | 0.50| 0.50                      |
| Planted tree mirrors (1–4)                    | 211 | 1.45 | 0.50| 0.51                      |
| Green strips (1–4)                            | 211 | 1.14 | 0.35| 0.41                      |
| Small neighborhood parks (1–4)                | 211 | 1.52 | 0.50| 0.37                      |
| Large green (1–4)                             | 211 | 1.73 | 0.45| 0.40                      |
| Ditches (1–2)                                 | 211 | 1.66 | 0.48| 0.40                      |
| Canals (1–2)                                  | 211 | 1.68 | 0.47| 0.48                      |
| Large blue (1–2)                              | 211 | 1.88 | 0.33| 0.44                      |

*1 = many, 2 = average, 3 = a few, and 4 = no trees; †1 = present and 2 = absent.

Table A6 Quality green ($\alpha = 0.74$)*

| Item                     | N   | Mean | SD  | $\alpha$ if item deleted |
|--------------------------|-----|------|-----|---------------------------|
| General impression       | 216 | 3.39 | 1.10| 0.58                      |
| Maintenance              | 216 | 3.22 | 1.13| 0.55                      |
| Overview                 | 216 | 3.56 | 1.00| 0.64                      |
| Human litter             | 216 | 2.62 | 1.36| 0.87                      |
| Quality green            | 216 | 3.25 | 0.97| 0.56                      |

*Scores range between 1 and 5. 1 = very negative and 5 = very positive.

Table A7 Quality blue ($\alpha = 0.86$)*

| Item                     | N   | Mean | SD  | $\alpha$ if item deleted |
|--------------------------|-----|------|-----|---------------------------|
| General impression       | 166 | 2.34 | 1.26| 0.86                      |
| Maintenance              | 166 | 2.87 | 1.22| 0.79                      |
| Human litter             | 166 | 3.05 | 1.40| 0.84                      |
| Quality green            | 166 | 2.97 | 1.10| 0.79                      |

*Scores range between 1 and 5. 1 = very negative and 5 = very positive.

Table A8 Overall perception ($\alpha = 0.86$)*†

| Item                                          | N   | Mean | SD  | $\alpha$ if item deleted |
|-----------------------------------------------|-----|------|-----|---------------------------|
| The streetscape has a large variety           | 212 | 3.03 | 1.07| 0.87                      |
| The street layout was very attractive         | 212 | 3.00 | 1.19| 0.82                      |
| The area looked properly cared for            | 212 | 3.17 | 1.15| 0.83                      |
| I felt safe                                  | 212 | 4.15 | 1.12| 0.84                      |
| There are elements that do not fit and disturb the character of this area | 212 | 3.86 | 0.86 | 0.86 |
| The layout of the area did not match its function | 212 | 3.95 | 0.90 | 0.85 |
| What was your impression of this area        | 212 | 3.18 | 1.02| 0.81                      |

*Scores range between 1 and 5. 1 = fully disagree and 5 = fully agree; †Scores range between 1 and 5. 1 = very negative and 5 = very positive.