A principal components model of soundscape perception[a)]

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There is a need for a model that identifies underlying dimensions of soundscape perception, and which may guide measurement and improvement of soundscape quality. With the purpose to develop such a model, a listening experiment was conducted. One hundred listeners measured 50 excerpts of binaural recordings of urban outdoor soundscapes on 116 attribute scales. The average attribute scale values were subjected to principal components analysis, resulting in three components: Pleasantness, eventfulness, and familiarity, explaining 50, 18 and 6% of the total variance, respectively. The principal-component scores were correlated with physical soundscape properties, including categories of dominant sounds and acoustic variables. Soundscape excerpts dominated by technological sounds were found to be unpleasant, whereas soundscape excerpts dominated by natural sounds were pleasant, and soundscape excerpts dominated by human sounds were eventful. These relationships remained after controlling for the overall soundscape loudness (Zwicker's N_{10}), which shows that 'informational' properties are substantial contributors to the perception of soundscape. The proposed principal components model provides a framework for future soundscape research and practice. In particular, it suggests which basic dimensions are necessary to measure, how to measure them by a defined set of attribute scales, and how to promote high-quality soundscapes. © *2010 Acoustical Society of America.* [DOI: 10.1121/1.3493436]

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I. INTRODUCTION

There is an increasing concern among environmental authorities and decision makers that existing environments of high acoustic quality must be protected (EC, 2002; DEFRA, 2006; WHO, 2000). Partly as a response to this, and partly reconnecting to Schafer's (1969, 1994) ideas, environmental-noise researchers have adopted a soundscape approach, which considers the overall acoustic environment including its potential for positive and restorative effects on human health and well-being (e.g., Berglund, 2006; Berglund *et al.*, 2001; Brown and Muhar, 2004; Raimbault, 2006; Schulte-Fortkamp and Dubois, 2006). Handbook for Acoustic Ecology defines 'soundscape' as "[a]n environment of sound (or sonic environment) with emphasis on the way it is perceived and understood by the individual, or by a society" (Truax, 1999). The emphasis on perception and interpretation is fundamental to soundscape research (Truax, 2001; Thompson, 2002).

The Canadian composer Murray Schafer (1969, 1994) founded soundscape research in the late 1960s. It has an extensive tradition in, for example, Canada and Japan (Hiramatsu, 2006; Porteous and Mastin, 1985). However, internationally soundscape research is still an evolving, interdisciplinary science, relatively, in its beginning. Notably, few researchers have yet proposed models that identify the underlying dimensions of soundscape perception that may guide measurement and help to improve soundscape quality. Based on general practice in perception psychology and psychoacoustics, adjusted to soundscape, the present work contributes to soundscape research by proposing such a model of soundscape perception grounded in empirical results from a comprehensive listening experiment.

Soundscapes typically contain many sounds that occur simultaneously or separately in time. These sounds may be positive (e.g., natural sounds) or adverse (e.g., busy road traffic). Despite this complexity, the soundscape can be meaningfully assessed (e.g., Berglund *et al.*, 2006). For example, the soundscape in a 'quiet' park may be perceived as more *pleasant*, more *soothing*, less *annoying*, and less *stressful* than the soundscape at a sidewalk close to a busy road.

Several previous studies have used Semantic Differential Scaling or related techniques to scale the perception of specific sounds (e.g., Kerrick *et al.*, 1969; Gabrielsson and Sjögren, 1979; Bjork, 1985). However, only a few studies have applied this methodology for perception of soundscapes (for a review, see De Coensel and Botteldooren, 2006). These previous soundscape studies have included a limited set of soundscapes or a limited set of perceptual attributes or both, and have therefore resulted in a large variability in the dimensions proposed to underlie soundscape perception. The main dimension found in several studies relates to preference or pleasantness. In addition, some studies have found a second dimension related to activity or variability in the soundscapes (Berglund *et al.*, 2001; Berglund and Nilsson, 2006; Cain, 2009; Kawai *et al.*, 2004; Raimbault *et al.*, 2003; Viollon and Lavandier, 2000). This pleasantness-activity pattern resembles results from research on emotions and in en-

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[a)] Part of this research was presented in "Soundscape assessment," at the 149th Meeting of the Acoustical Society of America, Vancouver, Canada, May 2005.

[b)] Author to whom correspondence should be addressed. Electronic mail: mats.nilsson@psychology.su.se vironmental psychology; especially Russell's circumplex model of affect (Russell, 1980; Russell and Snodgrass, 1987; Ward and Russell, 1981; see also Knez and Hygge, 2001). Russell's model identifies two dimensions related to the perceived pleasantness of environments and how activating or arousing the environment is. Västfjäll *et al.* (2003) showed that Russell's pleasantness-arousal model can be applied for describing emotions evoked by specific sounds, such as interior aircraft noise. Therefore, a similar type of model may apply to soundscape perception.

Field studies in urban parks and green open spaces suggest that 'informational' properties of soundscapes (i.e., categories of sounds) are better predictors of perceived soundscape quality than acoustic measures of the soundscape, such as the equivalent sound-pressure level, L_{Aeq} (Nilsson *et al.*, 2007). These studies indicate that people tend to perceive natural sounds, like bird song or sounds from moving water, as positive components of the soundscape, whereas traffic noise and other technological sounds are often perceived as negative components (Guastavino, 2006; Nilsson and Berglund, 2006). Sounds from human activities, such as people talking or children at play, are usually assessed as more pleasant than technological sounds, or as neutral in regard to pleasantness (Dubois *et al.*, 2006; Nilsson and Berglund, 2006; Viollon and Lavandier, 2000). In order to guide future soundscape design it is necessary to better understand the relationships between these informational properties and the underlying dimensions of soundscape perception (cf. "soundscape design," Truax, 1999).

The present experiment included a comprehensive set of excerpts of binaural recordings of urban outdoor soundscapes, henceforth 'soundscape excerpts,' selected to cover a variety of environmental sounds embedded in their natural context, as well as, a very large set of perceptual attributes relevant to soundscape perception. The main purpose of the experiment was to derive an empirically grounded model, which integrates a large set of potential perceptual attributes (pleasant, eventful, annoying, etc.) in a small number of basic dimensions of soundscape perception, by subjecting attribute measurements to principal components analysis (PCA). A second purpose was to determine relationships among these basic perceptual dimensions and physical soundscape properties, including categories of dominant sounds and acoustic variables. We anticipate that this knowledge will be helpful in evaluating existing soundscapes by listening walks, as well as, for guiding soundscape design based on promotion and abatement of specific categories of sound events.

II. METHOD

A. Listeners

The listeners were 100 university students (48 women, 52 men; mean age 25.6 years, range 19–54 years). All had absolute hearing thresholds (ISO, 1991) below 25 dB in their best ear at the tested frequencies 0.5, 1, 2, 3, 4, 6, and 8 kHz (Brüel & Kjær, Type 1800, pure-tone audiometer). The participants received a small monetary compensation.

B. Soundscape recordings

Fifty soundscape excerpts, 30 s in duration, were selected from a large database of binaural recordings of urban outdoor soundscapes from London and Stockholm. The selection aimed at a wide range of soundscapes with a large variation in overall sound-pressure level (43–79 dB $L_{\mathrm{Aeq,30s}}$) and a great diversity of environmental sounds embedded in their natural context, including sounds of technology, humans and nature. Importantly, to be accepted as a soundscape excerpt the excerpt had to include ambiance, as well as, more than one single sound event (cf. "soundscape" and "sound event," Truax, 1999). That is, a single foreground sound, like a car or a pedestrian passing by, without ambiance or proper acoustic context is not a soundscape, but a single sound event. Thus, it is the ambiance or the acoustic context, together with sound events that constitute a soundscape. Moreover, to be selected for the experiment the soundscape excerpts also had to be representative of the locations where the recordings took place.

The 50 soundscape excerpts were from 10 different kinds of locations: urban court-yards (2), motorways (2), a pedestrian street (1), school yards (14), suburban parks (5), suburban recreational areas (9), suburban residential areas (2), urban parks (4), an urban square market (1), and urban streets (10). The technological sounds in the soundscape excerpts included sounds from airplanes, individual cars, motorcycles, and road traffic, including car alarms and car horns; sounds from machines like chainsaw, rock drill, and street sweeper; as well as, sounds from construction work, trains, ventilation fans, and sirens of emergency vehicles. The natural sounds included sounds from bird song, wind whispering in the vegetation, rustling leafs, and moving water, like rain, fountain jets, waterfall, purling water spring, and a dog playing in the water. The sounds from human activity included sounds from children at play, footsteps, and human voices. The sounds present in the soundscape excerpts could be heard as foreground or background, or represent the ambiance or acoustic context.

Three members of the research team independently listened to all 50 soundscape excerpts and for each soundscape excerpt assessed whether technological sounds (e.g., road traffic), natural sounds (e.g., bird song), and/or human sounds (e.g., human voices) dominated. Dominance was defined as sounds perceived as foreground during a large segment of the 30 s soundscape excerpt. Please, observe that dominance here refers to a category of sounds in the foreground and not to single sound events. Moreover, our definition of soundscape excerpt requires that other sounds are included as ambiance or acoustic context. This is vital to soundscape research as opposed to traditional psychoacoustics that mainly is concerned with single sounds. The soundscape excerpts were thus assessed prior to the experiment, in a random presentation order and without knowledge of the exact identity of the recordings. For the majority of soundscape excerpts the three listeners were in agreement. For a remaining few soundscape excerpts it was hard to determine if sounds were background or foreground. Consensus was reached after repeated listening. The resulting dominance/

TABLE I. Descriptive statistics of acoustic variables, calculated for all 50 soundscape excerpts.

Acoustic variable	N	Min	Max	Mean	SD	Median
$L_{\mathrm{Aeq,30s}}$ (dB)	50	43	79	63	10	66
N_{10} (sone)	50	4	51	24	13	25
L_{A10}-L_{A90} (dB)	50	1	25	9	6	8
N_{10}-N_{90} (sone)	50	1	30	10	9	7
$L_{\mathrm{Ceq,30s}}$-$L_{\mathrm{Aeq,30s}}$ (dB)	50	−2	16	7	4	7

non-dominance assessments were coded in three dichotomous ‘dominant-sound-category’ variables, called Technological, Human and Natural Sounds. Only two soundscape excerpts contained more than one dominant sound-category. In both, technological and human sounds were perceived as dominant foreground sounds. In fifteen soundscape excerpts no specific sound-category dominated, that is, these only contained the undifferentiated background sound.

In addition to identification of sound-categories, the soundscape excerpts were subjected to acoustic analyses. For most soundscape excerpts, a sound-pressure-level difference was found between the left and right channel (median =1 dB $L_{\mathrm{Aeq,30s}}$; range: 0–6 dB). The acoustic analyses were therefore based on the channel, left or right, of the binaurally recorded soundscape excerpts with the highest sound-pressure level.

A large set of acoustic measures were calculated, referring to the overall level, the level variability over time and the spectral content of the soundscape excerpts. The psychoacoustic analysis, reported below, included the A-weighted equivalent continuous sound-pressure level in dB ($L_{\mathrm{Aeq,30s}}$) and the Zwicker loudness in sone [ISO 532B (ISO, 1975)] exceeded 10% of the time (N_{10}) as indicators of the overall loudness of the soundscape excerpts. We used the difference between levels exceeded 10 and 90% of the time as indicators of the soundscape variability, either expressed in A-weighted sound pressure-level in dB (L_{A10}-L_{A90}) or Zwicker loudness in sone (N_{10}-N_{90}). We used the difference between A- and C-weighted sound-pressure level in dB ($L_{\mathrm{Ceq,30s}}$-$L_{\mathrm{Aeq,30s}}$, hereafter $L_{\mathrm{C-A}}$) as a measure of the relative proportion of low-frequency sound (cf. Nilsson, 2007; Nilsson *et al.*, 2008). Table I shows descriptive statistics for the acoustic variables of the 50 soundscape excerpts.

C. Soundscape measurement

A set of 116 unidirectional attribute scales was created for measuring the 50 soundscape excerpts. We selected affective attributes applicable to soundscapes, such as ‘pleasant’ and ‘calm.’ We did not include descriptive adjectives, such as ‘loud’ or ‘sharp,’ because these may be more relevant to sounds from specific sources than to soundscapes (cf. the approach taken by Mehrabian and Russell, 1974). The attributes were selected as follows. First, 189 adjectives (in Swedish) were considered from a list developed for measuring aesthetic appeal of photographs (Axelsson, 2007). Second, synonyms and antonyms of these were found using dictionaries, thesauruses and publications on sound attributes (e.g., Gabrielsson and Sjögren, 1979; Namba *et al.*, 1991). Third, the extended set of adjectives was piloted with regard to applicability to soundscapes with the aid of 30 persons, all of whom had recently listened to many soundscape excerpts in another experiment. The adjectives judged to be most applicable to soundscapes were selected, in total 116. By this strictly empirical selection procedure, we reduced the set of attributes developed for measuring aesthetic appeal of photographs (cf. Axelsson, 2007) to a set of attributes relevant for soundscape perception.

In the present experiment on soundscapes each of the 116 adjectives was supplied with a 100-mm visual analog scale of ‘attribute-soundscape match’. The end-points were marked ‘No match at all (0%),’ and ‘Perfect match (100%)’. Our 100 listeners each measured the soundscape excerpts by a vertical mark on the scale, representing how well the attribute matched their soundscape perception.

D. Procedure

To keep the experimental time within reasonable limits, each listener scaled only 5 of the 50 soundscape excerpts, according to an irregular selection procedure. By recruiting 100 listeners, each of the 50 soundscape excerpts was scaled by 10 different listeners $[(100\times5)/50=10]$. Each listener was instructed to scale its own set of 5 soundscape excerpts on 140 attribute scales (116 unique scales and 24 replications used for assessing the consistency of the listeners' responses). These 140 attribute scales were organized in 10 different booklets, each booklet with the attribute scales presented in a unique random order. In order to avoid scaling order effects (e.g., Gescheider, 1997) the 10 scale booklets and sets of 5 soundscape excerpts were assigned to the listeners in an order that met three criteria:

(a) no single soundscape excerpt was allowed to be measured with the attribute scales in the same random order twice (i.e., each soundscape excerpt was scaled 10 times using a different scale booklet);
(b) no listener was allowed to use the attribute scales in the same random order twice (i.e., for each of their own 5 soundscape excerpts the participants used a different scale booklet); and
(c) no listener was allowed to measure the soundscape excerpts presented in the same order, as presented to any other listener (i.e., the soundscape excepts were always presented in a different irregular order to all participants).

The listeners were instructed to first listen through their five soundscape excerpts before measuring them:

> “Begin by listening through the five soundscape excerpts presented on the computer screen, and build your opinion about their character. Thereafter you measure the soundscape excerpts by the aid of a large set of attribute scales. The soundscape excerpts must be measured one at a time on all the attribute scales in the protocol, and in the order presented on the computer screen (from left to right). Thus, you are provided five soundscape excerpts

> and five protocols, one protocol per soundscape excerpt.
>
> Your task is to judge to what extent the attributes listed in the protocol are applicable to the soundscape excerpts. You indicate your judgment by putting a mark (a vertical line) on the scale delimited by: 'No match at all (0%),' and 'Perfect match (100%)'."

Then they listened to each of their soundscape excerpts as many times as needed while measuring them on the 140 attribute-match continua. On average, the experiment lasted 1 h and 40 min for a participant, including instructions and pauses, as well as, the hearing test.

E. Equipment

The 50 soundscape excerpts were recorded with a binaural recording system (Brüel & Kjær Type 4100 artificial head, with Type 4190 microphones, Type 2669 preamplifiers, and a Type 2690 NEXUS microphone amplifier) connected to a portable computer (Dolch NPAC-Plus P111) with a professional sound card (Lynx II, Model C, A/D: 16 bits, 48 kHz). The experiment was conducted in a semi echo-free listening room. The soundscape excerpts were binaurally reproduced in headphones (Sennheiser HD 600; Fostex PH-50 headphone amplifier), from a stationary computer (Dell Precision 220) with a Lynx II sound card. The experimental sounds were presented and replayed with the aid of Microsoft PowerPoint, at the authentic sound-pressure level (calibrated by a Brüel & Kjær Type 4231 sound calibrator).

III. RESULTS

To assess the internal consistency of the participants' attribute matches, the values obtained for the 24 attribute scales that appeared twice were correlated using Pearson's coefficient of correlation. The internal consistency was found to be high. The mean coefficients of correlation across the 24 attribute scales was 0.75 with a range of 0.61–0.87.

A. Principal components analysis

For each of the 50 soundscape excerpts, arithmetic means of the 116 unique attribute scale values were calculated. This resulted in a 50×116 data matrix. All pairs of the 116 column vectors of this matrix were intercorrelated using Pearson's coefficient of correlation. The resulting correlation matrix (116×116), with unity in the diagonal, was subjected to a principal components analysis (eigenvalue decomposition). [Please observe that the correlation matrix is singular, and the number of possible components is restricted to $N-1=49$, rather than to 116.] The component loadings and component scores were then calculated using Eqs. (1) and (2), respectively.

$$A = V \times \sqrt{\Lambda}, \tag{1}$$

$$F = Z \times V, \tag{2}$$

where A is the matrix of component loadings, V is the matrix of eigenvectors, Λ is the diagonal matrix of eigenvalues, F is the matrix of component scores, and Z is the matrix of standardized data scores (cf. Reyment and Jöreskog, 1996).

Component 1, 2 and 3 explained 50, 18, and 6%, respectively, of the variance in the data set. The interpretation of these three components was straightforward (see further below). Apart from the first three components, another eight components satisfied Kaiser's criterion (eigenvalue >1.0). Their contribution to the explained variance was marginal 1–3%, and they could not be meaningfully interpreted. Therefore, the following presentation is restricted to the first three components, which taken together accounted for 74% of the total variance.

Figures 1 and 2 display component-loading plots [Eq. (1)] of Components 1–3. The data points represent the component-loading vectors of each attribute (i.e., the distance to the origin). Each figure is divided into three zones according to the length of the component-loading vectors (v_a): Zone 1, $v_a^2 < 0.50$; Zone 2, $0.50 \leq v_a^2 < 0.70$; Zone 3, $v_a^2 \geq 0.70$, where v_a^2 represents the variance of each attribute that the corresponding components could explain. Attributes strongly associated with Component 3 are underlined in Fig. 1. Attributes found in zone 1 in both Figs. 1 and 2 are those which variance Components 1–3 could not explain well.

Component 1 (Fig. 1) is best explained by the five adjectives Uncomfortable, Comfortable, Appealing, Disagreeable, and Inviting (listed according to descending absolute loadings), which we have labeled *Pleasantness.* Component 2 (Figs. 1 and 2) is best explained by Eventful, Lively, Uneventful, Full of life, and Mobile and is therefore labeled *Eventfulness.* Component 3 (Fig. 2) is best explained by Commonplace, Common, Familiar, Real, and Rare and is labeled *Familiarity.*

Notably, many of the attributes do not cluster around the axes of the first two components, but are placed throughout the perimeter of the space in a meaningful circular order. For instance, the attribute Exciting load approximately equally on both factors, and should therefore be viewed as a combination *of Pleasantness* and *Eventfulness* (see Fig. 1), (cf. the circumflex model, e.g., Russell, 1980; Russell and Snodgrass, 1987; Knez and Hygge, 2001).

The reliability of the PCA solution was assessed in the following way. Among the 100 participants, pairs of individuals listened to exactly the same 5 soundscape excerpts, although in different irregular orders. By separating these pairs of individuals the sample of listeners was split in two halves and each of the two resulting data sets were subjected to PCA. For both data sets, three principal components were extracted and the component loadings [Eq. (1)] were intercorrelated. Pearson's coefficients of correlation between these two new solutions were 0.98, 0.97, and 0.87, for Component 1, 2 and 3, respectively ($p < 0.01$). These high coefficients of correlation show that the three-component PCA solution is reliable across the two groups of individuals.

B. Relationships between principal components, acoustic properties and sound-categories

Table II shows inter-correlations (Pearson's coefficient) among each component's scores [Eq. (2)] for the three main

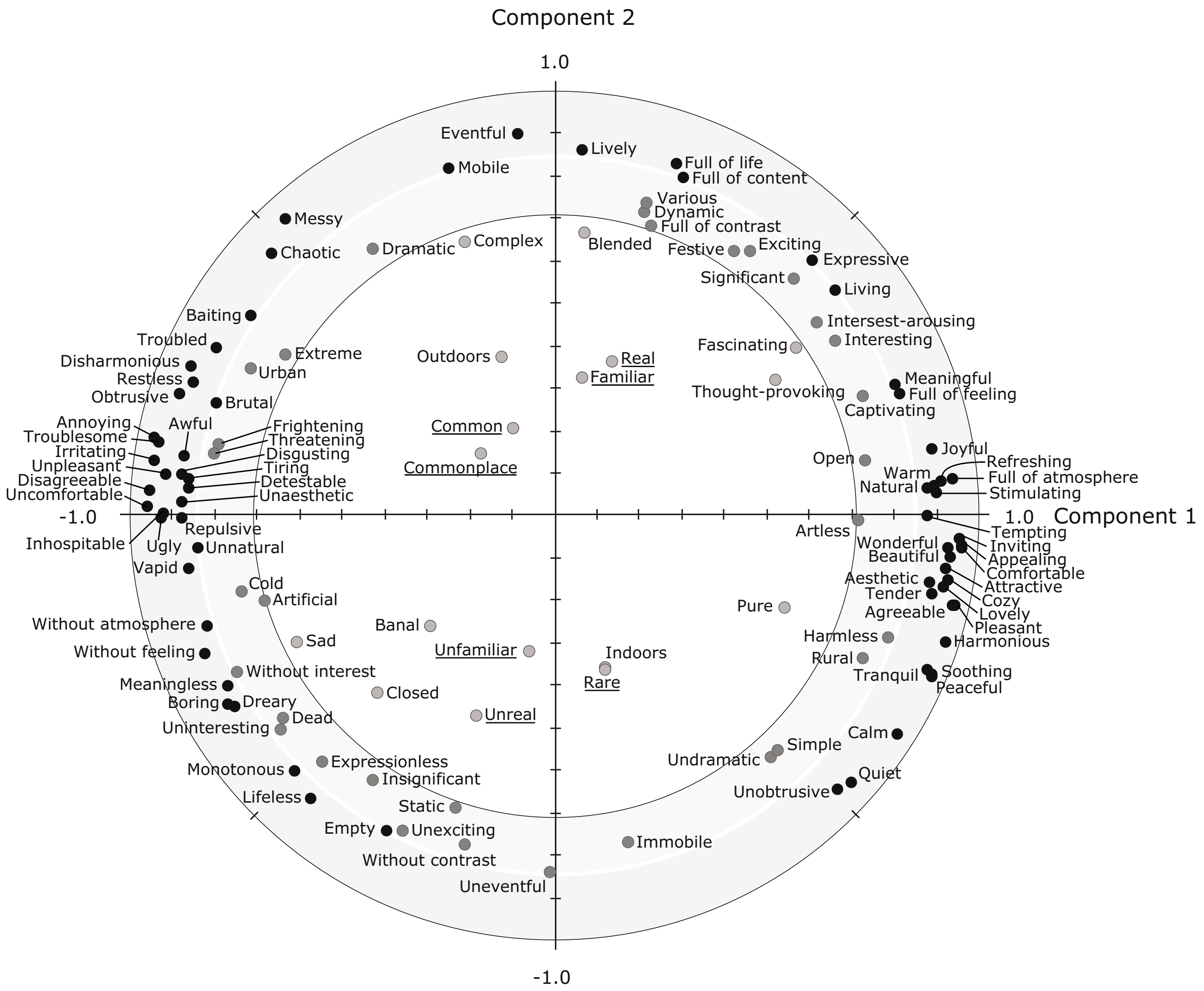

FIG. 1. (Color online) Loadings of the 116 attribute scales in Component 1 and 2. Underlined attributes are associated with Component 3 (see Fig. 2). The figure is divided into three zones according to the length of the component-loading vectors of the 116 attributes (v_a; the distance to the origin): Zone 1, $v_a^2 < 0.50$ (light gray circles); Zone 2, $0.50 \le v_a^2 < 0.70$ (dark gray circles); Zone 3, $v_a^2 \ge 0.70$ (black circles), where v_a^2 represents the variance of each attribute that the corresponding components could explain.

principal components, for the acoustic measures and for the three dichotomous dominant-sound-category variables (i.e., Technological, Natural, and Human Sounds). The *Pleasantness* scores were negatively correlated with acoustic measures of overall level ($L_{\mathrm{Aeq,30s}}, N_{10}$) and variability ($L_{\mathrm{A10}}$-$L_{\mathrm{A90}}, N_{10}$-$N_{90}$), as well as, with Technological Sounds, but unrelated to the relative proportion of low-frequency sound ($L_{\mathrm{C\text{-}A}}$) in the soundscape excerpts. Thus, as expected, soundscape excerpts free of dominant technological sounds were more pleasant than soundscape excerpts dominated by technological sounds. *Pleasantness* was positively but weakly correlated with Human Sounds and Natural Sounds.

Eventfulness scores were positively correlated with overall level ($L_{\mathrm{Aeq,30s}}, N_{10}$) and variability ($L_{\mathrm{A10}}$-$L_{\mathrm{A90}}$, N_{10}-N_{90}) of the soundscape excerpts, and negatively correlated with the relative proportion of low-frequency sound ($L_{\mathrm{C\text{-}A}}$). Notably, *Eventfulness* of the soundscape excerpts was positively correlated with Human Sounds, only weakly correlated with Natural Sounds and practically uncorrelated with Technological Sounds. That is, the participants tended to perceive the soundscape excerpts dominated by human sounds as more eventful than soundscape excerpts without dominant human sounds (cf. Viollon and Lavandier, 2000). Probably because of the low variance in the third component, the correlations between *Familiarity* and the acoustic and dominant-sound-category variables were weak.

The acoustic measures, in particular the overall loudness, appeared to confound the relationships between the three dominant-sound-category variables and *Pleasantness* and *Eventfulness*, especially the relationship between Technological Sounds and *Pleasantness* (Table II). This is illustrated in Fig. 3, where the relationships are compared between N_{10} and *Pleasantness* (left), as well as, N_{10} and *Eventfulness* (right), for soundscape excerpts dominated by technological sounds (filled circles), natural sounds (open squares) and human sounds (filled squares). Open circles indicate soundscape excerpts without pronounced sound-categories, that is, background sounds. The left panel of Fig. 3 shows that soundscape excerpts dominated by technological sounds had higher values of N_{10} than sounds dominated by human or natural sounds. The relationship between *Pleasantness* and N_{10} was considerably weaker within dominant

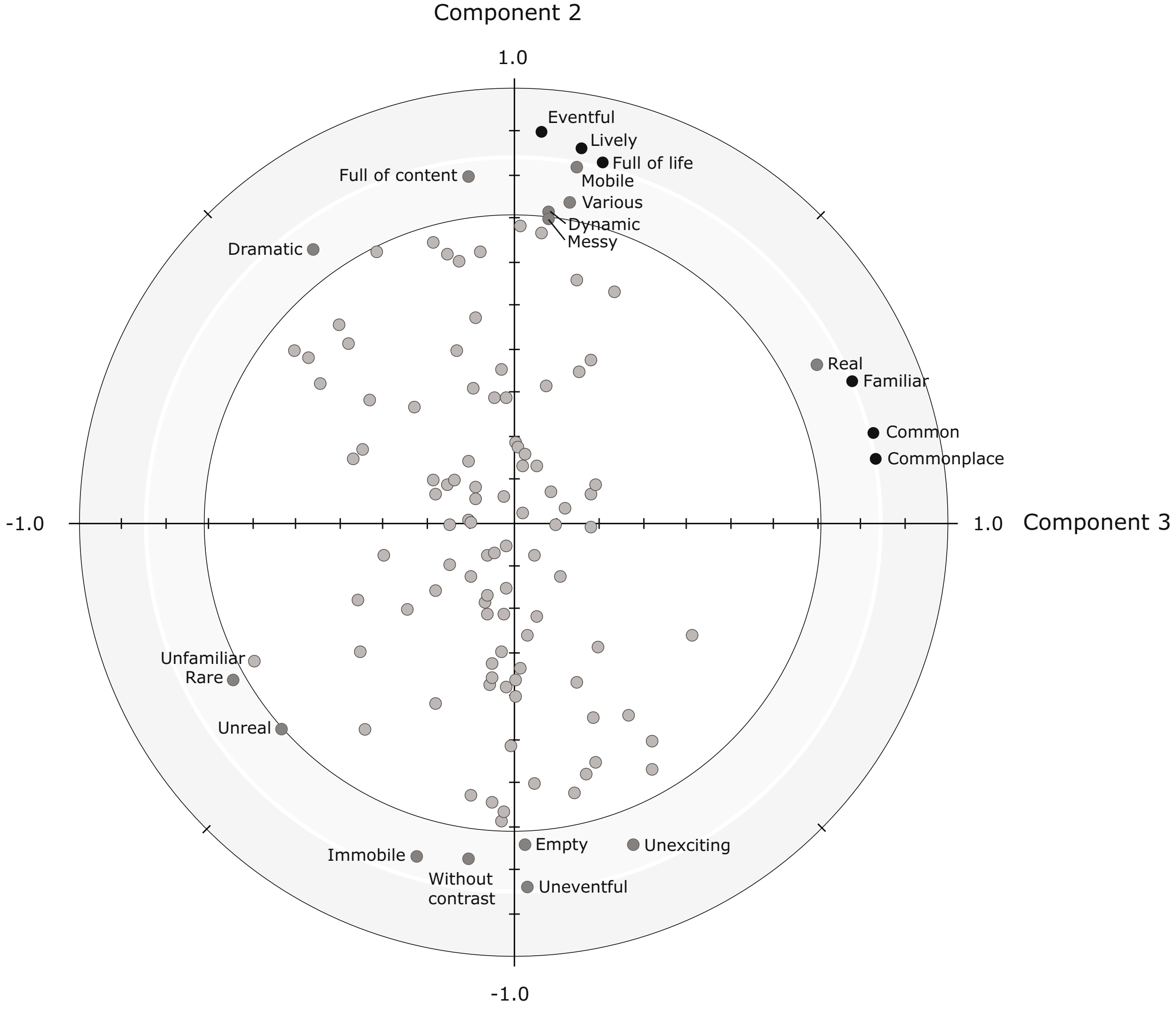

FIG. 2. (Color online) Loadings of the 116 attribute scales in Component 2 and 3. The figure is divided into three zones according to the length of the component-loading vectors of the 116 attributes (v_a; the distance to the origin): Zone 1, $v_a^2 < 0.50$ (light gray circles); Zone 2, $0.50 \leq v_a^2 < 0.70$ (dark gray circles); Zone 3, $v_a^2 \geq 0.70$ (black circles), where v_a^2 represents the variance of each attribute that the corresponding components could explain.

sound-categories than across the dominant sound-categories. The right panel of Fig. 3 shows that the positive bivariate relationship between *Eventfulness* and N_{10} does not apply to technological sounds (filled circles), for which a curvilinear trend is discerned. Soundscape excerpts dominated by technological sounds were most eventful at intermediate levels of N_{10}.

In order to evaluate the unique effect of dominant sound-categories on *Pleasantness* and *Eventfulness*, over and above the effect of overall loudness, stepwise multiple regression analyses were conducted (Tabachnick and Fidell, 1996). No regression models were tested for *Familiarity*, because all of its coefficients of correlation with the studied variables were below 0.3 (Table II). In the tested models, N_{10} was selected as acoustic indicator of perceived loudness, because it explained a higher portion of the variance for both *Pleasantness* and *Eventfulness* than $L_{\mathrm{Aeq,30s}}$ or any other tested acoustic indicator (cf. Table II).

The first model of the stepwise multiple regression analysis with *Pleasantness* as dependent variable used N_{10} as the only independent variable. In the second model, the three dominant-sound-category variables were added. This increased the variance explained from 47% to 59%. Mainly Technological Sounds were found to contribute to this increase in explained variance ($p = 0.051$), (Table III).

The first model of the stepwise multiple regression analysis with *Eventfulness* as dependent variable used N_{10} as the only independent variable. In the second model, the three dominant-sound-category variables were added. This increased the variance explained from 20% to 55%. This increase was mainly due to Human Sounds, but also Technological Sounds contributed to the variance explained, whereas Natural Sounds was not associated with *Eventfulness* (Table IV).

We also included indictors of variability (N_{10}-N_{90}) and proportion of low-frequency sound ($L_{\mathrm{C\text{-}A}}$) in the regression models describe above. None of these variables significantly increased the proportion of explained variance.

The general result of the experiment is well summarized in Fig. 4. It plots component scores [Eq. (2)] of *Pleasantness* against component scores of *Eventfulness*. The general pat-

TABLE II. Pearson's coefficients of correlation among the three sets of principal-component scores (C1–C3), acoustic measures and dominant-sound-category variables for the 50 soundscape excerpts.

	C1 (*Pleasantness*)	C2 (*Eventfulness*)	C3 (*Familiarity*)	$L_{\mathrm{Aeq,30s}}$	N_{10}	L_{A10}-L_{A90}	N_{10}-N_{90}	L_{Ceq}-L_{Aeq}	Techn.[a]	Human[b]
C2	0.00									
C3	0.00	0.00								
$L_{\mathrm{Aeq,30s}}$	-0.59***	0.49***	0.05							
N_{10}	-0.69***	0.45**	0.06	0.94***						
L_{A10}-L_{A90}	-0.16	0.28	0.17	0.44**	0.47**					
N_{10}-N_{90}	-0.54***	0.43**	0.13	0.76***	0.88***	0.78***				
L_{Ceq}-L_{Aeq}	0.01	-0.32*	-0.02	-0.60***	-0.41**	-0.30*	-0.33*			
Techn.[a]	-0.71***	0.04	0.11	0.59***	0.74***	0.41**	0.73***	-0.04		
Human[b]	0.17	0.51***	0.25	0.07	0.02	-0.02	0.01	-0.07	-0.18	
Natural[c]	0.31*	-0.11	-0.22	-0.06	-0.23	-0.16	-0.34*	-0.28	-0.34*	-0.25

* $p \leq 0.05$, ** $p \leq 0.01$, *** $p \leq 0.001$

[a] Soundscape dominated by technological sounds, dichotomous variable coded [0,1]

[b] Soundscape dominated by human sounds, dichotomous variable coded [0,1]

[c] Soundscape dominated by natural sounds, dichotomous variable coded [0,1]

tern in Fig. 4, which agrees with Fig. 3 and the statistical analyses (Tables II–IV), shows that soundscape excerpts dominated by technological sounds (filled circles) were mainly perceived as unpleasant and uneventful, and soundscape excerpts dominated by human sounds (filled squares) were mainly perceived as eventful and pleasant. The relationship between Natural Sounds and component scores was less strong (see the open squares in Fig. 4), although, a positive relationship with *Pleasantness* is discerned; for example, natural sounds dominated the two most pleasant soundscape excerpts. Soundscape excerpts without pronounced sound-categories (open circles) were in general perceived as pleasant and uneventful.

IV. DISCUSSION

Our results suggest that soundscape perception can be described in terms of three basic components: *Pleasantness*, *Eventfulness* and *Familiarity*. The meaningful pattern of associations between component scores, acoustic measures and the three dominant-sound-category variables support the interpretation of the three components. Thus, our results support a simple model of soundscape perception based on a small number of basic dimensions, which in a meaningful way are related to the informational properties of the soundscapes, that is, the categories of sounds.

In comparison with previous research, we used a large set of attribute scales and a comprehensive set of excerpts of binaural recordings of urban outdoor soundscapes (cf. De Coensel and Botteldooren, 2006). This would support the stability, representativeness and generalizability of the proposed model of soundscape perception. We believe that the model provide a fruitful framework for future soundscape research and practice. In particular, it suggests which basic dimensions are necessary to measure (theory), how to mea-

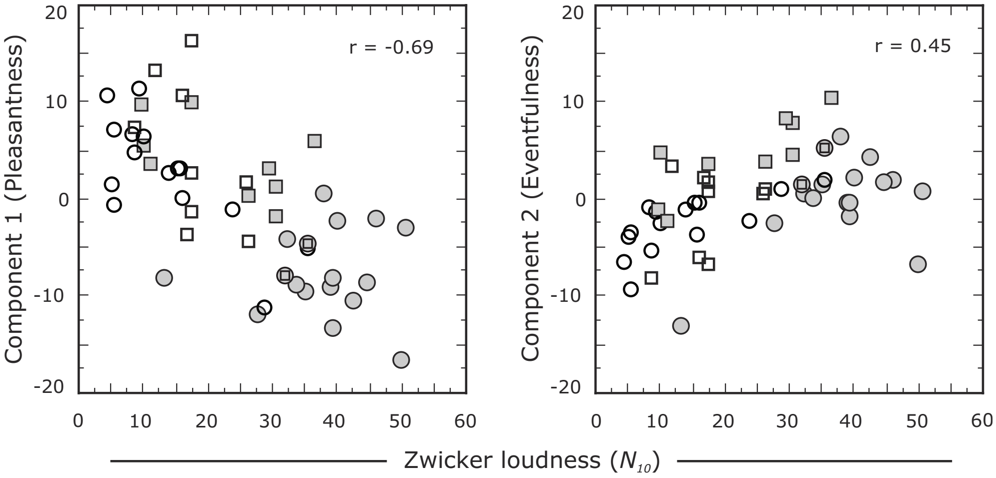

FIG. 3. Component scores of the 50 soundscape excerpts in *Pleasantness* (left) and *Eventfulness* (right) as a function of Zwicker loudness (N_{10}). Symbols represent dominant sound-categories: human sounds (filled squares), technological sounds (filled circles), natural sounds (open squares), and no dominant sound-category (open circles).

TABLE III. Stepwise multiple linear regression analysis relating *Pleasantness* (principal component 1) to N_{10} and dominant-sound-category variables.

Model	Model fit, R^2 (R^2_{adj})	Model fit increase, R^2-change	F-change	Independent variables	Standardized multiple regression coefficient	t-value
1	0.47 (0.46)		43.34***	N_{10} [a]	−0.69	−6.58***
2	0.59 (0.55)	0.12	4.10*	N_{10} [a]	−0.43	−2.93**
				Technological[b]	−0.32	−2.01
				Human[c]	0.16	1.50
				Natural[d]	0.14	1.31

*p≤0.05, **p≤0.01, ***p≤0.001.

[a] Zwicker loudness (ISO 532B) exceeded 10% of the time [sone].

[b] Soundscape dominated by technological sounds, dichotomous variable coded [0, 1].

[c] Soundscape dominated by human sounds, dichotomous variable coded [0, 1].

[d] Soundscape dominated by natural sounds, dichotomous variable coded [0, 1].

sure them by a defined set of attribute scales (method of measurement), and potentially how abatement and promotion of specific sound-categories within soundscapes (soundscape design) may affect soundscape perception (see Fig. 4).

The main component, *Pleasantness*, was found to explain 50% of the variance in soundscape measures, and ordered the soundscape excerpts on a pleasant-unpleasant continuum. The second component, *Eventfulness*, was found to explain 16% of the variance, and ordered the soundscape excerpts on an eventful-uneventful continuum. Previous soundscape research reviewed by De Coensel and Botteldooren (2006), as well as, research on emotions and in environmental psychology (further discussed below), support our first two components of soundscape perception. The third component, *Familiarity*, was found to explain 8% of the variance in soundscape measures, and ordered the soundscape excerpts on a familiar-unfamiliar continuum. Kawai *et al.* (2004), as well as, Viollon and Lavandier (2000) provide empirical support for this component.

Despite the fact that a large variety of urban outdoor soundscape excerpts were included in the present experiment, the variance in *Familiarity* was rather low. This suggests that urban soundscapes in general are perceived as similar in terms of familiarity, at least for listeners from the same cultural setting as the soundscape recordings used in the present experiment. This would mean that they have heard it all before. Probably, very unusual sounds would be necessary in order to obtain a substantial variation in *Familiarity*. The small variation in familiarity of urban outdoor soundscapes indicates that this component would be of limited importance for applied work aimed at promoting or mapping urban outdoor soundscapes. Nevertheless, this third component may still be important to basic research, for instance, in cross-cultural comparisons of soundscape perception.

As illustrated in Fig. 4, our results suggest that urban outdoor soundscapes may be represented by their position in a two-dimensional space defined by the two main components *Pleasantness* and *Eventfulness* (excluding *Familiarity* for reasons given above). This space resembles the 'circumplex' pleasantness-arousal model that Russell and coworkers proposed and which was based on research on emotions and environmental psychology (e.g., Russell, 1980; Russell and Snodgrass, 1987; Ward and Russell, 1981). Although 'eventfulness' is not synonymous with 'arousing,' it seems plausible that eventful soundscapes would be more arousing and activating than uneventful soundscapes. For example, Ward and Russell (1981) found that although *Activity* and *Arousal* were positively related, *Arousal* corresponded to an affective response to the environment, whereas *Activity*

TABLE IV. Stepwise multiple linear regression analysis relating *Eventfulness* (principal component 2) to N_{10} and dominant-sound-category variables.

Model	Model fit, R^2 (R^2_{adj})	Model fit increase, R^2-change	F-change	Independent variables	Standardized multiple regression coefficient	t-value
1	0.20 (0.18)		11.92***	N_{10} [a]	0.45	3.45***
2	0.55 (0.50)	0.35	11.40***	N_{10} [a]	0.77	5.06***
				Technological[b]	−0.45	−2.71**
				Human[c]	0.43	3.84***
				Natural[d]	0.03	0.23

*p≤0.05, **p≤0.01, ***p≤0.001.

[a] Zwicker loudness (ISO 532B) exceeded 10% of the time [sone]

[b] Soundscape dominated by technological sounds, dichotomous variable coded [0, 1].

[c] Soundscape dominated by human sounds, dichotomous variable coded [0, 1].

[d] Soundscape dominated by natural sounds, dichotomous variable coded [0, 1].

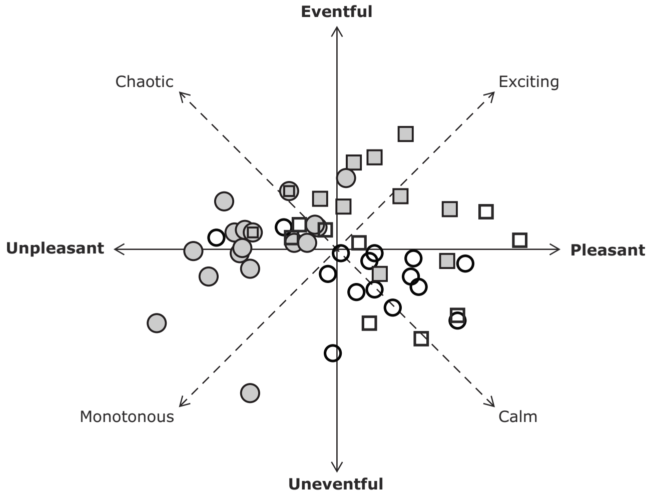

FIG. 4. Component scores of the 50 soundscape excerpts in *Pleasantness* and *Eventfulness*. Symbols represent dominant sound-categories: human sounds (filled squares), technological sounds (filled circles), natural sounds (open squares), and no dominant sound-category (open circles).

corresponded to the amount of activity observed in the environment. It is also interesting to compare our soundscape results with Russell and Snodgrass' (1987) ideas. They reported that, alternatively, environmental appraisal would be represented by the two components *Exciting* and *Calming* (cf. Cain, 2009), which share an evaluative component. *Exciting* mixes high arousal with pleasure, whereas *Calming* mixes low arousal with pleasure. Such an interpretation would correspond to the diagonals drawn in Fig. 4. Thus, our results on soundscapes agree well with results established in environmental research. Moreover, Västfjäll *et al.* (2003) showed that a circumplex model may be used in evaluating specific sound sources, and the present research findings show that a similar model also applies to perception of the more complex soundscapes (Fig. 4).

In our application, 'circumplex' means that soundscape attributes may be viewed as a 'mix' of *Pleasantness* and *Eventfulness* (cf. Russell and Snodgrass, 1987). Thus, an *exciting* and a *calm* soundscape may be equally pleasant, but differ in their degree of eventfulness. Imagine, for example, a vibrant soundscape in a downtown shopping street and compare it with a soothing soundscape in a quiet rural area; they may both be pleasant but differ in eventfulness. In addition, a *calm* and a *monotonous* soundscape may be equally uneventful, but differ in pleasantness. Imagine the soothing soundscapes in a quiet rural area and compare it with a monotonous soundscape in a courtyard dominated by a continuous low-intensity noise from a ventilation system. In addition, a *monotonous* and a *chaotic* soundscape may be equally unpleasant but differ in eventfulness. Imagine the monotonous courtyard soundscape and compare it with a chaotic soundscape at a busy and very noisy street corner.

As expected, soundscape excerpts dominated by technological sounds were in general judged to be unpleasant. Traffic noise and other technological sounds are often perceived as annoying, and several soundscape studies suggest that such sounds typically have an adverse influence on the overall quality of the soundscape (e.g., Nilsson and Berglund, 2006). Importantly, the negative association between pleasantness and Technological Sounds would remain also after controlling for overall intensity (N_{10}). This shows that this effect was not only related to perceived loudness, but also to the perceived character of the technological sounds. Thus, it is likely that audible technological sounds, which may not contribute significantly to the overall sound level of the soundscape, still exert a negative influence on perceived pleasantness.

For natural sounds our results were less clear. Although, natural sounds dominated in the most pleasant soundscape excerpts, several other soundscape excerpts with dominant natural sounds were less pleasant (see Fig. 4). This explains the weak association between Natural Sounds and component scores of *Pleasantness*. Several of the soundscape excerpts dominated by natural sounds also contained low-level noise in the background. This may explain why they were judged less pleasant. These results cast some doubt on the notion that adding or promoting existing natural sounds would improve soundscape quality. At least this may be difficult to accomplish in situations with detectable adverse sounds, such as distant road-traffic noise. Because such noises typically have a considerable low-frequency component, positive natural sounds would not easily mask them.

Soundscape excerpts dominated by human sounds were in general judged more eventful than soundscape excerpts without sounds from human activities (cf. Viollon and Lavandier, 2000). This suggest that different design measures would be needed if the goal is to obtain an activating, exciting and fascinating soundscape, compared to if the goal is to design a calm, soothing and restorative soundscape (cf. Kaplan, 1995; Ulrich *et al.*, 1991). Our research suggests that promotion of human sounds, for example from play-grounds and cafeterias, would increase the eventfulness of a pleasant soundscape, and thereby create a soundscape that is exciting rather than calm. Conversely, abatement of human sounds would make a pleasant soundscape calmer.

What is here said about the relationships between sound-categories and the basic components of soundscape perception is not intended as absolute truths. We acknowledge that unpleasant natural sounds and pleasant technological sounds might exist. Nevertheless, based on current research literature on soundscapes, pleasant technological sounds do not seem to be common in modern urban outdoor environments.

V. CONCLUSIONS

The main conclusions of the present research are:

(1) An extensive set of soundscape attributes, in total 116 ('pleasant,' 'eventful,' 'annoying,' 'calm,' etc.), were well integrated into three basic components or dimensions of soundscape perception: *Pleasantness*, *Eventfulness* and *Familiarity*.

(2) The two first (orthogonal) components, *Pleasantness* and *Eventfulness*, organized the soundscape attributes in a circular or 'circumplex' pattern. In this two-dimensional space, an *exciting* soundscape would be both pleasant and eventful, whereas a *calm* soundscape would be pleasant and uneventful. Correspondingly, a *chaotic*

soundscape would be unpleasant and eventful, whereas a *monotonous* soundscape would be unpleasant and uneventful.

(3) A simple pattern among sound-categories in the two-dimensional space of soundscape perception was determined. Soundscape excerpts dominated by technological sounds were found to be unpleasant, soundscape excerpts dominated by natural sounds to be pleasant, and soundscape excerpts dominated by human sounds to be eventful. Importantly, these relationships remained after controlling for overall soundscape loudness (Zwicker's N_{10}). This shows that informational properties of soundscapes, that is, the categories of sounds (technological, natural, human), significantly contribute to soundscape perception.

(4) A measurement system for soundscape quality is proposed, which consists of a two-dimensional space defined by the attributes: Pleasant, Exciting, Eventful, Chaotic, Unpleasant, Monotonous, Uneventful, and Calm, as eight vectors separated by 45° in a circumplex model of soundscape perception (see Fig. 4).

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