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Interactive soundscape augmentation by natural sounds in a noise polluted urban park

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ABSTRACT

Inappropriate sound environments are able to strongly deteriorate the user experience in parks. A possible remediation is adding positively perceived sounds. The case of an urban park, fully surrounded by busy roads, was studied to explore the potential of adding natural sounds in an interactive way. With a smartphone app, recruited users (N = 165) were allowed to mix in a combination of eight types of natural sounds, played back by a hidden loudspeaker, until their personally optimized soundscape was composed. These preferred soundscapes were then evaluated by other participants. A questionnaire showed that these compositions are able to improve the general appreciation of the auditive environment, especially for park visitors that rated the reference situation as poor. Road traffic noise, the dominant sound source in the park under study, was heard to a much lesser extent, showing the masking potential of the augmented natural soundscapes. Most people prefer a balanced combination of various types of (natural) sounds, in which songbirds and house sparrows were prominent. There was consistency among the participants to optimize the signal-to-noise ratio of the added natural sounds in the frequency range between 2.5 kHz and 8 kHz. So without the common and most often visually intruding noise abatements solutions, interactively augmented soundscapes can improve the sonic environment in noise polluted parks. More in general, the current ICT-based approach can be considered as an efficient methodology to improve the perception of urban public spaces.

1. Introduction

When well designed, urban parks are able to provide multiple ecosystem services. Of major importance for people living in city centers are the social and health related benefits (Egorov, Mudu, Braubach, & Martuzzi, 2016). However, these benefits can be jeopardized by excessive exposure to environmental noise, negatively impacting human health (Fritschi, Brown, Kim, Schwela, & Kephalopoulos, 2011). Especially the abundance of mechanical/technical sounds in urban parks (Nilsson & Berglund, 2006) might strongly deteriorate these services for citizens.

Sound levels inside parks, bordered by roads, can be mitigated in various ways. Although source related measures like e.g. a ban on heavy traffic, a reduction in the number of lanes or vehicle speed mitigation road infrastructure might be efficient, they prevent sufficient traffic throughput. This basic function of the road infrastructure is especially relevant in case of big arterial roads entering a city. At such places, noise polluted elongated parks often appear.

Besides such source oriented measures, the transmission of sound between source and receiver can also be reduced. Of special interest near parks is achieving this in a natural way (Van Renterghem et al., 2015) e.g. by placing dense tree belts near its borders (Van Renterghem, 2014) or by so-called "acoustical landscaping" (Van Renterghem & Botteldooren, 2018). However, such visually non-transparent park borders might provoke perceived unsafety (Fisher & Nasar, 1992; Jorgensen, Hitchmough, & Calvert, 2002; Jansson, Fors, Lindgren, & Wiström, 2013). In addition, they are unlikely to provide sufficient relaxation potential as it deviates from the human-preferred semi-open savanna-like natural environments (Balling & Falk, 1982; Kaplan & Kaplan, 1989; Misgav, 2000).

An alternative to improve the sonic environment is relying on the soundscape approach. Although "soundscape" (Schafer, 1994) is a rather broad concept, the idea of main interest (Kang et al., 2016) to this work is adding (human-preferred) sounds instead of mitigating unwanted sounds. The latter is typically the only path followed in traditional noise control. However, pure level reduction with the purpose of human noise perception improvement is not always efficient (see e.g. Filipan et al., 2017).

Adding sounds to public spaces, further indicated as "augmented soundscapes", has attracted the attention of researchers, city authorities and sound artists over the past decades (e.g. Barclay, 2017; Lavia et al., 2016; Licitra, Cobianchi, & Brusci, 2010; Schulte-Fortkamp, 2010;

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Steele, Bild, Tarlao, & Guastavino, 2019). The widespread use of smartphones has accelerated such initiatives and allows easy interaction. To frame the current research, a few examples, reported in scientific literature, are mentioned below where sounds were artificially added to existing environments.

In the "West Street Story: Come Together" pilot in Brighton (UK) (Lavia et al., 2016), ambient sounds were played along the streets in an otherwise "cacophonous" and problematic clubbing district. Body language analysis and reduced need for police resources showed its effectiveness in moderating anti-social behavior, showing that sound can effectively influence human behavior.

Another example is the "CANOPY/Rainforest listening" (Barclay, 2017), which is an augmented reality sound project that layers a canopy of rainforest sounds in urban environments. Geo-located sounds were played at specific locations on participants' smartphones through headphones. Goals were raising ecological awareness and offering relaxation to citizens by exposing them to these highly contrasting sounds at noisy places.

Some cases closely related to the current application are the "Sonic garden" project (Italy/France) (Licitra et al., 2010), "Nauener Platz" park remodeling in Berlin (Germany) (Schulte-Fortkamp, 2010) and the "Musikiosk" project (Steele et al., 2019) in Montreal (Canada). In the "Sonic garden" project, artificial sounds (from a music database and meta-compositions) were generated by loudspeakers in noise polluted urban parks and squares. The tracks were automatically selected by the playback system, based on spectro-temporal analysis of the momentary sound field captured by microphones, aiming at auditory masking of the background noise. The Berlin case deals with a park exposed to intense road traffic. As a result of soundwalks with local residents, the need for more pleasant sounds arose. This was achieved by so-called "audio islands", benches with integrated speakers playing continuously preset sounds (more precisely bird sounds and shingle beach shore sounds) to improve the auditive experience of the park visitors. The Montreal case also concerned a road traffic noise exposed urban park. People were invited to play their own music over publicly provided loudspeakers in a designated area of the park. Positive outcomes were reported regarding the soundscape evaluations by individuals and the park use. More examples on the use of outdoor loudspeakers as a soundscape improvement strategy in urban environments can be found in Cobianchi et al. (2019).

Note that the users and participants in the previously described projects are most often passive listeners and they do not have control over the sonic environment. In contrast, and similar to Montreal's "Musikiok", a fully interactive soundscape augmentation approach is proposed here and experimentally validated. In this study, the choice was made to exclude music from own devices and to focus on natural sounds. Such sounds are not only highly plausible in a park environment, but are also sounds that most people enjoy. A more detailed discussion on the importance of natural sounds in view of environmental noise perception, in relation to green infrastructure, was reviewed by Van Renterghem (2019). Previous research showed that mainly bird sounds (Viollon, Lavandier, & Drake, 2002; Ratcliffe, Gatersleben, & Sowden, 2013; Yang & Kang, 2015; Krzywicka & Byrka, 2017) and specific types of water sounds (Jeon, Lee, You, & Kang, 2010; Jeon, Lee, You, & Kang, 2012; Galbrun & Ali, 2013; Rådsten-Ekman, Axelsson, & Nilsson, 2013) score high in several listening tests. Much less is known on what combinations are most suited since natural sounds usually do not appear as separate auditory objects.

Another research question is how such preferences of (combinations of) sounds depend on the temporal and spectral content of the (unwanted) environmental sounds. Although such a question has been asked in previous studies (De Coensel, Van Wetswinkel, & Botteldooren, 2011; Hong et al., 2017), this was researched by listening tests in laboratory conditions, often neglecting audio-visual interactions (Fastl, 2004; Preis, Kociński, Hafke-Dys, & Wrzosek, 2015; Sun et al., 2018) that might be potentially strong in green infrastructure (Van Renterghem, 2019).

Besides knowing what types of sounds or what combinations are most preferred, a main research question is whether such natural sounds could improve the general appreciation of the sonic environment in a real-life park environment largely exposed to road traffic noise.

2. Methodology

2.1. Site description

The case of interest is the "Koning Albertpark" (often called "Zuidpark") in Ghent (Belgium), an elongated rectangular park (about 100 m wide and 380 m long, central coordinates at 51°2′42.54″N, 3°43′56.07″E) surrounded by intense road traffic due to its functioning as a portal to the city centre. At the east side of the park, a tramway is present. The park is surrounded by high-rise buildings.

The park has a rather open character; at most locations from within the park, the roads are visible. Tall trees, with a large number of plane trees (*Platani*), dominate the visuals. There is a limited amount of understorey. Wide straight gravel footpaths run through the park bordering large plots of grassland. A big fountain is present at the North side which was most of the time not operational. A children's playground can be found near to this fountain. At the north side, the park blends to an urban square.

Overall, the park's use is rather limited. Although the park contains a large number of benches, pedestrians mainly walk straight through the park to reach the other side. Some people use the park for walking their dogs or as a running track. Only in high summer, the park is used more intensively for leisure activities.

The experiment was held at the south end of the park (see Fig. 1) near a small wooden building used to store equipment for park maintenance. At this location (see Fig. 1 (b)), several benches were present overlooking a well maintained flower bed (see Fig. 1 (c)). The fountain was sufficiently far away so it could not be heard and hardly seen.

2.2. Reference environmental sound exposure

The site under study is strongly exposed to road traffic noise and occasional park maintenance or construction noise. The reference environmental sound field was assessed by long-term continuous SPL measurements at the façade of the building with an internet-based meter (see Fig. 1 (b) for its location). Although the SPL meter is not type approved (following IEC 61672, 2013), long-term testing showed a measurement accuracy of less than 1 dBA in road traffic noise dominated environments, in excess to the deviation between type-1 reference microphones themselves (Van Renterghem et al., 2011).

During the monitoring period of half a year (January-July 2019), an L_{den} value (for its definition, see END, 2002) of 61.8 dBA was obtained, while L_{day} (see END, 2002 – integration from 7 h to 19 h) was 59.9 dBA (see Table 1). During the two active user recruiting periods (see Section 2.5.1), similar levels were measured. In order to compare to the noise perception study of Nilsson and Berglund (2006) in urban parks, $L_{eq,15min}$ (= total equivalent sound pressure levels, integrated over non-overlapping 15-minute periods) statistics were calculated. These showed medians of 57.4 dBA and 56.6 dBA during the first and second recruiting period, respectively, for the period of the day where users could access the experimental device (9 h–21 h). As these levels exceed 50 dBA, this zone could be categorized as a low-quality park as regards its sound exposure (Nilsson & Berglund, 2006). This 50-dBA criterion is needed to achieve 80% satisfied visitors (Nilsson & Berglund, 2006). The spectral data in Fig. 2 show evidence of a road traffic noise dominated zone; the local maximum near 63–80 Hz originates from engine noise, while the maximum near 1 kHz can be attributed to tyre-road interactions (Sandberg & Ejsmont, 2002).

Fig. 1. Images of the zone in the park where the experiment took place. In (a), a satellite image (from Google Earth) of the south side of the park is shown, indicating the estimated zone with local wifi access, in which people could participate in the experiment. In (b), the info panel is shown, together with the location of the hidden loudspeaker and the continuous and ad-hoc (see Appendix) sound pressure level (SPL) measurement equipment. In (c), the view from the bench is provided.

2.3. Natural sound samples

In this study, eight types of natural sounds were chosen, more precisely insect/bird sounds, water sounds and meteorologically induced sounds. This set contains top-rated natural sounds as known from other research (see introduction). A few sounds that might also provoke negative reactions like "bumblebees" or "seagulls" were deliberately added. This was done to have sufficient contrast, helping participants making up their mind regarding what they like or dislike.

The spectrograms of the natural sound samples are presented in Fig. 3. Sounds were chosen to have spectrally and temporally diverse properties. The fauna-related sounds are intermittent and operate in specific frequency bands. The sounds related to leaves (by wind and raindrop impact) and water sounds are more continuous. The "waterfall" fragment is very broadband and has pink noise characteristics. The "water stream" exhibits some harmonics and is less stationary compared to the falling water. The "rustling of leaves" shows some intermittency due to the turbulent driven nature of such sound excitation. The raindrops on vegetation is again more noisy in nature, but operate in a higher frequency range than e.g. the "waterfall".

Each original fragment was 5 min long (without parts being repeated). Each sample was processed to have an equal A-weighted equivalent SPL over its full duration to allow a direct comparison of channel volumes.

2.4. Sound playback equipment

The loudspeaker box contained a loudspeaker driver that was controlled by a Raspberry Pi 3 Model B single-board computer (SBC) and a Caliber CA75.2 power amplifier. The loudspeaker box was attached to the façade of the small building. All equipment was hidden from sight by the vegetation as shown in Fig. 1 (b).

Python code was written to mix the sound samples. The 5-minute samples were looped for continuous playback. The starting point for playback in each sample was randomized. For the more intermittent samples, it was ensured that each sample started and ended with a few seconds of silence to prevent abrupt transitions during the looping. For the continuous samples, a smooth transition was obtained naturally.

An external Gaoxing Tech. precise RTC clock was connected to the SBC (which was offline) to ensure correct reading after e.g. restarting the device. The internal clock of the SPL meter was synchronized by Network Time Protocol (NTP) via 3G. Clock drift between both devices was not observed (or was less than 1 s) during the course of the experiment. This means that the time stamps of the SPL measurements and logging times of the playback device could be combined for analysis.

Note that the sound level meter was attached to the building and therefore did not measure the SPL exactly where the users would appear. A preliminary test was performed to set the amplification of the playback equipment at the location where people were expected (see Appendix).

2.5. Interactive smart phone app

2.5.1. Participant recruiting

In theory, no instructor was needed; sufficient information was provided by an info panel at the site regarding the purpose of the experiment and how to install the app that guided the users through the experiment. However, in order to speed up participation, there were two active recruiting campaigns, where park visitors were invited to participate. The recruiter was asked to play a passive role unless specific questions were asked by the user. When a session was completed

Table 1
Sound exposure levels at the experimental location in the park.

Period	L_{den}	L_{day}	$L_{eq,15min}$ in between 9 h and 21 h
Full period of measurements (January, 1 – July, 29)	61.8 dBA	59.9 dBA	median = 58.4 dBA standard deviation = 2.6 dBA
Active recruiting period 1 (April, 8 – May, 1)	63.1 dBA	59.2 dBA	median = 57.4 dBA standard deviation = 2.4 dBA
Active recruiting period 2 (June, 24 – July, 9)	62.9 dBA	58.0 dBA	median = 56.6 dBA standard deviation = 2.2 dBA

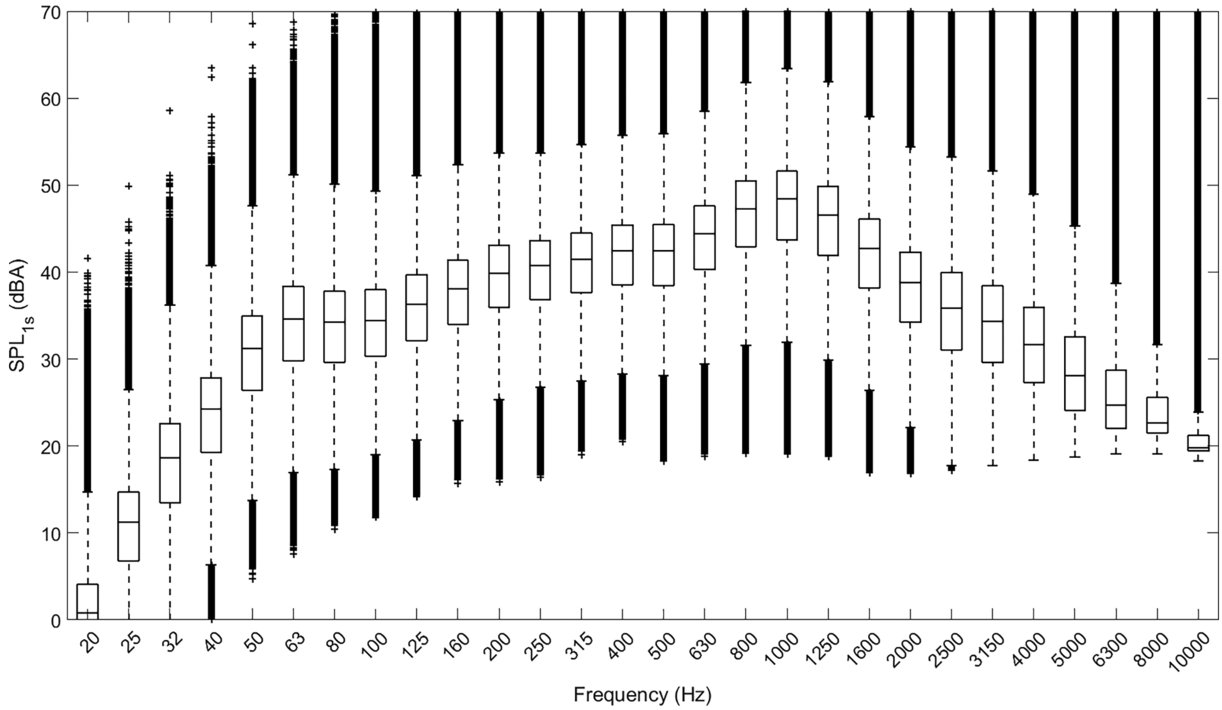

Fig. 2. Boxplots showing the sound pressure level (SPL) spectrum using the 1-s 1/3-octave band logged measurements, over the period January-July 2019 (amounting to more than 18 million data points). The (middle) horizontal line in each box indicates the median of the data. The boxes are closed by the first and third quartile. The whiskers extend to 1.5 times the interquartile distance above the maximum value inside each box, and to 1.5 times the interquartile distance below the minimum value inside each box. Data points that fall outside these limits (outliers) are indicated with the plus-signs.

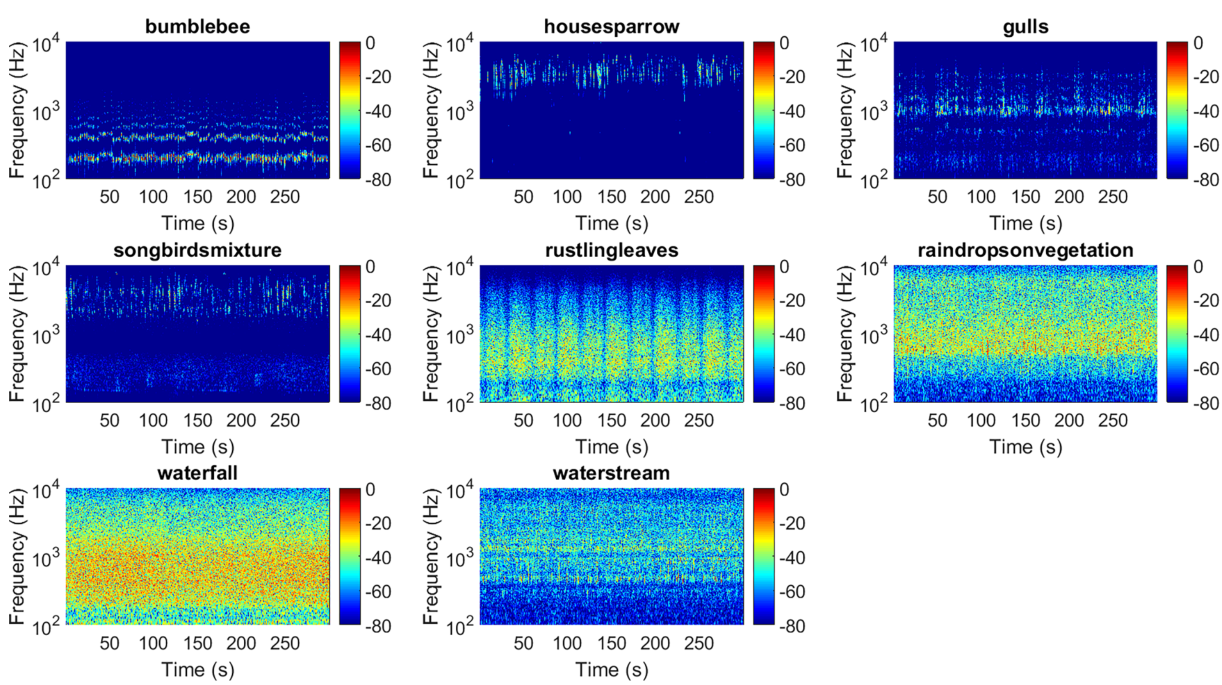

Fig. 3. Spectrograms (window size 8192 samples, 50% overlap) of the eight natural sound samples considered in this experiment (.wav files, sample frequency 44.1 kHz, 16 bits). The levels (in dB) as depicted here are referred to the maximum level across all frequencies and times within each separate fragment.

(see Section 2.5.3), each user received an anonymized lottery ticket to potentially win a smart phone.

This study was approved by the independent Commission for Ethics and Data Management in Political and Social Sciences at Ghent University, with the registration number EC29 (approved on January, 21 2019).

2.5.2. Connection with the playback device

Interaction with the loudspeaker box was performed by an Android app ("zuidpark soundscape experiment", made available on the Google Play Store) and to be installed on the personal smart phone of the participant. When a recruiter was present, a test smart phone was offered in case users had another operation system on their own smart phone, in case they did not want to install the app (for perceived safety

Table 2
Overview of instructions and questions asked by the smartphone app.

	Specific instructions or question	Answering scale
I1: Welcome screen/go to experimental spot	"Welcome to the Zuidpark app. Thanks for your participation. This app aims at assessing the park's environmental quality as experienced by its users. Move to the indicated area."	
I2: Setting the reference/background assessment	"Please take a minute to experience the park before answering a few questions."	
Q1: Overall evaluation of the sound environment (ISO, 2018)	"Overall, how would you describe the present surrounding sound environment you just experienced?"	□very bad (1), □bad (2), □neither good nor bad (3), □good (4), □very good (5)
Q2: Attention drawing potential (Sun et al., 2019)	"How much did the sound draw your attention during the last minutes?"	□Not at all (1), □slightly (2), □moderately (3), □highly (4), □extremely (5)
Q3: Disruptiveness assessment (Sun et al., 2019)	"Would the sound environment you just experienced prevent you from doing the things you usually do or would like to do in this park?"	□Not at all (1), □slightly (2), □moderately (3), □highly (4), □extremely (5)
Q4: Types of sounds heard (ISO, 2018)	"To what extent did you hear the following types of sounds?" • Traffic noise (cars, buses, trucks, trams, etc.) • Sounds from human beings (conversations, children at play, footsteps, laughter, …) • Natural sounds (birds, water related sounds, wind in vegetation, …) • Other noise sources (sirens, construction, delivery, …)	□Not at all (1), □a little (2), □moderately (3), □a lot (4), □dominates completely (5)
I3: Preferred soundscape creation	"Design what you think is the most suited soundscape for this park by moving the sliders to add or increase the volume of the eight types of natural sounds provided."	Channel volume settings between 0 = mute and 1 = maximum level (see Appendix), in steps of 0.1.
Q5: Personal information	"Age?" "Gender?"	Integer number Male/Female

reasons) or in case they did not have a smart phone with them.

A web service running on the SBC allowed wirelessly connected client devices, more precisely those using the interactive smart phone app. Connecting to this Wi-Fi access point allowed controlling the loudspeaker and logging the answers to the questionnaires and other use statistics. When the participant went outside the range of the Wi-Fi access (see Fig. 1 (a)), the session stopped. This confined the participants to a limited zone and ensured that they could actually hear the sounds being played. The experiment could be accessed during day hours, more precisely from 9:00 h until 21:00 h.

2.5.3. Participants' tasks and questionnaires

In Table 2, the specific instructions (I) and questions (Q) are summarized. The welcome screen of the app asked participants to move sufficiently close to the experimental location (I1).

To begin, each participant was instructed (I2) to listen to the current background noise for at least one minute. Next, an ISO-certified question (ISO 12913, 2018) was asked regarding the general appreciation of the sonic environment (Q1) to set a personal reference level for his or her evaluation of the current sonic environment. After that, a few specific soundscape related questions were posed (Q2 and Q3), inspired by the work by Sun et al. (2019). Lastly, it was asked to what extent specific types of sounds could be heard (Q4) (ISO 12913, 2018). The background noise could only be rated once, and users could not change this rating afterwards.

In the next part of the experiment, the user was asked to rate a random soundscape (I2), previously composed by another participant (a few examples were created by the researchers at the start of the campaign). Again, the minimum listening time was set to 1 min. The same set of questions (Q1-Q4) was posed. During the answering of the questions, the soundscape continued playing, similar to the background noise that obviously continued as well (see previous paragraph). The start of actually answering questions could be delayed if people wanted to listen longer to the current soundscape. Various soundscapes could be rated by the user.

Thirdly, the user was invited to compose his or her own preferred soundscape (I3). Only when task I2 was performed at least once, this task could be started. The natural sounds that could be added (using a software mixing panel in the app, see Fig. 4) were not named as some might have a positive or negative connotation. When finished, the volume settings were stored on the SBC, and the soundscape was added to the database and could potentially be presented to future users.

Note that participants were not asked to rate the acoustic environment as a result of adding their own composed soundscape. In such a short user session, this could potentially lead to a (positive) overreaction bias.

In a last step, some personal information was asked (Q5). Although more personal information could be useful for further analysis, this was kept deliberately minimal. Especially when the experimental setup in the park was unmanned, asking for detailed personal information would probably be unsuccessful (fear for inappropriate data protection and management) and could make people abandon the experiment.

3. Results and discussion

3.1. User statistics and consistency checks

The major portion of the respondents were the direct result of on-site recruiting. The recruiting was performed in two periods during non-rainy days. The success rate in making people participate during the first recruiting campaign was 35%, during the second one 57%.

The analysis presented in this section is based on participants who completed all tasks (more precisely: evaluating the background noise, evaluating at least one pre-composed soundscape, and mixing their own preferred soundscape). In addition, all questions must be answered, including the personal ones (Q5). Based on the logging information, a few checks were made to evaluate whether a respondent genuinely participated. For each group of questions, a minimum duration was set to ensure that the users at least read the questions. Composing the preferred soundscape needed to have a minimum duration too, and the volume of each of the eight channels needed to be changed at least once since their content was hidden in the mixing panel (see Section 2.5.3). Note that a minimum listening time (of 1 min) to the background noise and the pre-composed soundscape was already hardcoded in the app.

In this way, 165 complete and valid sessions were retained. The median session duration was 480 s (where the 5th percentile value was 314 s, and the 95th percentile 1291 s), 53% were female (47% male), and the median age was 27 years (mean age was 32.6 years, with a standard deviation of 14.4 years). So the time needed to complete a session is fairly short and gender is well balanced, although there is a clear bias towards younger participants.

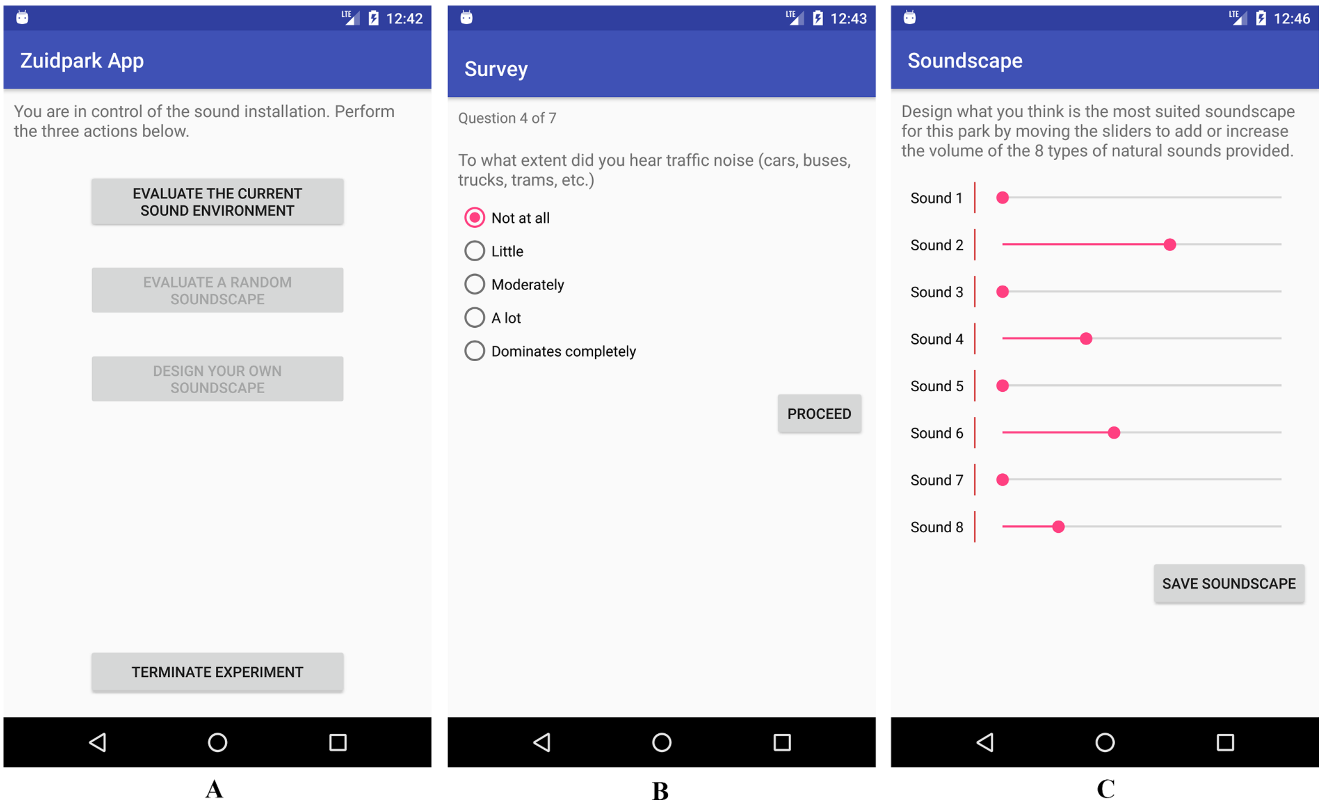

Fig. 4. Some screenshots of the smartphone app.

3.2. Preferred natural soundscapes

The average volume settings of each natural sound channel is shown in Fig. 5. Since these volumes over all participants are far from being normally distributed, confidence intervals on the means were calculated with a non-parametric bootstrap method (using the bias-corrected percentile method, as implemented in the Matlab statistics toolbox). An alternative representation of this same data is shown in Fig. 6, giving a better indication of the combinations of sounds chosen by the participants.

Although preferences for types of natural sounds inevitably leads to interpersonal variation, some trends can nevertheless be observed. Bird sounds, and more specifically "song birds mixture" and "house sparrows", are the most preferred natural sounds from the current list. This is consistent with other research (Viollon et al., 2002; Yang & Kang, 2015; Krzywicka & Byrka, 2017). The somewhat higher average performance of the "songbirds mixture", relative to the "house sparrow" sample (although not significantly different with 95% certainty), might

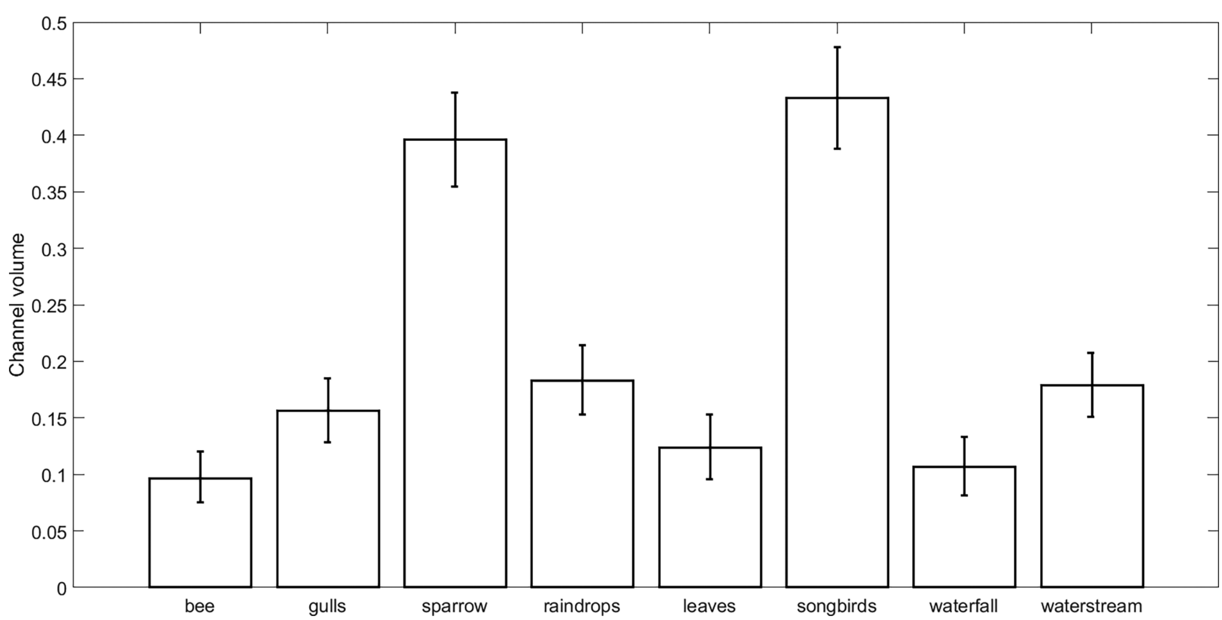

Fig. 5. Averaged volume settings of the composed soundscapes over all participants (0 = mute and 1 = maximum level). The error bars indicate the 95% confidence on the means.

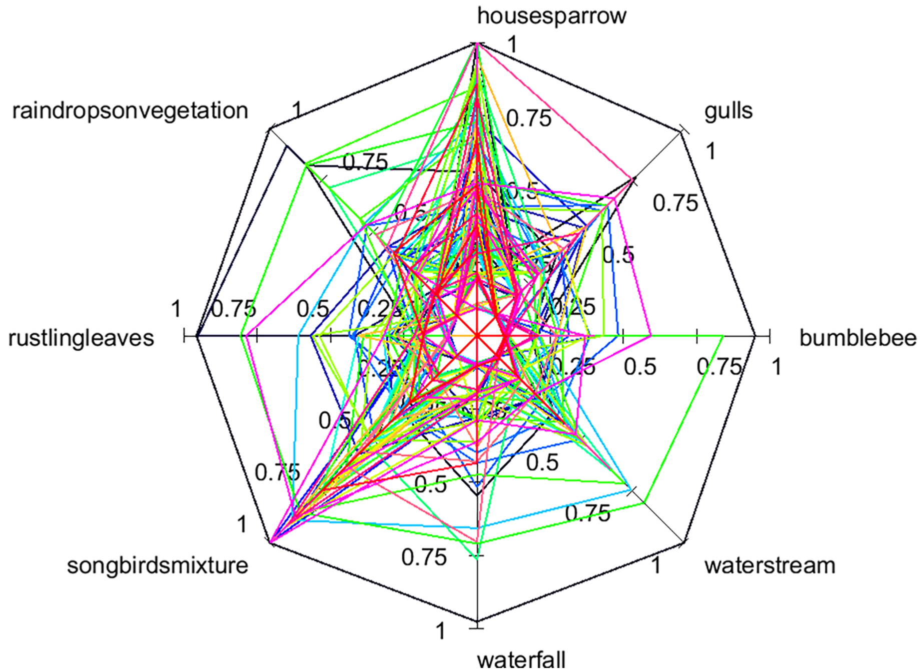

Fig. 6. Spider plot linking the volumes of the natural sound components constituting each individual composed soundscape.

be explained by the importance people put on the richness of bird species in respect of experiencing calmness (Hedblom, Knez, Ode Sang, & Gunnarsson, 2017). "Sea gulls" is a bird sound that is clearly less preferred; this finding is consistent with the discussion made by Ratcliffe et al. (2013). Furthermore, this sound is rather "incongruent" (Brambilla & Maffei, 2006; Van Renterghem, 2019) in the current visual setting since there is no nearness of a sea-side or a waterfront. This statement is backed up by a virtual reality experiment in a harbour environment (Botteldooren et al., 2019) with this same set of natural sound samples to choose from. There, the gulls were much more popular in the composed soundscapes.

Water related sounds seems to be less preferred. The fact that the "water stream" is chosen more than the "falling water" is nevertheless consistent with other research (Jeon et al., 2010; Galbrun & Ali, 2013; Rådsten-Ekman et al., 2013), and with the finding that water sounds at higher sound frequencies are more preferred (Watts, Pheasant, Horoshenkov, & Ragonesi, 2009). Note that the absence of visual water features, which was shown before to strongly improve the tranquility assessment (Watts, Pheasant, & Horoshenkov, 2011; Jeon et al., 2012), could be responsible for the rather low preference for these sounds. "Raindrops on vegetation" is chosen to a similar extent as the flowing water. "Rustling leaves" are even less mixed in, contrasting strongly with "wind" being assessed as the most preferred sound by the subjects in the work by Guastavino (2006), in response to the "imagined ideal urban soundscape" in the subcategory "nature". A possible reason is that in the reality of the current park, the spectra of such sounds are noise-like and coincide too much with the background noise. This contrasts with most bird sounds, operating in a frequency range (3–6 kHz) that easily reaches a high signal-to-noise ratio. In addition, these sounds are strongly intermittent and thus more easily attract attention (Oldoni et al., 2013).

The "bumble bee" sound scores low, but not worse on average than e.g. the "falling water" sample. However, the "bumble bee" sound provoked most (verbal) negative reactions (as observed by the recruiters). In the current study, 49% of the respondents muted this channel, although this is not the most muted channel (more precisely "rustling leaves" and "falling water", both by 55%). Note e.g. that in the study of Zhang, Zhao, Zeng, and Qiu (2019) "insect sounds" were labeled as positive sounds.

Consistent with the aforementioned findings on preferred natural sounds, the least muted channels were the "song birds mixture" (6%) and the "house sparrow" (9%). However, this does not mean that these most preferred sounds were set to the maximum volume; this was only done by a small percentage of the people (9% and 5%, respectively). The occurrence of maximization of other channels was nearly absent (only by 1%).

Most users prefer multiple natural sounds as shown by the histogram in Fig. 7. The median of the number of non-muted channels was 5. However, this does not imply that these channels were played at high volumes: the mean of the sum of the volumes of all channels equaled 1.7. This is the equivalent of playing somewhat less than 2 channels at full power. The corresponding histogram is shown in Fig. 8.

The signal-to-noise ratio (SNR) of each preferred soundscape, relative to the background noise, is shown in Fig. 9. Overall, the sound compositions seem to be optimized to have a good SNR from roughly the 1/3 octave band with centre frequency 2500 Hz till 8 kHz. This frequency range coincides with the drop in the intensity of the background noise as shown by the long-term spectrum in Fig. 2. Higher frequencies might be less efficient while trying to improve the sonic environment given the lower sensitivity of the human hearing system. This "window of opportunity" seems to be intensively used by most of the participants. Clearly, the "house sparrow" sample and "songbirds mixture" sound are most energetic in this specific frequency range. Sufficient sound samples are nevertheless available that would allow a good SNR in other frequency ranges as well, even down to 300–400 Hz (see Fig. 3 and Fig. 13). Also bird sounds might peak at lower frequencies like "seagulls" at 1 kHz. Therefore, it can be concluded that only considering energetic masking will not be able to explain this preference. Most likely, a combination of informational and energetic masking will result in the clear preference for the "song birds" and "house sparrow". A more detailed analysis of psycho-acoustic metrics might help to further explain this preference, but is beyond the scope of the current paper.

3.3. General appreciation of the sound environment

The use of additional sounds to improve the acoustic environment is analyzed by subtracting the rating after listening to the background

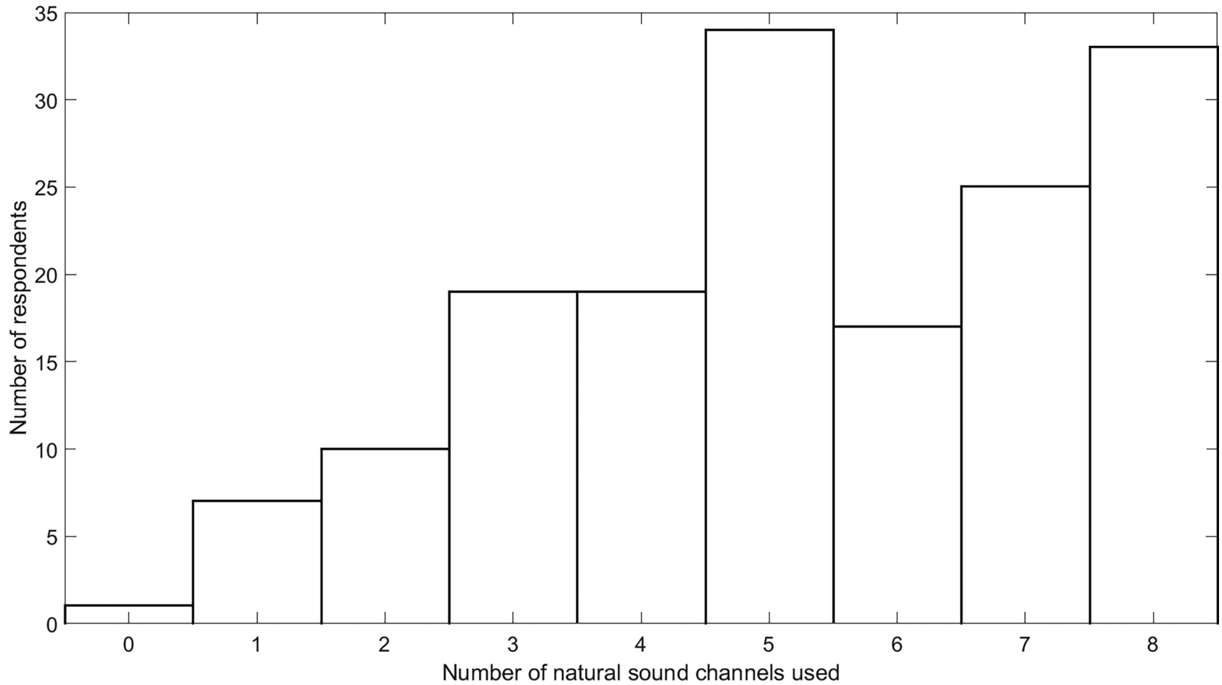

Fig. 7. Histogram of the number of (non-muted) sound channels to constitute the preferred soundscape.

noise from the rating after being exposed to a random soundscape (which is not necessarily the personally preferred one, see Section 2.5.3). Such a relative comparison removes interpersonal differences that might appear in absolute rating levels. The answers of the qualitative ordinal scale presented to the participants were linearly mapped to numbers between 1 and 5 (see Table 2) in order to quantify such improvements.

The overall appreciation of the sound environment is on average improved by 0.36 units, where a unit of 1 would mean shifting e.g. from "neither good nor bad" to "good", or from "very bad" to "bad". This improvement is statistically significantly different from 0 (pair-wise *t*-test, $t_{164} = 4.00$; $p < 0.001$), with the 95% confidence interval on this mean shift between 0.18 and 0.53. The histograms of the ratings in the reference and soundscape-augmented case, together with the distribution of the differences, are shown in the upper row of Fig. 10.

When a sub-selection is made of the persons giving a score of 2 ("bad") in the reference situation, the improvement is much stronger, exceeding a full unit (mean difference equals 1.24, 95% confidence interval is [0.89 1.60], $t_{32} = 7.13$, $p < 0.001$). For persons evaluating the reference environment as "neither good nor bad", the improvement is more moderate and equals 0.60 (95% confidence interval is now [0.33 0.87], $t_{49} = 4.48$, $p < 0.001$). For people starting off with a

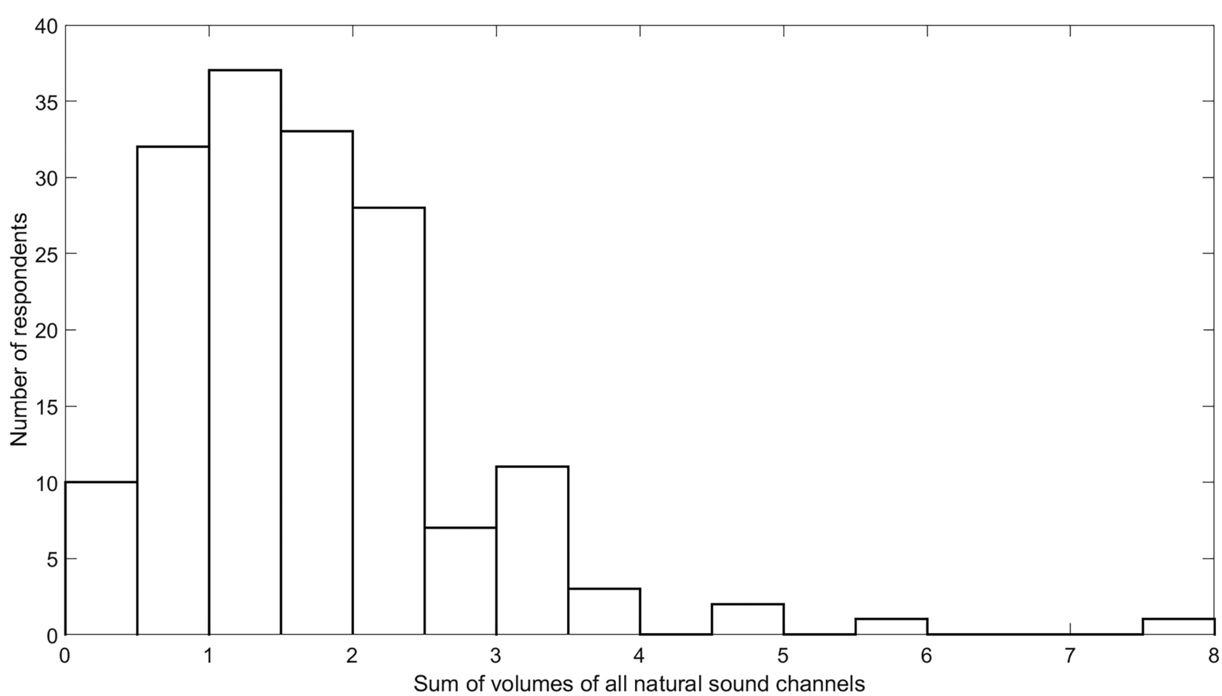

Fig. 8. Histogram of the sum of volumes over all channels used to constitute the preferred soundscape. When all channels are put at maximum volume, the sum would be 8.

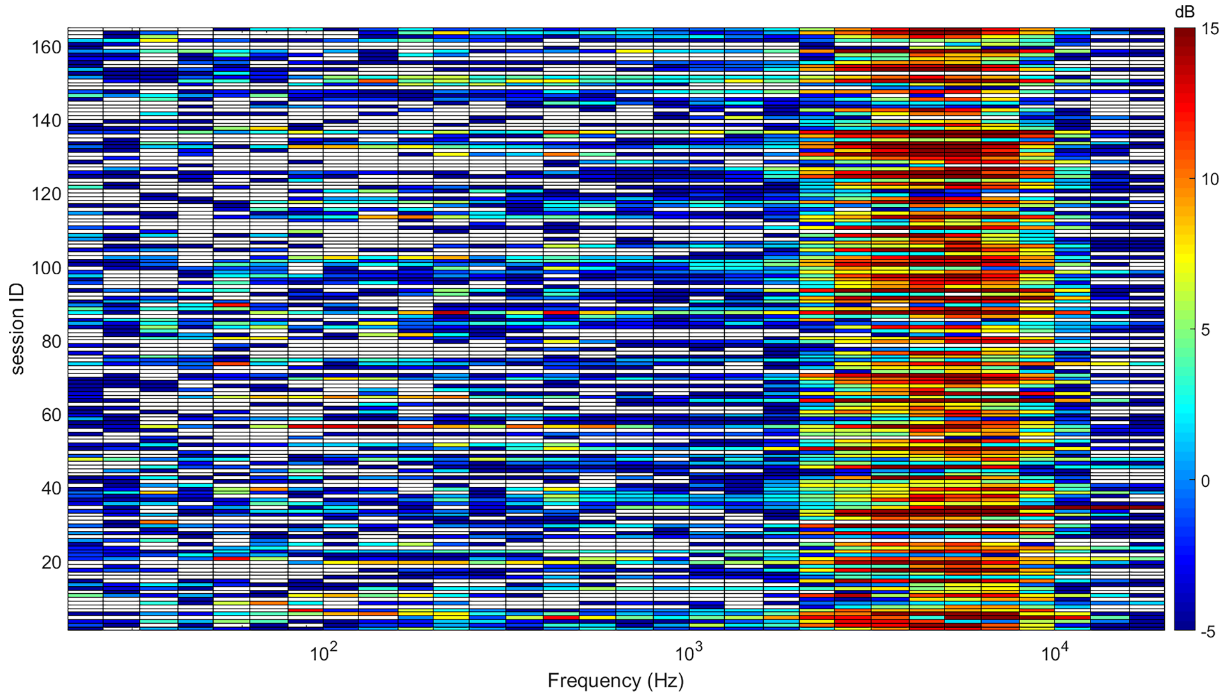

Fig. 9. Spectral signal-to-noise ratio (SNR) of the preferred natural sounds composition relative to the background noise, for each of the retained sessions. The white patches indicate 1/3 octave bands for which a SNR could not be determined due to variation in background noise level.

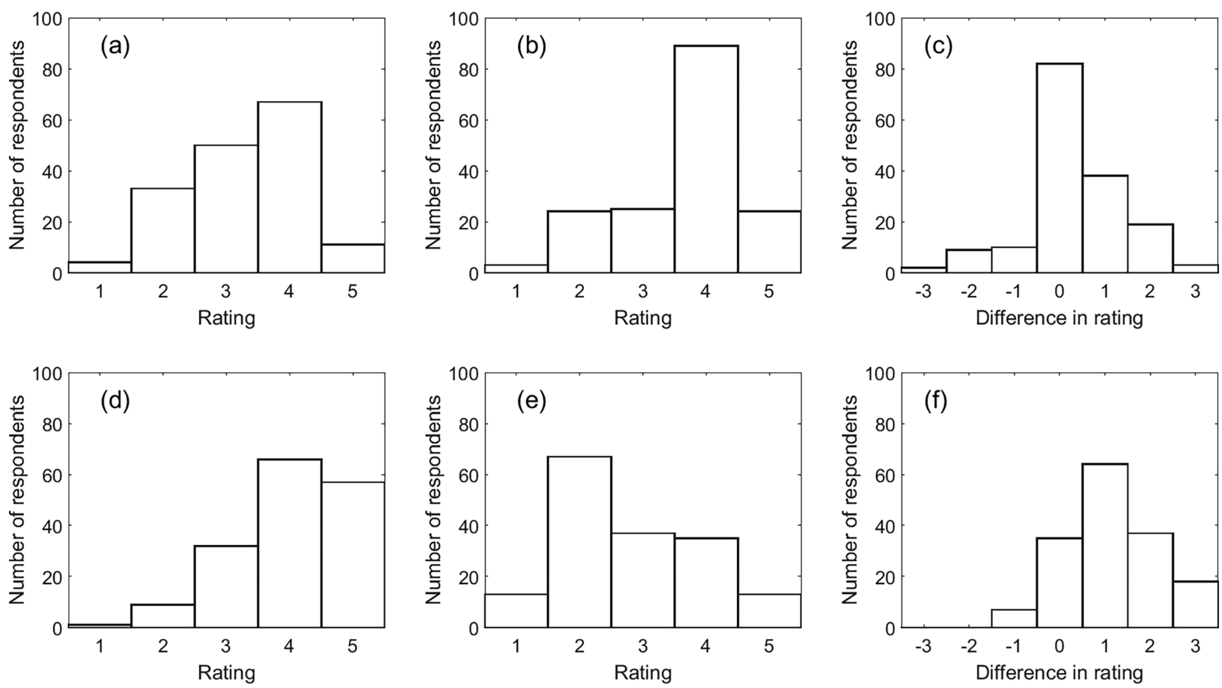

Fig. 10. The histograms in the upper row deal with the overall rating of the acoustic environment (see Q1, Table 2): (a) background/reference situation, (b) augmented soundscape, (c) pair-wise difference between (a) and (b). In (c), positive values indicate an improvement in the overall rating of the sonic environment, negative values a worsening relative to the reference situation. In the bottom row, the data for hearing road traffic are depicted (see Q4 – road traffic noise, Table 2): (d) background/reference situation, (e) augmented soundscape, (f) pair-wise difference between (d) and (e). In (f), positive values indicate that road traffic noise is less heard while playing the augmented soundscape relative to the background case, negative values that road traffic noise is better heard.

rating equal to 4 ("good"), a tendency to a slight average decrease (-0.19) in rating is observed, although not statistically significant anymore at the 5% level. It can thus be concluded that augmented soundscapes especially improve the rating when the reference situation is perceived as negative, and thus for those where it is actually most needed. In case of a neutral or more positive rating, further improvements are limited or absent.

The full potential of improving the overall appreciation of the sound environment might be somewhat undervalued in the current approach of presenting a soundscape composed by someone else. Nevertheless, as shown in Section 3.2, there is some consistency in the preferred soundscapes over all the participants. The deviation from the preferred (own) composed soundscape, and the one exposed to while evaluating, is quantified by the root-mean-square difference between the volume

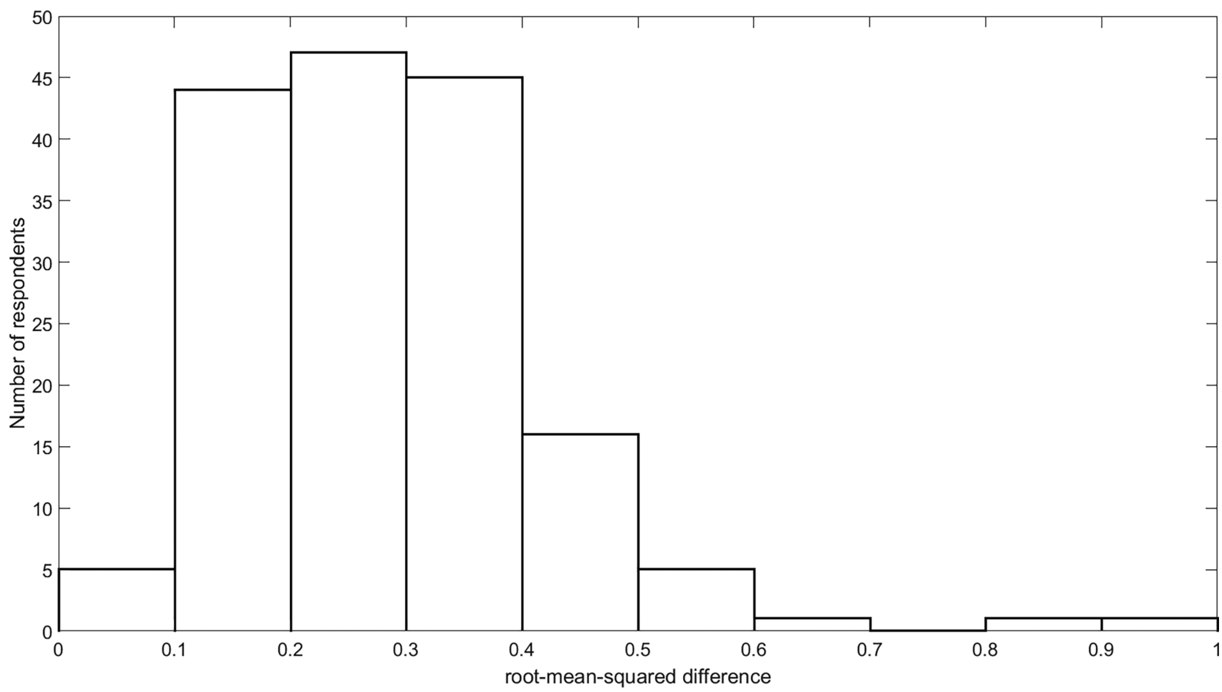

Fig. 11. Histogram showing the root-mean-squared difference between the volume settings of the eight natural channels heard during evaluation of the soundscape-augmented park environment, and the own composed soundscape.

settings in both situations (see Fig. 11). The mean value of this quantity is 0.29.

3.4. Masking potential of the natural soundscapes

The dominant noise source near and inside the park is clearly road traffic noise: 75% of the respondents answered (Q4) that they heard at least "a lot" of road traffic noise, so the masking potential of the augmented soundscapes towards this source is of main interest. The distributions of the degree to which road traffic noise is heard in the reference situation, in the soundscape augmented situation, and their pairwise difference, are depicted in Fig. 10. A similar quantitative and linear mapping is performed as for the general appreciation question (see Section 3.3) as indicated in Table 2.

Overall, the augmented soundscape results in a shift of 1.22 units (t_{164} = 14.16, [1.05 1.39], $p < 0.001$) to less hearing road traffic noise, showing its strong masking potential. With increasingly hearing road traffic noise in the reference situation, the masking potential of the augmented soundscape becomes stronger. At rating 3 ("moderately" hearing road traffic noise in the reference situation), the shift amounts to 0.75 units ([0.51 0.99], t_{31} = 6.3, $p < 0.001$); at rating 4 ("a lot"), 1.29 units ([1.04 1.54], t_{65} = 10.26, $p < 0.001$); at rating 5 ("dominates completely"), 1.63 units ([1.31 1.95], t_{56} = 10.23, $p < 0.001$).

For the other sound sources (see Table 2), less clear results are obtained, probably since these types of sounds are much less present. The category "other sounds" are slightly less heard (0.42 units, [0.27 0.58], t_{164} = 5.41 $p < 0.001$) in presence of the soundscape.

Less obvious is the finding that human voices were significantly better heard when the augmented natural sounds were played (1.25 units, [1.06 1.45], t_{164} = 12.48, $p < 0.001$). A possible hypothesis is that auditory processing capacity in the human brain, fully occupied by road traffic noise in the reference case, becomes available by diverting attention away from the traffic noise. This statement is backed up by the fact that road traffic noise negatively impacts cognitive performance in people (Schlittmeier, Feil, Liebl, & Hellbrück, 2015) and allocates part of the finite attention in animals (Chan, Giraldo-Perez, Smith, & Blumstein, 2010). At the other hand, natural sounds could lead to attention restoration (Abbott, Taff, Newman, Benfield, & Mowen, 2016). Anyhow, more research is needed to confirm the finding that human sounds are better heard when natural sounds appear in tandem with road traffic noise. Note that human sounds, in general, have the potential to strongly attract attention due to the degree of implication of the perceiver as discussed by Viollon et al. (2002) and Guastavino (2006). However, this does not imply that hearing voices in a park leads to an increase in noise annoyance, as shown by Brambilla, Gallo, and Zambon (2013)

3.5. Attention drawing and disruptiveness

As can be expected, while playing soundscapes, more attention was drawn to the sound than in the reference case. However, its mean effect is rather modest (0.50 units on a linearly mapped answering scale, see Q3 in Table 2, [0.33 0.68], t_{164} = 5.64, $p < 0.001$) as shown in Fig. 12. Sound being more foregrounded does not necessarily mean that a worse soundscape is obtained. Especially in the case of foregrounded natural sounds, their relaxation potential (Alverson et al., 2010) for the park visitors might be enhanced. As discussed by Van Renterghem (2019), natural sounds could support the visual aspect of green regarding its stress reduction and attention restoration potential.

About 68% of the respondents stated that the sound they experienced did not or only slightly influenced their planned activity in the park (in the reference situation, see Fig. 12). The presence of the soundscape had almost no impact on this self-reported activity disturbance assessment ($p = 0.56$). This could potentially be explained by the rather limited residence time in this park, since most visitors just walked through the park to the other end to reach their destination.

4. Conclusions

An interactive smart phone driven app was developed to study the potential of augmented natural soundscapes (in an artificial way) in a road traffic noise polluted urban park. The natural sound samples were carefully chosen based on literature on human preferred sounds, ensuring a sufficient diversity in their spectro-temporal properties. Most

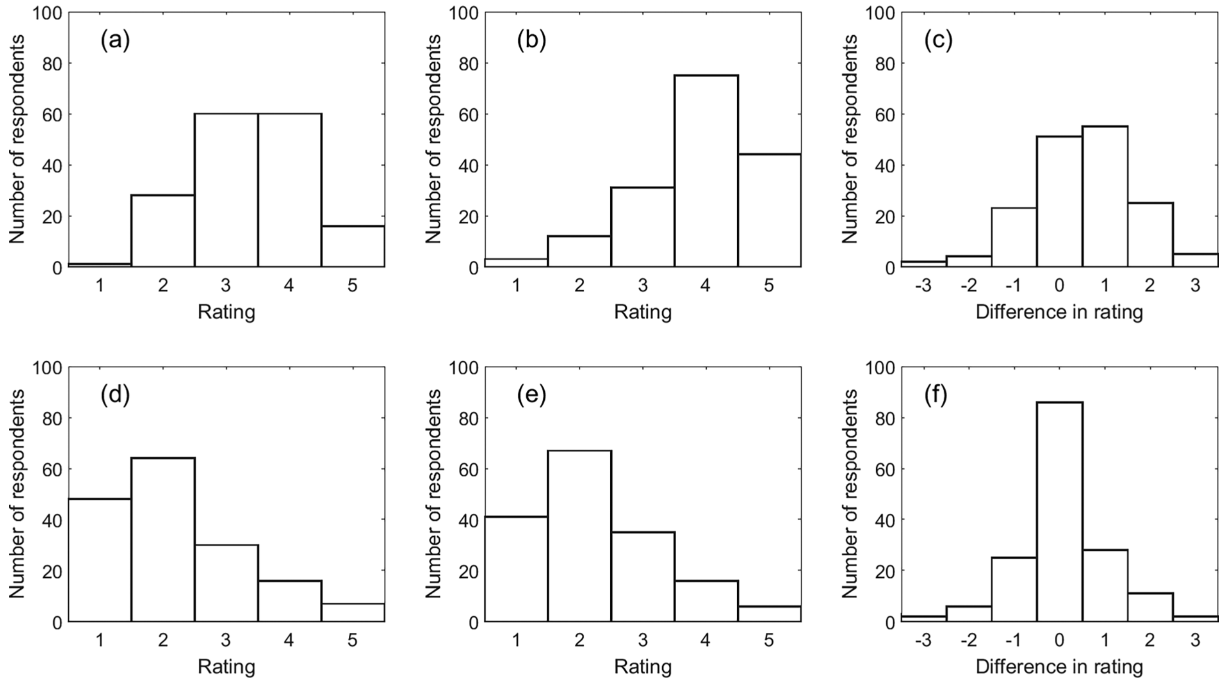

Fig. 12. The histograms of the answers to Q2 (upper row, related to "attention") and Q3 (bottom row, related to "disruptiveness"). in (a) and (d) the reference situation is evaluated, in (b) and (e) the augmented soundscape. Pairwise difference distributions are depicted in (c) and (f). Positive differences in (c) mean that more attention is paid to the sound, and larger disturbance of the planned activity in (f).

participants were actively recruited on-site, from which 165 sessions were retained based on completeness of the answers and based on an assessment of the motivation of the participant by analyzing user statistics logs.

Most people like a balanced combination of various types of natural sounds, with a clear preference for bird sounds (more precisely "house sparrow" and "song birds mixture") in the current setting. Most of the added acoustic energy ended up in the frequency range between 2.5 kHz and 8 kHz, where people seem to consistently maximize the signal-to-noise ratio relative to the background noise.

Such composed soundscapes, even when they deviate from the own preferred one, are able to improve the general appreciation of the sonic environment, especially for park visitors that rated the reference situation as poor. In addition, the augmented natural soundscapes were able to strongly mask the dominant road traffic noise, which was then declared to be less heard.

5. Strengths and weaknesses

For the first time, a fully interactive natural soundscape augmentation method is proposed, tested and evaluated in real life. The current application shows a lot of potential to improve the sound experience in the many urban green spaces exposed to high levels of road traffic noise. More in general, the ICT-based approach proposed in this work could be promoted as a methodology to improve urban public spaces.

Valuable information was gathered on how such augmented natural sounds should look like in a real setting. Although not specifically studied here, audio-visual interactions are inherently accounted for. The findings at least suggest that congruency between the sounds played and the visual environment is important, and should be kept in mind when the current results are to be extrapolated to other environments.

The current experiment focused on natural sounds only. Artificial sounds such as light or ambient music were not considered to confine the current experiment. Especially in an urban park in a city centre, such sounds could be appreciated (Steele et al., 2019), but might also provoke negative reactions following e.g. the survey by Guastavino (2006). Their preference, relative to natural sounds in an urban park, is not known and needs further studies.

The true purpose of the experiment, namely the focus on sound, was revealed to the participants from the very beginning. This might bring the attention to an aspect of the environment most people are less aware of, although it also affects them e.g. through chronic stress reactions (see e.g. Westman & Walter, 1981; Lercher, 1996; Fritschi et al., 2011). The importance of sound exposure in the overall park experience in the current case could therefore not be explicitly assessed.

A consequence of the limited number of personal questions posed, although clearly justified in the intended unmanned experiment, is that no diversification between people could be made. E.g. noise sensitivity (see e.g. Job, 1999; Heinonen-Guzejev et al., 2005), connectedness to nature (Mayer & McPherson-Frantz, 2004), and audio-visual aptitude (Sun et al., 2018) all might play a role in the efficiency of improving the sonic environment by playing natural sound samples through loudspeakers.

The current experimental setup uses a single loudspeaker only. Although the current speaker was hidden from sight, multiple (synchronized) speakers could further increase the impression that sounds actually arose from natural sources. In addition, moving closer to the true envelopment of environmental sounds could then be achieved.

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Appendix A

In a preliminary test, the sound pressure level spectra were measured (with a type-1 sonometer, see Fig. 13) as actually played by the loudspeaker near the location of the info panel where participants are expected (see Fig. 1 (b), "ad-hoc SPL measurements"). This is done for each channel separately, at maximum volume, during one minute. The background noise spectra were measured just before and just after this playback (during each time one minute as well).

Although there is some inevitable short-term variation in background noise level, each natural sound sample has distinct frequency bands higher than the background noise level. Note that also at negative signal-to-noise ratios, sounds can potentially still be heard (see e.g. Oldoni et al., 2013 and Hong et al. (2017) for listening tests with natural sound samples). These measurements thus show sufficient flexibility for users to play with the volume of the channels.

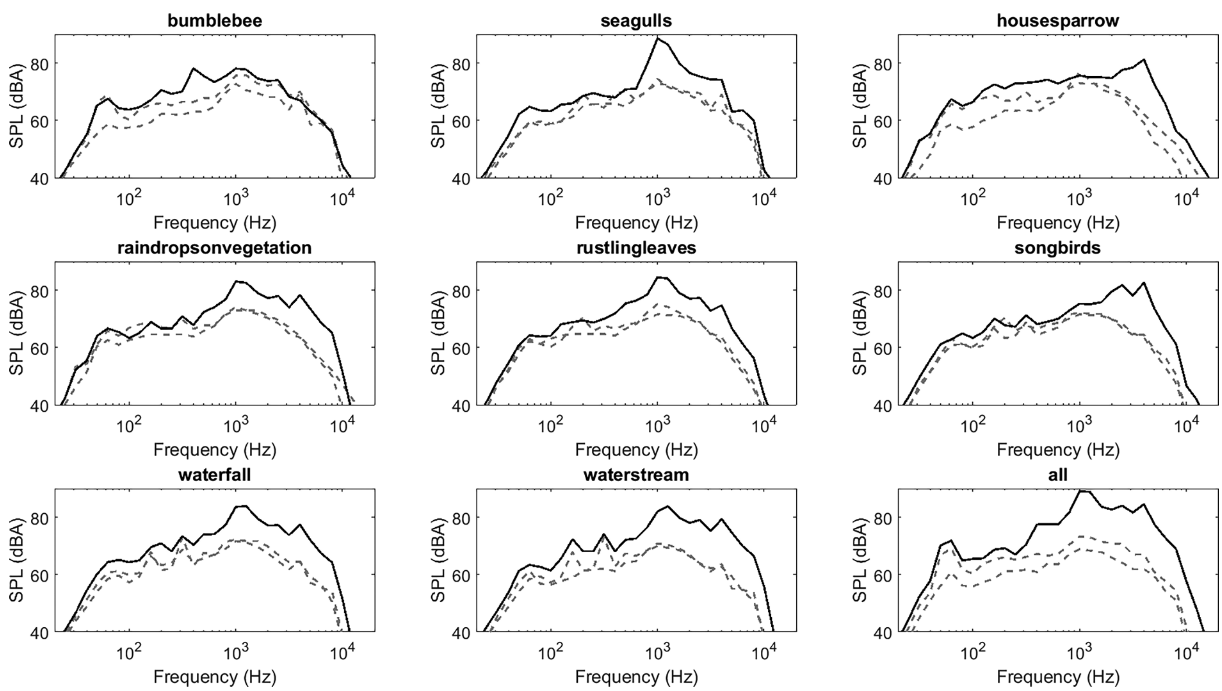

Fig. 13. Measured sound pressure level (SPL) spectra near the info panel (see Fig. 1 (b)), with each channel separately at maximum volume (full lines). The dashed lines are the background noise levels just before and just after the natural samples were played. The last figure (right bottom) are the spectra with all samples playing together at maximum volume.

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