Soundscape characterisation of two motorway service areas

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Abstract
Since the European Noise Directive, noise mapping and actions plans are now part of everyday language for those managing transport infrastructures. These instruments are targeted to year-long exposures in dwellings near the infrastructure: after entering the motorway, passengers and drivers give up agency on their soundscape, which is decided by the vehicle's sound insulation. Service areas are an exception: they are effectively part of the motorway, and thus not controlled by legislation, but users expect from them a restorative soundscape, which is rarely offered. In this work, we present a set of measurements taken in two service areas near Florence. We characterise them in terms of energy levels, semi-structured interviews, and more advanced perception-focused indices, highlighting the potential limitations of classical methods. Finally, we discuss potential restorative actions and their impact on users.

Keywords: soundscapes, short-term, indicators, service areas.

1 Introduction

First recognised by the European Noise Directive [1], quiet areas play a key and irreplaceable role in our modern life: they offer respite from the acoustic siege to which we are exposed, since the early days of the industrial revolution. Queit areas can be found even in the open countryside [2]....but not everywhere. When entering a motorway, drivers give up the agency on wanted/unwanted sounds they may have at home: energetic levels that would be intolerable elsewhere become a "necessary pain". With time, regulation (EU) No 540/2014 [3] will progressively reduce the amount of traffic sounds reaching the drivers in passenger vehicles, but access to quiet areas would be highly desirable, also on a motorway. A possibility in this direction is offered by service areas: with other facilities, they could also offer them a restoring soundscape.

In this work, we describe a field survey carried out in two service areas near the Italian city of Florence, in Tuscany. During the survey, we used both sound level meters (fixed and mobile ones) and semi-structured interviews, to acquire a complete characterisation of their soundscape, both in terms of acoustic climate and perception-focused assessments.

It is nowadays quite common, for the characterization of the soundscape in a certain area, to refer to a combination of quantitative and qualitative elements [4, 5, 6]. Examples of the former are the geometrical characteristics of the area and its acoustic climate. Examples of the latter are the individual aspects of perceived sounds, as assessed in a specific spatial and temporal context. In this study, we present a preliminary exploration on how the different parameters interact in places where users tend to stay as little as possible (see below), and of how this knowledge may be used to improve the soundscape in motorway service areas.

2 Experimental campaigns

In this work, we will refer to the current definition of “soundscape", as it appears on ISO 12913-1 [7]: “a soundscape is an acoustic environment as perceived or experienced and/or understood by a person or people, in context". This definition was crucial in determining the two locations for this study: since we were looking for two different soundscapes under the label "service area", we sought for two places having different context (e.g. sound sources beyond motorway traffic), but also, potentially, two different user groups.

“Arno Est", our first choice, is a classical motorway service area. It is located on the A1 motorway, along one of the busiest motorway stretches in Italy: far from urban centres, but very close to the motorway. A high-speed railway (see Figure 1a) is the other key source of sounds in the area. The station is relatively large, with two different restaurants and shower-equipped toilets, with plenty of parking for both light and heavy vehicles. This means that Arno Est has a very varied user base, including families and truck drivers, and a fairly continuous flow throughout the day and the year. Nevertheless, peaks in user presence can be observed throughout the day, in correspondence of meal times [8] and visitors typically stay longer than 30 minutes.

“Peretola Sud" is also located along the A1 motorway, but where the latter joins the A11 motorway: a main way for commuters towards the centre of Florence. The location is close to urbanised area of Sesto Fiorentino, with various productive activities nearby (see Figure 1b). Florence International airport (“Amerigo Vespucci") is the other key source of sounds in the area. Peretola Sud is frequented mainly by drivers of passenger cars and light commercial vehicles and much less frequently by truckers, partly because of the absence of a restaurant inside and the very limited presence of parking spaces for heavy vehicles. Visitors are therefore mainly commuting workers, on their way to Florence, who generally stop for breakfast and for short periods of time. A quick search online confirms that the average customer stops for no longer than 15 minutes and that the busiest time of day is between 7.00 and 10.00 in the morning [9].

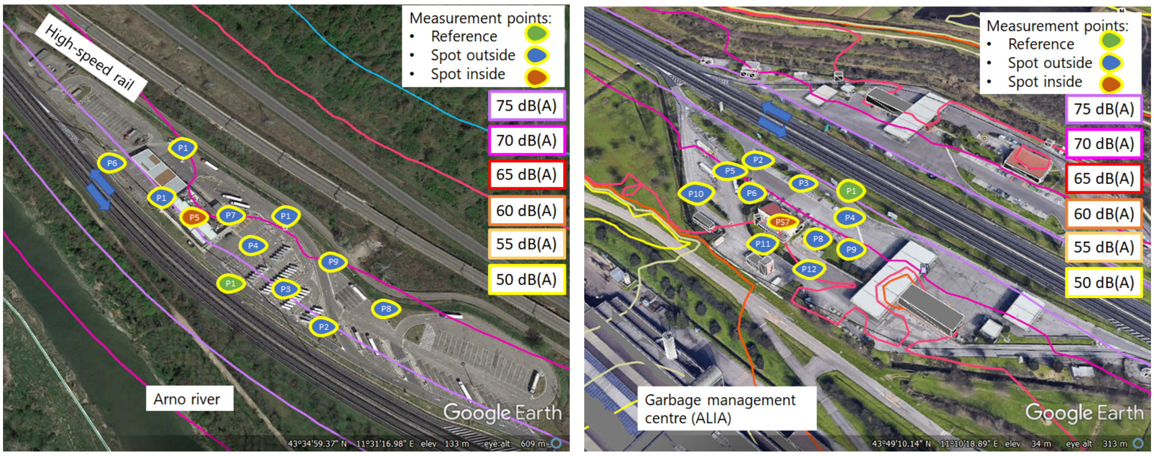
We visited each station twice, in the months of May and July 2021. On the first visit, the areas were mapped with microphone measurements to calculate acoustic indicators. This part of the study consisted mainly of mobile measurements (30 min), with a synchronous continuous monitor (8 hours) used as a reference “acoustic clock". The information from the first visit was used to plan the second one, which was focused on capturing users’ perception and potentially the “non-acoustic" factors that influence the experienced soundscape. This was done using semi-structured interviews (15-20 min), while a continuous monitor was used to check potential changes in the acoustic climate between the two visits[1].

2.1. Acoustic measurements

The acoustic monitoring in each service area was carried out using a fixed monitoring station (also known as “continuous reference") located near the motorway and two mobile measurement stations (“spot" measurements). Both in Arno Est and Peretola Sud, the positions of the spots were selected taking into account the noise map (courtesy of Autostrade per l’Italia through MOVYON) and proceeding radially away from the continous reference monitor (see Figure 1). When different positions were available, the positions for the spots were selected with the second survey in mind - i.e. in areas where human activities would be expected to be higher, in the second visit (e.g. playground, smoking area, pic-nic area, parking area).

The spot measurements were carried out using two portable sound level meters (model 870, by 01dB), mounted on a tripod at 1.5 m from the ground at at least 1 m from any other reflecting surface. The reference measurements were carried out using the same sound level meters (model 870 by 01dB), but mounted in monitoring stations with the microphone at 4 m from the ground. In all cases, the microphones were protected with a windproof cap and the instrumentation chain had been recently calibrated for Class 1 [12]. In all cases, the calibration was checked within ±0.5 dB at the start and at the end of the day with a portable calibrator (model

[1]This was necessary to take into account potential weather effects on sound propagation, but also that the state-imposed rules for lockdown changed, in Italy, between the two visits. In particular, during the first visit the Florence area was affected by a curfew from 10 PM to 5 AM, which was not present in July.



(a) Arno Est (b) Peretola Sud

Figure 1: Visualisation of the two service areas in this study. The pictures also show the noise mapping contours (in terms of L_{DEN}, obtained from Autostrade per l'Italia [10], the main sources of sounds in the areas (e.g. the railway in Arno Est, the garbage treatment plant in Peretola Sud) and the locations of the measurements. Maps were obtained from Google Earth [11].

CA200 by 01dB). Each of the service areas included a spot measurement indoor (e.g. near the restaurant tables), which will not be discussed in this study.

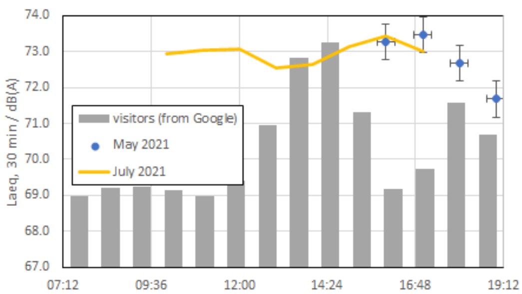
2.2. Results of the measurement campaign

Figures 2a and 2b report the energetic level registered by the reference monitor as function of time, respectively for Arno Est and Peretola Sud. In particular, the points reported in the graph refer to the periods of time when a spot was simultaneously being measured (during the first visit), while the continuous line summarises the $L_{Aeq,1h}$ recorded by the monitor during the second visit. In both cases, very little difference can be observed in the values recorded by the monitor.

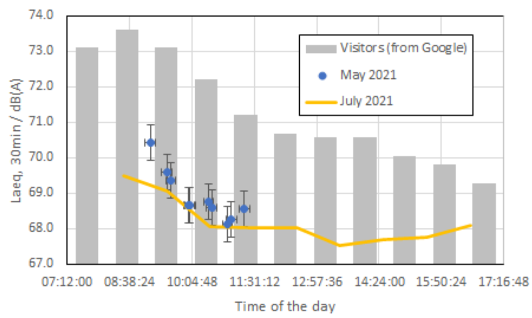
It is worth noting that in Peretola Sud the energetic levels follow the number of visits (as reported by Google [9]), confirming that most of the visitors arrive at breakfast time. This is not true for Arno Est, where the energy levels measured by the fixed monitor peak when the number of visits recorded by Google [8] is at its minimum. This may be because of the delay between the arrival recorded by Google and the delay in leaving the services (e.g. truck drivers are actually travelling after lunch hours).

In both cases, however, the energy level measured by the monitor - ($L_{day} = 72.8 \pm 0.5$ for Arno Est and $L_{day} = 68.8 \pm 0.5$ for Peretola Sud) - was much lower than the one appearing in the noise map. This could be due to a difference between the indicators: since L_{DEN} penalises the acoustic emissions recorded in the evening and at night, in locations affected by motorway traffic (which tends to be constant over the day and the evening), the additional weighting always gives $L_{DEN} \geq L_{day}$. Another possible reason could be the decreased number of vehicles in circulation at the time of measurements (i.e. due to the local pandemic rules). One fact to support this latter hypothesis is that the energy levels decrease more quickly than expected from a linear source i.e. the level decreases quicker than what expected from the linear approximation used to obtain the noise map contours. This is particularly noticeable in Peretola Sud (Figure 2d), where the energy levels decrease by 13 dB when the noise map would suggest a reduction of less than 10 dB instead. However, since no significant change was observed in the energy levels in July 2021, after the local lockdown had been relaxed, this hypothesis was parked, waiting for further investigations.

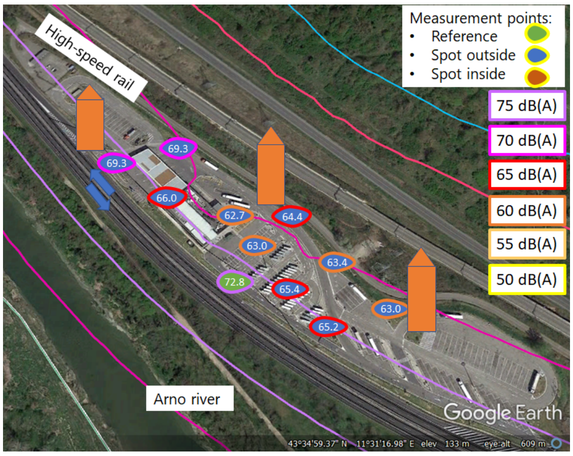
In Arno Est (Figure 2c), the levels clearly show a more complex acoustic climate, since they decrease towards the centre of the services to increase again getting close to the high-speed railway and to the parking space for heavy vehicles.



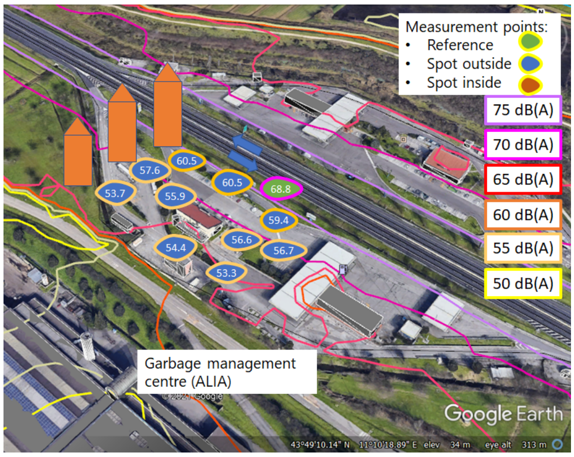
(a) Arno Est, reference



(b) Peretola Sud, reference



(c) Arno Est, spots



(d) Peretola Sud, spots

Figure 2: Results of the acoustic measurements: (a,b) values at the reference position as a function of time and (c,d) spot results, reported as if they were simultaneous. Also shown in (a,b) is the relative presence of customers at each service station, as reported by Google Maps [8, 9]. (c,d) also report the values of the Harmonica index [13]. The colours on the side refer to the noise map contours of L_{DEN}, but have also been used in (c,d) to colour-code the measurements values. .

Figures 2c and 2d also report the value of the Harmonica index relative to investigated areas. Harmonica is one of the many indices that have been developed after the European Noise Directive to bridge the gap between time-averaged energy levels and user perception, taking into account background noise and occurrence of events. As it can be seen, even if there is a significant decrease in energy levels, Harmonica gives approximately a constant value across each service area i.e. $H_{AE} = 5.5 \div 6.2$ for Arno Est (with the minimum in the parking area for heavy vehicles) and $H_{PS} = 5.0 \div 6.3$ for Peretola Sud (with the value decreasing with increasing distance from the motorway). It is worth noting that, while Harmonica has no proven correlation better than dB levels with perception, this indicator has been voted as much easier to understand that dBs and successfully used to map road traffic in urban areas [14]. According to Harmonica, then, the two service stations are therefore very similar.

2.3. Semi-structured interviews

In order to capture the visitor's perception of the soundscape, we designed a questionnaire to run semi-structured field interviews. It was inspired by the one proposed by Fields et al. in 2001 [15], but with some key differences. The questionnaire that guided our interviews contained indeed the standard questions to describe the interviewee (e.g age, gender, education, perception of noise at home, self-assessed sensitivity), common to most experimental psychology studies, but also investigated whether the participant had auditory disturbs or was particularly interested in music. Moreover, all the wording “noise" in [15], was substituted with “sounds" to avoid biasing the participants (as suggested by ISO 12913 [7]). In addition, all the questions were designed for word-based 5-points Likert scales (e.g. “Never", “Very Rarely", “Rarely", “Occasionally", “Very Frequently", “Always" for frequency questions), as this type of scales is deemed more appropriate than 11-point numerical ones for in-person interviews. Finally, interviews were designed to last no longer than a successful marketing or fundraising interaction (i.e. 15 minutes, according to the Market Research Society [16]). Last, but not least, our interaction was designed to contain two listening experiences: one to identify and assess the sources present in the soundscape and the other to place unwanted sounds in the context of the other potential critical points during a visit to a service area (as identified by MOVYON). The study was approved by the local ethics committee (at Sussex) and 30 interviews were collected for each site.

3.1 About the users

Figure 3 summarises the demographics of the 30 interviews collected in Peretola Sud (Questions 1-6). The numbers show that we managed to collect responses from most age groups, with a prevalence of males (83%). Most of the participants had at least concluded high school (83%) and the majority (57%) declared to be “very" or “extremely" sensitive to noise. Similar results were obtained from the 30 interviews in Arno Est (77% males, equally distributed among the age groups), where all the participants had at least a high-school degree and only 37% declared to be in the top two notches of the noise sensitivity scale. From the demographics, the two groups (30 users each) were therefore similar, with a slightly more sensitive sample in Peretola Sud.

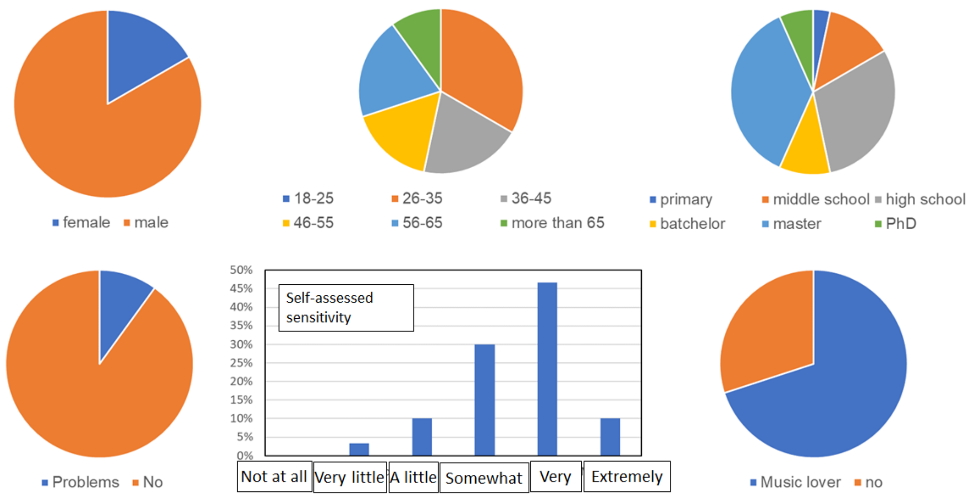


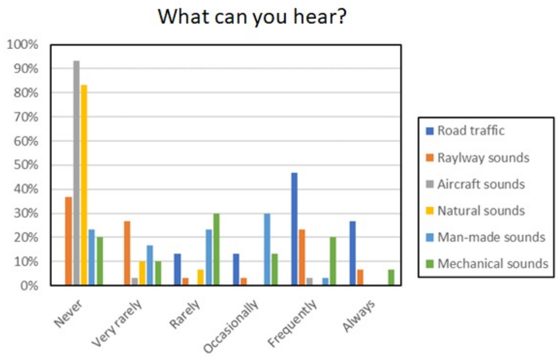
Figure 3: Demographics for Peretola Sud (from top-left to bottom right): gender, age group, education, auditory problems, self-assessed sensitivity and relationship with music. .

The differences between the two user groups, however, started to appear when we asked how much time the interviewee normally spent in a service station and how much of that time was spent outside (Questions 7-9). In Peretola Sud, 57% of the participants in the study shared that they would spend “less than 15 minutes" at the services, with 37% spending “between 15 and 30 minutes". In Arno Est, an equal number of the respondents would spend either “less than 15 minutes" (40%) or “between 15 and 30 minutes" (43%), with all the others (17%) planning a visit “between 30 minutes and 1 hour". Considering that, in both cases, most respondents would not want to spend more than 50% of their time outdoor (e.g. for smoking a cigarette) and that 30 minutes is the minimum for a quick lunch or dinner, this difference seems to confirm the information we had on the user base of the two service stations when we selected them: Peretola Sud is mostly active at breakfast, while Arno Est also collects customers for longer stays.

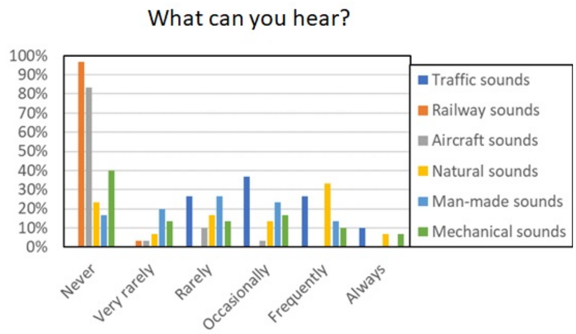
In this study, we will not discuss the attitude reported by the participants towards the presence of unwanted sounds at home (Questions 16-19).

3.2 About the soundscape

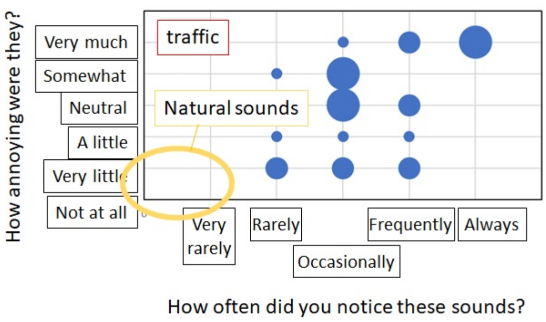
At this point in the interview (Question 10) the participant was asked to listen to the different sources in the soundscape. Since the start of soudscape research [17], listening whas been a key activity for the classification (and the enjoyment) of soundscapes, so we felt it was crucial to have this aspect in our evaluation. Due to time constraints and the need to respond to users potentially staying for only 15 minutes, it was not possible to fit a soundwalk in our interview, even if these exercises have become a practical and widespread way to evaluate soundscapes [5, 18]. We therefore asked, following [15], how much different sources were present in the soundscape and how much “annoying or bothering" they were[2].



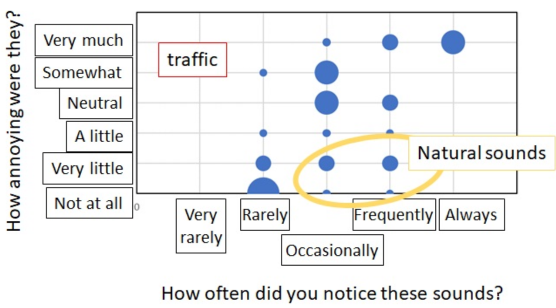
(a) Arno Est, detected sound sources



(b) Peretola Sud, detected sound sources.



(c) Arno Est, judgments on the sources.



(d) Peretola Sud, judgement on the sources.

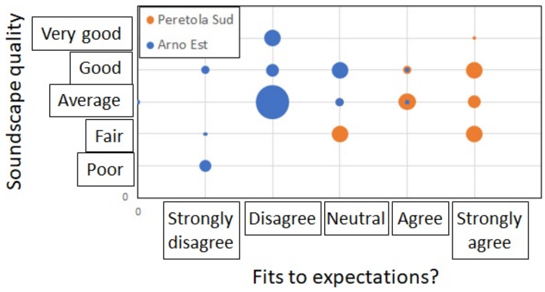
Figure 4: Results of listening experiences in Arno Est (a,c) and Peretola Sud (b,d) in terms of sources noted (a,b) and of judgment on these sources (c,d). The bubble plots (c,d) represent with the size of the bubble the number of answers in a specific combination (e.g. the people saying that traffic sounds were “always" noticed and were “always" annoying or bothering them was bigger in Arno Est than in Peretola Sud). .

The results can be found in Figure 4. In Arno Est, traffic sounds dominate perception, followed by “mechanical" sounds and “railway" sounds (Figure 4a), with natural sounds almost not present. In Peretola Sud, the second source most detected (after “traffic") was instead “natural sounds" (Figure 4b), with only 1-2 persons reporting aircraft sounds from the nearby airport. Focusing on the sounds from traffic (Figures 4c and 4d), they were found to be more annoying in Arno Est than in Peretola Sud.

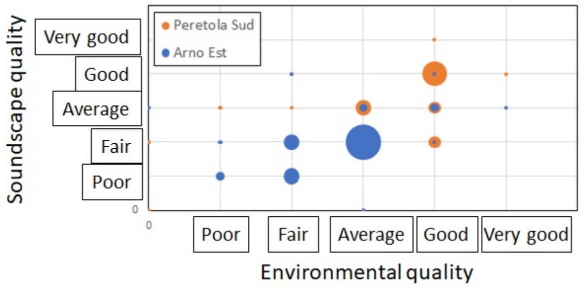
Following the listening experience, interviewees were asked to give an overall judgement of their experience (Question 11: “How do you evaluate the quality of the soundscape around you") and to compare it with their expectations (Question 12: “Do you think the soundscape is appropriate for a service area?") and the general environment (Question 13). Expectations are a key aspect of soundscape assessment [19, 5] and it is on this scale that the greatest differences between the two service areas were found.

[2] In translating the classical definition of annoyance into Italian, we removed the word "disturbing", as it is linked better to long-term exposure

As shown in Figure 5a, in fact, while the judgment on the soundscape was almost the same, the expectations of the two user groups were very different: in Arno Est the respondents thought that the acoustic climate did not fit their expectations, while in Peretola Sud our participants could hear the sounds they expected in a service station. The fact that the average soundscape judgement in Arno Est is greater than the average one in Peretola Sud (see 5a) suggests that our listeners may have been pleasantly surprised by the soundscape in Arno Est. A component of this result was the average judgement on the general environmental quality, which was above “average" in Peretola Sud and just below ‘average" in Arno Est (see Figure 5b.



(a) Perceived soundscape vs. Expectations



(b) Perceived soundscape Vs. General Environment.

Figure 5: Questions following the listening experiences: soundscape assessment vs. expectations (a) and vs. a judgement on the general quality of the environment (b). .

3 Discussion

In this paper, we have used measurements and semi-structured interviews to capture the soundscape in two service areas, which proved to be different both in terms of acoustic climate and user base. With our study, we have already highlighted the limitations of dBs and the opportunities offered by perception-focused surveys, but the point is that both these instruments have been designed for capturing impressions over the soundscape which have developed over long-term. Even if there is some evidence that 16 minutes are sufficient to develop an acoustic judgement over a soundscape [20] and there are different attempts to capture acoustic perception “there and then" (see e.g. [21] and [22]), there is not an established way to capture short-duration acoustic perception yet.

This challenge was even stronger in this study, where (e.g. in Peretola Sud) we expected the average visit to be long 15 minutes or less. We decided therefore to solve this impasse by forcing an interaction between the users and the surrounding acoustic environment, lasting at least 16 minutes (i.e. our structured interviews). This choice was reinforced by running two listening experiences within the semi-structured interviews (the first typically at minute 5 and the second at minute 14) and by taking measurements lasting at least 30 minutes. The complementary analysis of measurements and questionnaires gave a more comprehensive picture of the soundscape in the two selected areas.

Our study highlighted how visitors minimise the time they spend in service areas and particularly outdoor, where the soundscape is potentially compromised by exposure to traffic sounds. If service areas want to offer restoring quietness to drivers, their soundscape needs to be improved. The design of actions in this direction, however, depends on the unresolved (but crucial) link between objective measurements and semi-structured interviews. Part of the challenge is making this link is due to the inherent difficulty of interpreting Likert scales [23], but a much larger part comes from the non auditory factors impacting on acoustic judgements [24]. As our contribution to the design of such action, we would like to share the following line of reasoning:

- First, we calculated the percentage of “highly annoyed" (%HA) by counting for each site the number of people who answered “Very much" and half of the interviewees who answered “Somewhat" [25]. This gave us $\%HA_{AE}$ = 40.5 and $\%HA_{PS}$ = 26.5. While %HA is a biased indicator of perception, it is one that has been studied by many [25].

– Second, we compared the "measured %HA" with the value expected from the energy levels where each interview was conducted, using the curves published by the World Health Organisation in 2018 [25] (see Table 1). This was possible since the measured values only changed within 1 dB(A) between May (1^{st} visit) and July (2^{nd} *visit*). As shown in Table 1, in both service areas the measured value of annoyance is much higher than the one calculated using L_{spot}/dB(A) and the WHO curves. In the case of Peretola Sud, however, the measured %HA was very similar to the one obtained from L_{day}/dB(A), hinting that it is the most energetic sounds that decide how the mostly annoyed classify a soundscape, at least for short experiences and in places where the general environment is pleasant. For this type of users, actions should be focused at reducing the most energetic sounds (e.g. with small places offering respite from intruding traffic sounds).

– Third, we tried to attribute the remaining difference in %HA to non-auditory factors, looking at correlations with noise sensitivity, gender and education, but did not find a sufficiently strong effect. Recent studies, in fact, show that it is the most sensitive that benefit from restorative actions in places near motorways (see [26]).

– Finally, we realised that there was a correlation between lower expectations and higher perceptions of the soundscape (see Figure 5a). Equally, we noticed how positive soundscape experiences were correlated to positive judgements on the overall ecological quality of a site (see Figure 5b).

It is known that the presence of desired sounds, such as natural sounds due to biophony and geophony, is more acceptable to humans than technological sounds and the sounds generated by vehicle traffic [27, 28]. If expectations are therefore key to acoustic judgements, at least for short experiences like the ones in this work, actions to improve the soundscape could be based on the introduction of visual and sound installations eliciting surprise in the users (i.e. masking). Future studies, and a larger number of interviews in different sites, will be needed for more solid conclusions.

Table 1: Comparison of measurements and interviews on the scale of annoyance. Energetic levels refer to the positions of the interviews (L_{spot}/dB) or to the continuous monitor (L_{day}/dB).

Location	"Very much"	"Somewhat"	%HA	L_{spot}/dB	L_{day}/dB	%HA (from L_{day})	%HA (from L_{spot})
Arno Est	17.0%	47.0%	40.5	72.9	65.0	33.0	20.9
Peretola Sud	20.0%	13.0%	26.5	68.8	56.0	27.0	11.0

4 Conclusions

In this work, we have used a combination of measurements and semi-structured interviews to characterise the soundscape in two service areas near Florence (Italy): Arno Est and Peretola Sud. Our study showed that the label "service area" may hide different soundcapes, both in terms of users and context. For this study, we designed an interaction-guiding questionnaire to assess perception for short-term users, which typically stayed at the services for less than 30 minutes. Our questionnaire included a listening experience and the interviews highlighted a key role of expectations in the self-reported acoustic judgements.

Acknowledgements

The study has been funded by a collaboration between Metasonixx and MOVYON. GM acknowledges funding also from the UKRI funded project "AURORA" EP/S001832/1.

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