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Psychoacoustic, Physical, and Perceptual Features of Restaurants: A Field Survey in Singapore.

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Abstract

Sound is a multi-faceted phenomenon and a critical modality in all kinds of servicescapes. At restaurants, our senses are intensively stimulated. They are social places which depend on acoustic design for their success. Considering the large economic interests, surprisingly little empirical research on the psychoacoustics of restaurants is available. Contributing to theory building, this article proposes a typology of designed and non-designed sonic elements in restaurants. Results from a survey of 112 restaurants in Singapore are presented, with a focus on one element of the typology, namely interior design materials. The collected data included on-site sound level, audio recordings from which psychoacoustic descriptors such as *Loudness* and *Sharpness* were calculated, perceptual ratings using the *Swedish Soundscape Quality* protocol, and annotations of physical features such as *Occupancy*. We have introduced a measure, *Priciness*, to compare menu cost levels between the surveyed restaurants. Correlation analysis revealed several patterns: for example, that *Priciness* was negatively correlated with *Loudness*. Analysis of annotations of interior design materials supported a classification of the restaurants in categories of *Design Style* and *Food Style*. These were investigated with MANOVA, revealing significant differences in psychoacoustic, physical, and perceptual features between categories among the surveyed restaurants: for example, that restaurants serving Chinese food had the highest prevalence of stone materials, and that Western-menu places were the least loud. Some implications for managers, acoustic designers, and researchers are discussed.

Keywords

soundscapes; environmental quality; psychoacoustics; perceptual features; interior design; restaurants

Highlights

- We propose a typology of acoustic design elements relevant to restaurants.

- Empirical results from a survey of 112 restaurants in Singapore are presented.
- Correlation analysis revealed relationships between various features.
- Interior design materials supported classifications by *Design Style* and *Food Style*.

1.INTRODUCTION

The introduction reviews articles about restaurant soundscapes published in the recent literature on acoustics and hospitality research, with a focus on those that report acoustic measures. A typology for acoustic design elements in restaurants is then proposed.

1.1.Servicescapes and Soundscapes

The concept of 'servicescape' was introduced by Mary Jo Bitner, referring to “the built environment... the manmade, physical surroundings as opposed to the natural or social environment” (Bitner 1992, p. 58). A more narrow definition has since then emerged, pointing specifically towards hospitality service settings, such as restaurants, shops, commuter areas, lounges, hospitals and so forth. Research into servicescapes considers the multiple factors that affect peoples’ emotions, responses, and behaviours when engaged in hedonic interaction in such environments. Designable physical factors in servicescapes include temperature, lighting, noise, music, and scent. Bitner suggested that the ambient conditions affect the five senses “in purely physiological ways. Noise that is too loud may cause physical discomfort, the temperature of a room may cause people to shiver or perspire, the air quality may make it difficult to breathe, and the glare of lighting may decrease ability to see and cause physical pain. All of those physical responses may in turn directly influence whether or not people stay in and enjoy a particular environment.” (ibid. p. 64)

Sound is a critical modality of servicescapes. Since the 1970s, R. Murray Schafer used the term ‘soundscape’ to refer to all aural fields of study – scientific and creative (often interdisciplinary) – such as soundscape design, acoustic ecology, sound walks, and so forth (Schafer 1994, Truax 2001, World Soundscape Project 1999). As Berglund, Nilsson, and Axelsson (2007) pointed out, soundscapes are complex perceptual phenomena. It is possible to simultaneously have positive and negative perceptions of a sonic environment, or rather, aspects of it. Perception depends on expectations, preferences, mood, and current activities. While we react physiologically to some aspects of soundscapes in ways determined by our biological setup (Lindborg 2013), other aspects are dealt with in cognitive, individual ways, yet predictably moderated by personality traits (Lindborg, submitted).

1.2.Restaurants

In Bitner’s classification scheme, ‘restaurants’ are characterised as offering “interpersonal services... of elaborate physical complexity”. She stressed the importance of considering how environmental factors affect the well-being of employees as well as customers, and found that managers might control the physical surroundings but frequently lacked an understanding of their impact on people. Her call for wider

application of environmental psychology was echoed by Novak, La Lopa, and Novak (2010), who claimed that hospitality researchers have paid too little attention to how the physical environment of servicescapes influences the customers' emotional responses. The empirical evaluation of soundscape quality in restaurants and how it affects the overall experience of patrons has only recently started to be addressed.

Restaurants are intensively social places. Their design is subject to competing requirements. They need to attract customers; and so they have large windows towards the street or open doors towards the shopping mall in which they are located, leaking in external noise. They need to give an impression of cleanliness; so floors and tabletop materials are hard and acoustically reflective. Managers and waiters need to scan the tables; so there are few wall partitions to absorb sound and provide lateral first reflections. Sometimes, customers want a 'vibrant atmosphere' where appropriate music mixes with voices into an agreeable din; so there is a rationale for reverberant acoustics (cf. 'metabolic environments', discussed in Hellström 2003, 2011). Other times, customers seek calm to digest the beautiful food or privacy for a spoken conversation. Whatever the expectations are, restaurateurs must get return on their investment, and therefore depend on their customers being overall pleased with the experience; so that they may appraise positively and display return behaviour (cf. Musinguzi 2010, Novak et al. 2010).

Considering the large economic interests that depend on successful restaurant design, and Bitner's constructive call twenty years ago for more attention to multi-sensorial responses to servicescapes, including sound, there are surprisingly few published studies that report objective acoustics. For a long time the basic measurement (often the only one considered) has been Sound Pressure Level (SPL, in dB *re* 20 μ Pa), typically A-weighted and averaged over time (e.g. LAeq_{3m}). Most researchers agree that this descriptor on its own is insufficient to predict perceptual responses to complex sonic environments, and several others that aim to describe amplitude variation and aspects of timbre have been proposed (cf. Nilsson 2007, Hall et al. 2013, Fastl & Zwicker 2007). Nevertheless, LAeq remains a fundamental descriptor, and provides a way for comparing sonic environments historically. In our review, we have identified six articles that report on-site sound levels in restaurants:

- Lebo and co-workers (1994) recorded average noise levels in 27 restaurants around San Francisco in the range LAeq = {59...80} dB, with peaks ("noise crests") at 87 dBA "in some of the restaurants" (ibid. p. 46).
- A study by Sweetow and Tate (2000; quoted in Novak et al. 2010) reported exposure levels of LAeq_{8h} = {50.5...90} in five restaurants "ranging from a noisy bistro to a quiet restaurant/bar" (ibid. , p. 199) at unspecified locations.
- Rohrmann (2003) took acoustic measures in twelve cafés and restaurants in Melbourne and found levels to be in the range LAeq_{1...3m}) = {56...85} dB.

- Investigating ten bars, cafés and restaurants in Wellington, Christie and Bell-Booth (2006) found that the highest sound level, in a restaurant, was = 81 dB.
- Rusnock & Bush (2012) surveyed 30 bars and restaurants in Florida and recorded “15-20 random instantaneous sound level readings” (ibid. p. 110) at each place. They found eight with “maximum levels above 85 dBA” and practically all the rest in the range between 75 and 85 dBA .
- Frid (2013) included multiple acoustic measures in her investigation of 31 restaurants in Stockholm (cafés, lunch restaurants, and fast-food places). She found sound levels in the range $L_{Aeq} = \{62.7 \dots 82.4\}$ dB, and the average across all locations was 73.7 dBA.

A detailed comparison between these results is difficult since the methods used were not always reported and might have been different. Peak sound level has little informative value on its own, though together with L_{Aeq} and range may indicate the distribution of sound levels. There are anecdotal reports of average noise levels in contemporary restaurants and cafés at 80 dBA or higher, accompanied by claims that generally rising volume levels are due to managers seeking a “hip and boisterous ambiance” (Anderson 2008; see also McLaughlin 2010). Recall that Schafer and his collaborators documented a long-term trend of SPL increase of 3 to 5 dB per decade in traffic noise levels and sirens (Schafer 1994, p. 185-6). Is the same thing happening in restaurants? The published data do not rule out a long-term increase in restaurants, but the records are too sparse to firmly support this assumption. .

It is appropriate to recall the texts of law concerning workplace safety and health. For example, the regulations in Singapore and in USA, which are practically identical in this regard, state that the employer must take certain actions when there are indications of an employee’s sound exposure exceeding $L_{Aeq_{8h}} = 85$ dB (OSHA 2008, MoM 2011). In Europe, the limit is lower, 80 dB (European Parliament 2003). As sound levels go up, regulation limits go down. Such limits are minimal requirements that some audiologists consider insufficient. In Singapore, Noise-Induced Deafness (NID) has been the most prevalent occupational disease for many years, accounting for ~80% of cases, and with significant year-on-year increases. While ministries have shown a willingness to stimulate awareness and engagement with the private sector, empirical acoustic measurements are not part the policy publications (ibid; also MoM 2007). One important aim of the present work has been to provide data from a fairly large sample of restaurants.

1.3.Acoustic Design

Building on earlier research (Bitner 1992, Muller & Woods 1994, Rohrmann 2003, Hellström 2003, Ertzberger 2009, Musinguzi 2010), we have drafted a typology of acoustic design elements that have a bearing on restaurant soundscapes. It has provided a theoretical framework to guide our ongoing

investigations. Firstly, a distinction was made between non-designed sound sources and designed physical elements and sources. Sounds within the ‘non-designed’ category are those beyond the awareness and/or control of restaurant managers and interior designers. They were classified according to origin: technological, human, or natural (Nilsson 2007), and furthermore, as intermittent or continuous. Within the ‘designed’ category, distinctions were made between maskers (acoustically active, sound-emitting sources though not perceived as such), enclosures, and attenuators (acoustically passive, physical elements). Secondly, each type of element was considered as located either inside or outside the restaurant itself.

Table 1 charts the typology, with examples of typical elements. In a real restaurant, the soundscape might be complex and the different design categories not easily delimited. For example, it could be argued that ‘chairs scraping the floor’ is a source of technological origin, or that ‘caged birds’ are elements of musical design, i.e. an imitation of nature rather than nature itself.

Section 2.4 of the present article focusses on interior design materials, which fall under “designed, passive” in the typology. In parallel, other ongoing work focus on “non-designed, technological, point-like” elements, and “designed, active, music” elements.

*** Table 1 about here ***

1-typology-acou-elems-resto.numbers

Bitner (1992) pointed out that certain materials can communicate cues to establish the character of a restaurant. Besides creating an overall aesthetic impression, the quality of interior design materials have symbolic meaning. Restaurant managers know that hard floors signal cleanliness, and thick curtains intimacy. White table cloths symbolise service and higher prices, and plastic furnishings symbolise casual dining and lower prices. Christie and Bell-Booth (2006) noted that the finishings in practically all their surveyed premises were acoustically reflective. Rusnock & Bush (2012) remarked that contemporary restaurants typically have an open layout, causing noise from the kitchen and bar to spill over into the dining area. They also noted a prevalence for bare surfaces, with few textiles such as carpets, draperies, or linens. Their general impression was that few restaurants made efforts to dampen noise levels with interior design materials. Frid (2013) annotated design materials in her survey and found that glass walls and facades were common, as were tile floorings. Wooden materials were more often used in cafés and lunch restaurants than in fast-food places. Moreover, cafés were associated with textiles, while only hard materials and hard chairs were used in the fast-food places.

1.4.Aims

To sum up, servicescapes are complex physical environments, created to stimulate our multiple senses. While there is some research on sound levels, qualitative assessments of restaurant soundscapes and their influence on the experience have not been made. The effect of materials on room acoustics is known, but the actual prevalence of these materials in restaurant design is not.

This situation urged us to investigate restaurants in Singapore, asking: *How important is the soundscape to the experience of the whole environment? Are prices and noise levels related? Considering their acoustic impact, which interior design materials are common? What differences are there between various types of places: for example, between fast-food and table-service restaurants, between cheap and expensive places, or between places serving Western and Asian food?* We performed a broad survey aiming to shed light on these questions, and to provide empirical data to serve researchers in further work.

Section 2 of this article describes the procedure of the survey, with results and analyses that are briefly discussed. Section 3 is a conclusion of the main findings.

2.SURVEY

The survey was designed to collect recordings and acoustic measurements from a large number of restaurants, together with annotations about physical features and perceptual quality ratings.

2.1.Procedure

The author and his students individually visited 118 restaurants between 17 August and 9 December 2012. The author collected data from 20 locations, using an ANSI Type 2 compliant and calibrated Sound Pressure Level (SPL) meter (Extech 407790) to record un-weighted integrated SPL, i.e. LZeq. Simultaneously, uncompressed and un-filtered audio recordings were made using a high-quality microphone (CoreSound Tetramic to SoundDevices recorder) and low-cost equipment (Edirol R-09) in parallel. A- and C-weighted SPL were obtained computationally from the audio recordings (W omni channel) using the program Psysound3 (Cabrera 2014, Cabrera et al. 2008), taking the corresponding LZeq as the calibration level for each case.

Students collected data from 98 locations (~5 each). They were free to choose any five or so places, as long as their selection was reasonably varied in terms of price, style, and location. At least one had to be a ‘table-service dining restaurant’. The ambient noise level was measured on-site with a method similar to that described by Rusnock & Bush (2012, p. 110). Over a period of one minute, ten readings on a low-cost SPL meter (Galaxy Audio CM-130 ‘Check Mate’) were recorded at approximately regular intervals, with

‘Slow’ response setting and A-filter weighting. This was followed by another set of ten readings using the C-filter weighting. The dB-averages of these readings were taken as estimates of $LAeq_{1m}$ and $LCeq_{1m}$, respectively. Simultaneously, an audio recording was made with an Edirol R-09.

A separate test of the reliability of the estimates obtained by this method was made in studio. Recordings of the 20 restaurants collected by the author were played back using high-quality loudspeakers (Genelec 8030, 7050A) at the $LZeq$ level recorded on-site. He then estimated $LAeq_{1m}$ and $LCeq_{1m}$ with the method described above. The results suggested that $LAeq$ estimates were on average 1.5 dB lower than the reference $LAeq$ (calculated as in Section 2.2.2), while $LCeq$ estimates were typically less than 1 dB too low. These discrepancies were considered acceptable for the survey. Furthermore, the mean difference between (on-site) $LZeq$ and (calculated) $LCeq$ across the 20 restaurants was 1.0 dB, representing the amount of acoustic energy attenuated by the C filter. Therefore, $LZeq$ estimates for the student-collected locations were obtained by taking (on-site) $LCeq_{1m} + 1.0$. These values were used in the calculation of psychoacoustic descriptors (see Section 2.2.2). The method allowed us to use low-cost equipment in this project. While it can be improved upon, we believe that the estimates are acceptable within the context of an exploratory survey.

Each collector filled out two protocols on site: one for annotations and one for perceptual ratings. The annotations included observations about the following physical features:

- *Location* [“Name, Address, Date, Time”];
- *Situation* [“Indoors / Outdoors / Comment (unusual location etc) / Weather (e.g. rain)”];
- *Food Style* [“Chinese / Indian / Japanese / Other Asian (specify) / Italian / American / Other Western (specify)”];
- *Design Style* [“Restaurant / Coffee house / Canteen / Hawker / Bar / Buffet / Other (specify)”];
- *Prices* [“Average set meal (or typical menu) / Coca Cola / Alternative typical item & price (specify)”];
- *Physical Environment* [“Number of chairs or stools (i.e. estimated maximum capacity) / Number of people (currently at location & within sight) / Architecture & materials (free-form)”].

For perceptual ratings we used the *Swedish Soundscape Quality Protocol* (SSQP; Axelsson et al. 2011), which employs 5-point Likert scales anchored by adjectives (e.g. from “disagree completely” to “agree completely”, from “very good” to “very bad”, and so forth) covering four aspects of soundscape perception:

- *Sonic Quality* [“Overall, how would you describe the present surrounding sound environment?”];
- *Visual Quality* [“Overall, how would you describe the present surrounding visual environment?”];
- *Sound Source* [“To what extent do you presently hear the following 5 types of sounds? (Traffic noise, Fan noise, Other noise, Sounds from human beings, Natural sounds)”];

- *Qualia* [“To what extent do you agree with the 8 statements below on how you experience the present surrounding sound environment?... pleasant, exciting, eventful, chaotic, annoying, monotonous, uneventful, calm”]. The label ‘qualia’ does not appear in the original publication and is used here for convenience.

In their work on soundscape perception, Axelsson et al. (2010) used factorial analysis to reduce 116 adjectives to a model with the eight listed above, which are considered as equidistant and equally strong semantic concepts. Scores for *Pleasantness* and *Eventfulness* are given by:

$$\text{Pleasantness} = \sum R_{\text{Adj}} * \cos(2\pi * N_{\text{Adj}}/8)$$

$$\text{Eventfulness} = \sum R_{\text{Adj}} * \sin(2\pi * N_{\text{Adj}}/8)$$

where R_{Adj} is a vector of ratings $\{0...1\}$ on the one-dimensional scales and N_{Adj} is a whole number $\{0...7\}$ corresponding to the adjective’s index in the list. Scores can be in the range $\{-2.41...2.41\}$.

Six locations were discarded due to missing SSQP ratings (4 out of 118) or incorrect recording settings (2). One missing recording (Edirol battery failure) collected by the author was replaced by a stereo reduction of the corresponding ambisonic recording. Apart from this single case, all analysed audio was recorded with identical equipment and settings to produce recordings of homogenous and reasonably high quality. From each location, the author selected a representative excerpt of 60 seconds duration, free of any audible artefact (e.g. microphone handling noise). In nine cases, excerpts between 58 and 30 seconds were accepted.

2.2.Results

The collection process produced a random sample of 112 Singaporean restaurants. The methods for processing the data are outlined in this section, with results given in tables. The analysis was made in three parts: first, by pair-wise correlations (Section 2.3); then, by restaurant categorisations and annotations of design materials (Sections 2.5 and 2.6); and last, by multiple analysis of variance between categories (Section 2.7).

2.2.1.Location and Categorisations

In regards to Location, analysis of the *Time* of visit showed that no weekday was over-represented ($\chi^2(6) = 5.12$, $p = 0.53$ n.s.), and that 90% of the observations made between 8 and 22 hours. Unsurprisingly, the distribution showed modes at ~13 and ~19 hours, corresponding to lunch and dinner.

In regards to *Situation*, more places were indoors (82) than outdoors ($\chi^2(1) = 24$, $p = 0.00$). Weather conditions, in particular rainfall, would be a prominent reason for acoustic differences between indoor and outdoor locations. In the present data, there was only one location where the presence of rain was noted (“drizzle”). Since the rain was barely audible in the recording it was deemed reasonable to include this

location. Anecdotally, it could be noted that the torrential rainfall in the tropics is sometimes so heavy that its impact on the tiled roofs of foodcourts makes spoken conversation impossible.

Food Style and *Design Style* categorisations are discussed in Section 2.3.

2.2.2. Psychoacoustic Descriptors

From the audio recordings were calculated a set of psychoacoustic descriptors (Fastl & Zwicker 2007; cf. Rychtáriková & Vermeir 2013), Hall et al. 2013):

- *Loudness* (N , *sone*) expresses the experience of a sound's intensity. It is related to acoustic intensity and the distribution of energy in the frequency domain.
- *Sharpness* (S , *acum*) is related to the centroid of the sound's frequency magnitude spectrum, and thus to pitch. Loudness has little influence on sharpness.
- *Roughness* (R , *asper*) is related to dissonance, and is mainly determined by the prevalence of relatively rapid amplitude variations. The perception of roughness reaches a peak for modulation frequencies around 70 Hz. Roughness is normally ascribed a negative correlation with pleasantness (Daniel 2009).
- *Fluctuation* strength* (F^* , magnitude; see below) is related to relatively slow audible amplitude variations. The perception of fluctuation strength reaches a peak for modulation frequencies around 4 Hz. The fact that this rate is similar to that of syllables in normal speech is believed to result from biological co-adaptation of speech and hearing functions (Daniel 2009).

The program *Psysound3* (Cabrera 2014, Cabrera et al. 2008) was used to calculate the first three descriptors. *Loudness* and *Sharpness* were given by the Dynamic Loudness Model by Chalupper & Fastl (2002), with values sampled every 0.002 seconds. The algorithm from Daniel and Weber (1997) produced *Roughness*, with values sampled every 0.186 s (fixed by the program).

As for fluctuation strength, the model given by Fastl and Zwicker (2007) refers to pure tones and assumes only one modulation frequency. It is therefore not generally applicable to real-world sounds (Densil Cabrera, personal communication, Feb. 2014). At the time of the analysis, the *Psysound3* implementation of fluctuation strength was being revised. We therefore calculated an estimate using the *mirfluctuation* function of the MIR Toolbox (Lartillot et al. 2013). Its algorithm is similar, except that the excitation levels in Bark bands are expressed in dB rather than sone. Summing across bands, *Fluctuation* strength* is therefore expressed as a relative magnitude, rather than in the Zwicker unit *vacil*. Values were sampled every 0.25 s, in overlapping windows of 1 s duration.

Finally, to facilitate comparison with other studies, the estimate for A-weighted sound level, obtained on-site, was included (cf. Rychtáriková & Vermeir 2013).

From the time-series envelopes, statistics for the 10th, 50th, and 90th percentiles were calculated. For example, $N50$ is the median loudness, $N10$ the loudness exceeded 10% of the time (representing 'loud events') and $N90$ the loudness exceeded 90% of the time ('background'). The difference between 10th and

90th percentiles indicates the variability in a descriptor, and thus N_{10-90} indicates *Loudness Variability* (cf. Axelsson et al. 2010).

Table 2a lists results for the psychoacoustic descriptors.

2.2.3. Prices and Physical Environment

The survey collectors annotated menu prices in Singapore dollars for “Average set meal” (102 restaurants out of 112) and “Coca Cola” (90), as well as an “Alternative typical item” (33). The last type included many various foods and drinks, such as ‘espresso’ and the local specialities ‘chicken rice’ or ‘ice kachang’. In order to make comparisons between these, the perceived costliness of each item was estimated on a 5-point Likert scale (from “cheap” to “expensive”) by five independent raters with local knowledge; their agreement was high (Cronbach’s alpha = 0.89, mean pair-wise correlation = 0.64). The three price estimates (set meal, coca-cola, alternative) were z-transformed separately and then averaged, yielding a variable named *Priciness*, describing the relative cost levels among the surveyed restaurants. This measure is assumed to be important to the perception of how expensive a place is.

The median number of chairs at each location was 100, with 90% of the locations having between 30 and 500 chairs. The median number of guests was 35, with 90% of the restaurants having between 5 and 100 guests. Both of these distributions were positively skewed. In line with earlier research (e.g. Lebo et al. 1994), *Occupancy* was calculated as the reciprocal between the number of guests and the number of chairs. *Occupancy* is assumed to be important to the perception of how crowded a place is.

Table 2b includes results for *Priciness* and *Occupancy*.

2.2.4. Sound Sources and Ratings of Quality

The SSQP ratings of *Sonic Quality* and *Visual Quality* are one-dimensional, as are ratings on each of the five Sound Source scales. *Qualia* ratings can be reduced to yield two measures with higher reliability. In the model by Axelsson et al. (2010), the eight adjectives (*pleasant*, *exciting*, *eventful*, *chaotic*, *annoying*, *monotonous*, *uneventful*, *calm*) are considered as equidistant and equally strong semantic concepts in relation to soundscapes. They can be imagined as spokes 45° apart within a two-dimensional circumplex, so that scores for Pleasantness and Eventfulness are given by the Cartesian coordinates:

$$Pleasantness = \sum R_A * \cos(2\pi * N_A / 8)$$

$$Eventfulness = \sum R_A * \sin(2\pi * N_A / 8)$$

where R_A is a vector of ratings $\{0 \dots 1\}$ on the one-dimensional scales and N_A is a whole number $\{0 \dots 7\}$ corresponding to the adjective’s index, as listed above.

Results for these scores are listed in Table 2b, together with ratings on the five *Sound Source* scales, and the two scales for *Sonic* and *Visual Quality*.

*** Table 2a and 2b about here ***

2a-EAT112-acoustic-mysummary

2b-EAT112-SSQP-pric-occ-mysummary

2.3. Correlation Analysis

The relationships between psychoacoustic, physical, and perceptual features were investigated with correlation analysis. The median values of psychoacoustic descriptors ($N50$, $S50$, $R50$, $F*50$) and on-site $LAeq_{1m}$ (henceforth $LAeq$) were included, together with *Loudness Variability* (N_{10-90}), which Axelsson et al. (2010) had found to correlate with *Pleasantness*.

Each distribution was tested for normality using Shapiro-Wilks test. *Pleasantness* and *Eventfulness* were normally distributed, but psychoacoustic descriptors, *Priciness*, and *Occupancy* were positively skewed. These variables were subjected to power transformation using a Box-Cox method implemented in the R package *AID* (Dag et al. 2012). The transformed variables were approximately normal (Shapiro-Wilk's $W = \{0.98...0.99\}$, $p = \{0.053...0.91\}$), except $S50$, which could not be successfully transformed with this method. This was also the case for the one-dimensional SSQP ratings *Sonic Quality*, *Visual Quality*, and the five *Sound Source* scales.

Pair-wise correlations were then calculated, with Pearson's product-moment correlation r for comparisons where both variables had normal distributions, and Kendall's τ for all others. Kendall's τ is a rank-based correlation statistic with known standard error.

Table 3 shows the cross correlation matrix, followed by a brief discussion of relationships of interest.

*** Table 3 about here ***

3-EAT1-korr0.05.v2

PRINT AS LANDSCAPE!?

2.3.1. Psychoacoustic Descriptors

The correlation between $LAeq$ and *Loudness* ($N50$) was high ($r = 0.82^{***}$) and there were only minor differences in how they correlated with other variables. For practical purposes, $LAeq$ might thus be an

adequate descriptor of loudness (cf. Rychtáriková & Vermeir 2013). *Loudness* correlated strongly with *Roughness* ($r = 0.71^{***}$) and *Loudness Variability* ($r = 0.70^{***}$), which also correlated between them ($r = 0.62^{***}$).

Loudness had positive correlations with *Occupancy* ($r = 0.27^{**}$) and *Human* ($\tau = 0.24^{**}$), and negative with *Nature* ($\tau = -0.20^{**}$), *Pleasantness* ($r = -0.26^{**}$), *Visual Quality* ($\tau = -0.19^{**}$), and *Priciness* ($r = -0.26^{**}$). In other words: in the surveyed restaurants, louder places had rougher sound and larger variations in noise levels. They were more crowded and had more sounds from people than from nature. They were rated as more unpleasant, had worse visual quality, and were less expensive.

2.3.2. Prices and Physical Environment

The correlations between *Priciness* and *Loudness* ($r = -0.26^{**}$), and *Visual Quality* ($\tau = 0.26^{**}$), indicate that expensive places were less loud and had visually better environments. There was a moderately strong correlation between *Priciness* and *Fluctuation* strength* ($r = 0.26^{**}$), and the amount of *Fan* sound sources correlated with *F*50* ($\tau = 0.21^{**}$), but *Fan* amount was not associated with *Priciness*, as might have been expected. This gave rise to the question if another sound source could contribute to fluctuation strength and at the same time be (negatively) correlated with price levels. It is conceivable that vocal communication (cf. Daniel 2009) could do this, but it must be emphasised that fluctuation strength is not a validated descriptor of the relative amount of speech among other sounds sources. In the survey, the correlation between *Priciness* and *Human* was non-significant, indicating that the amount of human-origin sounds was not related to the price level of the restaurants. These intriguing results could be due to some other, unidentified factor that we have not considered. Moreover, we surmise that the *Sound Sources* protocol did not lead raters to distinguish between a background din of voices and a foreground spoken conversation. The former might presumably contribute negatively to quality scores, and the latter positively. Further research is needed to investigate the relation between *Priciness* and non-designed human sources, in particular vocal utterances of different valence, such as loud talking versus laughter.

Occupancy correlated positively with *Loudness* ($r = 0.27^{**}$) and *Loudness Variability* ($r = 0.33^{***}$). Unsurprisingly, it was associated with the amounts of *Human* and *Natural* sound sources and in opposite directions ($\tau = 0.36^{***}$ and -0.26^{***} , respectively). Thus, the more densely crowded places in our survey had noisier and more varying ambiances, with sounds identified as coming from people rather than from natural sources.

Additionally, the association between *Priciness* and *Occupancy* was borderline significant ($r = 0.19$, $p = 0.046^*$) in the survey, which might indicate that expensive places tended to be operating nearer maximum capacity.

2.3.3. Ratings of Quality

Pleasantness was negatively correlated with *Loudness* ($r = -0.26^{**}$) as well as with the amount of sounds from sources identified as *Human* ($\tau = -0.19^{**}$), *Fans* ($\tau = -0.20^{**}$), and *Othernoise* ($\tau = -0.24^{***}$). Thus, pleasant places were less loud and had fewer noises from people and machines. In addition, it was noted that the correlation between *Pleasantness* and *Loudness Variability* (N_{10-90}) was weakly significant ($r = -0.20$, $p=0.033^*$) and in the expected direction, thus lending support to results reported in Axelsson et al. (2010).

The only significant correlation involving *Eventfulness* was with *LAeq* ($r = 0.23^*$). Since the A-filter boosts levels in the 2...4 kHz frequency region, it could be that this measure is more sensitive than *N50* in capturing features linked to *Eventfulness*, such as speech. However, the association was fairly weak ($p = 0.015$) and will not be pursued here.

As expected from earlier results (Lindborg, submitted), *Sonic Quality* and *Visual Quality* correlated strongly ($\tau = 0.41^{***}$), and also with *Pleasantness* ($\tau = 0.46^{***}$ and 0.39^{***} , respectively). A separate test revealed that the restaurants were consistently rated higher on *Visual* than *Sonic Quality* (Wilcoxon signed rank $V = 327$, $p = 4e-06^{***}$), with a medium-sized effect of almost 0.5 standard deviations. This result could indicate that sonic environments generally are worse than visual environments in Singaporean restaurants, or, alternatively, that the raters were more critical to sounds than sights in the surveyed restaurants.

For both kinds of quality ratings, the pattern of associations with other variables were similar. *Visual Quality* correlated with *Human* and *Natural* sound sources ($\tau = -0.21^{**}$ and 0.25^{**} , respectively) as well as with *Loudness* ($\tau = -0.19^{**}$). For *Sonic Quality*, these correlations had the same sign, but were generally weaker.

2.3.4. Sound Sources

The amount of *Natural* sounds correlated with that of *Human* sounds and *Traffic* ($\tau = -0.32^{***}$ and 0.32^{***} , respectively). Also, *Traffic* correlated with *Fan* ($\tau = 0.28^{***}$) and, as we have seen, *Fan* with *Fluctuation* strength* ($\tau = 0.21^{**}$). In other words, restaurants tended to be dominated either by a mix of traffic and nature sounds, or by human sounds.

2.4. Summary and Discussion of the Correlation Analysis

To sum up, the correlation analysis revealed patterns of relations between quality ratings, descriptors, and physical features. As for the research question ‘*Are prices and noise levels related?*’, conclusions are at

this point tentative, given that the measure for price levels, *Priciness*, was developed as part of this investigation and further work is needed to validate the approach. The results for the surveyed restaurants showed that less expensive places had higher noise levels. Furthermore, *Priciness* was associated with timbral characteristics of the ambiances, specifically fluctuation strength. This might indicate a higher prevalence of spoken voices in less expensive places, but fluctuation strength can also depend on sound from other sources. Moreover, as discussed in Section 2.2.2, the present study used a non-standard method for estimating fluctuation strength, so this result must be interpreted cautiously. We believe that a measure for fluctuation strength of time-varying, natural sounds (in particular complex soundscapes) has yet to be developed; such a measure would be a valuable contribution.

Of a more general consideration, the reviewed servicescape literature does not clearly state whether prices for food and beverage should be considered a factor that the restaurant manager has control over on par with other servicescape design elements, e.g. lighting or interior design materials (this would make it an independent factor in a regression analysis) or if it is a dynamic factor that, perhaps, reflects the popularity of a place (this would make it a response variable). To investigate this topic further, an analyst might have to work with a more elaborate theory of multimodal restaurant design and branding, that would generate a testable hypothesis related to quality perception.

As for “*How important is the soundscape to the experience of the whole environment?*”, the results showed that ratings of *Visual Quality* and *Sonic Quality* shared patterns of relations with psychoacoustic descriptors and sound sources, but that the latter had weaker correlations than the former. However, both correlated strongly with *Pleasantness* scores. Overall, *Visual Quality* was significantly higher than *Sonic Quality* in the surveyed restaurants. If this is a real effect, it reveals a need to pay more attention to sound in the design of restaurant environments: this is a business opportunity. Conversely, the effect could be due to rater bias. Since the raters were aware that soundscape quality was the focus of the survey, they might have been more critically inclined in this regard. The question of the relative importance between sound and visuals (as well as other sensorial input) might be probed with a factorial experiment design in a VR simulation of restaurants, where auditive and visual aspects of the environment can be modified separately and their contributions to overall quality assessed.

2.5. Analysis of Restaurant Categories

We now turn to the question of how ratings, descriptors, and physical features differ between categories of places. Taking indoor and outdoor *Situation* under one, the analysis involved two classifications, by *Food Style* and *Design Style*.

For *Food Style*, the annotation protocol offered seven *a priori* defined categories (see Section 2.1). As it happened, the annotators frequently chose to be specific, employing in all 32 different attributes for the 112 restaurants. 62% of places were labelled as either *American*, *Chinese*, *International*, *Japanese*, or *Western*. The author grouped places with annotations denoting a mixed yet exclusively Asian cuisine, e.g. "Chinese, Malay, Indian", in a new category *OtherAsian*, and places with annotations denoting an East-West crossover menu, e.g. "Chinese, Indian, Western" or "International" in a new category *MixFusion*. The single places labelled as *British*, *Canton[ese]*, *Dim Sum (Hong Kong)*, *French*, *Fusion*, *Indonesian*, *Italian*, *Korean*, *Local*, *Mix[ed]*, *Thailand* and *Vietnam[ese]* could easily be sorted into these broader categories. This yielded a revised classification by *Food Style* in four categories: *Chinese* (22 places), *MixFusion* (31), *OtherAsian* (23), and *Western* (37). They were of similar size ($X^2(4) = 5.9$, $p = 0.12$ n.s.).

For *Design Style*, the 112 places were originally annotated as: *Bar* (3 places), *Buffet* (4), *Canteen* (10), *Coffee or Tea House* (25), *FastFood* (11), *FoodCourt* (2), *Hawker* (19), *NightMarket* (1), and *Restaurant* (37). It was found reasonable to merge *FoodCourt* and *Hawker* since these are essentially synonyms referring to a south-east Asian version of the "multi-unit Quick Service Restaurant" (Muller & Woods 1994; however, the historical necessities that gave rise to the Asian food court are likely to have been different). The single place annotated *NightMarket* was put in this category. Under *Canteen* appeared several fast-food places on the University Campus, often part of a franchise as down-town places categorised as *FastFood* (for example MacDonaldis); this provided a rationale for merging these two categories. Note that there is a clear difference between a foodcourt and a fast-food place. While the former contains several small food vendors (called 'hawkers') spread out around a central, common eating area with tables, the latter is run by a single company. Finally, *Bar* and *Buffet* were merged and 'Restaurants' were re-baptised *Dining* to avoid confusion. This yielded a revised classification by *Design Style* in five categories: *Bar&Buffet* (7 places), *Café* (25), *FastFood* (21), *Hawker* (22), and *Dining* (37). The first category contained a smaller sample than the others. Excluding it, the four others were of similar size ($X^2(3) = 6.2$, $p = 0.10$ n.s.).

See Table 4 for an overview of the number of places in each category. Note that the contingency table does not have cells of similar size ($X^2(12) = 33$, $p = 0.000$); for example, hawker stalls could never be entirely 'Western', although they often include a 'Western Food' stall. Therefore, separate analyses were made (cf. Christie & Bell-Booth 2006).

*** Table 4 about here ***

2.6. Interior Design Materials

While the categorisation by *Food Style* was based on observations of menu items, the categorisation by *Design Style* was based on observations of the physical environment, specifically architecture and materials. One research question was ‘*Considering their acoustic impact, which interior design materials are common in restaurants?*’, and the collectors had been instructed to make free-form notes of elements which could be suspected to have an influence on room acoustics. Their annotations were analysed with a quantitative linguistic analysis approach using functions in the *R* package *koRpus* (Michalke 2011). First, irrelevant words (e.g. “it”, “and” and so forth) were excluded, and plurals were collapsed with singulars. Then, alternative spellings were corrected manually. This yielded a list of 592 single-word annotations, out of which 78 were unique and meaningful attributes in this context. The most common were: *table* (80 times), *chair* (73), *plastic* (61), *wood* (58), *floor* (25), *concrete* (22), *wall* (20), *glass* (17), *tile* (15), *furniture* (9), and *laminated*, *marble*, *metal*, and *steel* (8). In this analysis, the focus was directed to words indicating the materials used, and therefore words describing furniture, eating utensils, and physical dimensions of the room were discarded. This left 30 unique terms, used 255 times in total, which the analyst clustered into six types: *Plastic* (*plastic, fiberglass*), *Wood* (*wood, plywood, laminated, chipboard, rattan, parquet*), *Stone* (*concrete, stone, pillars, rock, brick, ceramic, tile, marble*), *Glass* (*glass, glasspanel*), *Metal* (*metal, steel, aluminium*), and *Textile* (*canvas, cloth, curtain, carpet, sofa, parasol, cushion*). The two remaining terms (*sand, beach*) only appeared in the *Bar&Buffet* category and were excluded.

Figures 1a and 1b show the frequencies of annotations of materials in restaurants by *Food Style* and by *Design Style*. Note that *Plastic*, *Wood*, and *Stone* were more common overall than *Glass*, *Metal*, or *Textiles*.

*** Figure 1a about here ***

MATERIALS FOOD

*** Figure 1b about here ***

MATERIALS STYLE

2.6.1. Regression onto Categories

The relationships between frequencies of materials and the categorisations were investigated with multinomial logistic regression using a neural net approach and the *R* package *nnet* (Venables & Ripley

2013). This technique can be understood as an extension of binomial logistic regression to cases with more than two levels of a categorical response variable. The method compares the vector of predictors between all the pair-wise combinations of the levels of the response. The corresponding multiple Wald tests for pair-wise dichotomous differences is similar to Tukey's Honest Significance Difference test, but for the case of a multinomial instead of a continuous response variable.

Results for the multinomial logistic regression of six materials onto *Design Style* revealed no significant differences between *Bar&Buffets*, *Cafés*, or *Dining* (there was borderline more *Wood* in *Bar&Buffet* than in *Dining*, with Wald's $z = 1.96$, $p = 0.050^*$). Note that the small category of *Bar&Buffets* had no annotations of *Glass* or *Metal*. Likewise, there were no significant differences between the *Hawker* and *FastFood* categories. Note that *Hawker* places had no *Glass*, and *FastFood* places had no *Textiles*.

Hawkers had significantly more *Plastic* than *Bar&Buffet* ($z = 2.71^{**}$), *Café* ($z = 3.09^{**}$), and *Dining* ($z = 2.73^{**}$) places. They had more *Metal* than *Bar&Buffet* and *Dining* ($z = 2.21^*$). *FastFood* places had more *Plastic* than *Bar&Buffet* ($z = 2.03^*$), and more *Metal* than *Cafés* ($z = 2.00^*$) or *Dining* places ($z = 2.46^*$).

To sum up, there were significant differences between *Design Style* categories in terms of interior materials. Analysis of free-form text annotations revealed that the surveyed restaurants split into two main groups: on the one hand, *Hawkers* and *FastFood* places had more *Plastic* and *Metal*, and on the other hand, *Cafés*, *Dining*, and *Bar&Buffets* had more *Textiles*.

Results for the multinomial logistic regression of six materials onto *Food Style* showed that the amount of *Stone* was significantly higher in places with *Chinese* style than in places where *OtherAsian* or *Western* food was served ($z = 2.06^*$ and 2.16^* , respectively). *Western* food places had borderline less *Plastic* than *MixFusion* places ($z = 1.93$, $p = 0.054$). Note that *OtherAsian* places had no *Glass*.

2.6.2. Predicting Categories from Materials

To further the investigation of the usage of materials in interior design, we analysed if restaurant categories could be predicted directly from the annotations. We followed a method for multinomial prediction described in the IDRE webpages (IDRE 2014), and for cross-validation applied a repeated random sub-sampling approach in order to achieve a more robust assessment of how generalisable such a prediction would be. In cross-validation, first, a subset of the data is used to train a model (in our case the same neural net as described in Section 2.1.1, *nnet*; Venebles & Ripley 2013). Then, a data point outside the training set is taken as input, producing a response by maximum likelihood estimation. If this estimate corresponds with the target (i.e. the known, true value), the prediction is considered 'successful'. For example, after training the model on a subset of the restaurant data, a vector representing the number of

annotations of each material (Plastic, Wood, Stone, Glass, Metal, Textile) at one particular location yielded its most likely *Food Style* or *Design Style*, which would be correct or not. In the analysis, a random sample of 101 restaurants (approximately 90% of all) was used to train the neural net model, and then to predict *Style* in the remaining 11 restaurants. Sub-sampling was repeated 5000 times for each model, and mean prediction success rates were formed by averaging.

This method applied to *Food Style* achieved an overall success rate of 34%, higher than chance (which would be 25%). Success rates were simultaneously calculated for each category separately, with correction for different category size. The model was best at predicting *MixFusion* places (58% of these), then *Western* (47%), and less successful with *Chinese* (9%) and *OtherAsian* places (5%). It was found that the pattern of prediction success changed when sets of smaller numbers of predictors were tested. An exhaustive analysis of all 63 combinations of the 6 predictor variables revealed that many combinations yielded high average prediction rates for *MixFusion* and *Western* places, and much lower for *Chinese* and *OtherAsian* places. This might indicate that the two former categories were more specific in terms of the materials they featured, while the two latter categories featured materials in more random ways. The latter categories might be better characterised by some other materials that the present analysis did not include.

Similarly, applying the prediction method to *Design Style* achieved an overall success rate of 32%, higher than chance (20%). The simultaneous size-corrected success rates for separate categories were highest for *Dining* (47%), *FastFood* (42%), and *Hawker* (34%); and much lower for *Cafe* (6%) and *Bar&Buffet* (0%). The first three might thus be said to have more specific interior design materials than the two latter. However it must be recalled that the number of places in the *Bar&Buffet* category was significantly smaller than in the others. A larger sample should allow better predictions for such places.

To sum up, the categories could be predicted overall from interior design materials alone at higher than chance level. The classifications by *Food Style* and *Design Style*, that had been made on-site and simplified in a previous part of the analysis, were thus supported.

2.7. Analysis of Variance between Categories

To analyse the how psychoacoustic descriptors, physical features, and perceptual ratings vary among the categories, we performed multiple analyses of variance (MANOVA), with *Food Style* and *Design Style* as independent, categorical variables. This investigation had been planned *a priori* and the significance level for each test was set at $\alpha_{2\text{-tailed}} = 0.05$. Results are given in Table 5. Categorisations with significant differences were further explored with Tukey's Honest Significant Difference test for multiple comparisons. The results are discussed below and illustrated in the plots in Figures 2a and 2b.

*** Table 5 about here ***

5-MANOVA-FoodStyle+DesignStyle

2.7.1. Results for the planned comparisons

Psychoacoustic descriptors. In both *Food Style* and *Design Style* categories, there were significant differences for *L_{Aeq}* and *N50*. As seen earlier, these two measures correlated strongly overall ($r = 0.82$). Tukey's HSD test revealed that places in the *Food Style* category *Western* (37 out of the 112 places) were significantly less loud than the others, with a difference of 3.4 sone (for *L_{Aeq}*, the difference was 2.7 dB).

Prices and physical environment. Unsurprisingly, the small group of *Bar&Buffet* places was the most expensive. The HSD tests revealed that it was significantly higher in *Priciness* than *Dining* (difference = 0.45 standard deviations), which in its turn was significantly higher than the remaining three categories ($d = 0.46$ SD). Moreover, the test showed that *Western* places were significantly more expensive than *Chinese* ($d = 0.40$ SD). *Occupancy* did not differ significantly between categories.

Ratings of quality. Neither *Pleasantness* nor *Eventfulness* was significantly different between categories. In terms of *Design Style*, the patterns for ratings of *Sonic Quality* and *Visual Quality* were similar (cf. Section 2.3.3), and there were significant differences between *Design* categories. This is further discussed in Section 2.7.2.

Sound Sources. In terms of *Food Style*, the *MixFusion* category (31 places) stood out for having significantly more *Fan* sounds. In terms of *Design Style*, Tukey's test showed that *Bar&Buffet* places had significantly more sounds of *Nature* origin and fewer sounds heard as *Human*.

*** Figure 2a about here ***

MANOVA BARPLOTS FOOD

*** Figure 2b about here ***

MANOVA BARPLOTS DESIGN

2.7.2. Post-hoc contrasts

Inspection of the barplots revealed two patterns of difference between categories that led to making post-hoc contrast comparisons. Effect size of the difference between group means was calculated with Cohen's d , with pooled standard deviation estimate.

Figure 2a suggested that *Western* places (37 restaurants) were less loud than *Chinese*, *MixFusion*, and *OtherAsian* grouped together (75 places in all). The difference for $N50$ was 3.4 sone (Cohen's $d = 0.51$ SD), and for L_{Aeq} it was 2.7 dB ($d = 0.59$ SD).

Figure 2b suggested that on the one hand, *Bar&Buffet*, *FastFood*, and *Dining* (58 places) could be grouped together, and on the other, *Caf  s* and *Hawkers* (47 places). An "M"-like pattern was evident for $N50$, L_{Aeq} , *Traffic*, and *Fan*, as well as a "W"-like pattern for *Sonic Quality* and *Visual Quality*. For $N50$, the contrast between these two groupings was 4.1 sone, with an effect size of 0.60 SD, and for L_{Aeq} , it was 2.4 dB ($d = 0.55$ SD). For *Visual Quality*, the difference was 0.64 scale steps on the 5-degree Likert scale of the protocol ($d = 0.62$), and for *Sonic Quality*, it was 0.61 steps ($d = 0.58$ SD). For the amount of *Traffic* sounds, the contrast was 0.86 steps ($d = 0.76$ SD). The effect sizes in all cases above can be considered as medium size.

The colour plot in Figure 3 visualises the 112 surveyed restaurants, categorised by *Food* and *Design Styles*. The x-axis represents 'Sound Level' (L_{Aeq} was chosen over $N50$ since it is more familiar), the y-axis represents 'Quality' (calculated as the average of z-scaled *Pleasantness*, *Sonic Quality*, and *Visual Quality* ratings), and symbol sizes are proportional to *Priciness*. Note that larger symbols tend to be found in the upper left quadrant, i.e. the more expensive restaurants in the survey were less loud and more pleasant.

In a final analysis of contrasts, we combined the two groupings that were identified for *Food Style* and *Design Style*, respectively, as discussed above. One group thus consists of *Western Bar&Buffet*, *FastFood*, and *Dining* places (25 restaurants), and the other of *Chinese*, *MixFusion*, and *OtherAsian* places designed in the styles *Caf  s* and *Hawkers* (36 places). The differences between means of these contrast groups were: for $L_{Aeq} = -4.4$ dB (Cohen's $d = 1.02$ SD), for *Quality* = 0.47 ($d = 0.65$ SD), and for *Priciness* = 0.85 ($d = 1.37$ SD). The effect sizes can be considered large for L_{Aeq} and *Priciness*, and medium for *Quality*.

Two ellipses have been drawn in Figure 3 in order to highlight these differences. The radii of the black ellipse represent 95% confidence intervals around the means of L_{Aeq} and *Quality* for the first group, and similarly, the purple ellipse represents confidence intervals around the means for the second.

*** Figure 3 about here ***

4-EAT112-selectfeatures.pdf

IN COLOUR

2.8. Summary and Discussion of the Analysis of Categories

Summing up, the categorisation by *Design Style* and *Food Style* were slightly modified to better capture the on-site observations. To answer the research question ‘Which interior design materials are common in restaurants?’, a lexical analysis of annotations was performed. It revealed that *Hawkers* and *FastFood* places had significantly more *Plastic* and *Metal*, and that *Bar&Buffets*, *Cafés*, and *Dining* restaurants had significantly more *Textiles*. This is in line with Frid’s observations (2013). While *Stone* was a relatively common material in places with *Chinese* food on the menu, *Plastic* was less common in *Western* places.

Several authors have remarked that contemporary restaurant interiors are dominated by hard surfaces and open space architecture (e.g. Rusnock & Bush 2012, Frid 2013), with obvious implications for room acoustics, in particular reverberation time and vocal communication comfort (Rindel 2010). Further empirical research into the relative proportions of interior design materials, taking categorisations into account, might inform predictive models of environmental quality in restaurants.

As for ‘What differences are there between various types of restaurants?’, the analysis revealed significant differences between restaurant categories in terms of *Loudness*, *Priciness*, *Visual* and *Sonic Quality*, and *Sound Sources*. Post-hoc comparisons showed that *Bar&Buffet*, *FastFood*, and *Dining* formed one group, and *Cafés* and *Hawkers* another. The former group tended to be less loud and more expensive, and to have higher quality ratings as well as fewer sounds from traffic and fans.

There was a greater number of features that distinguished among *Design Styles* (both acoustic, physical, and perceptual) than among *Food Styles* (no acoustic differences) in the survey. This could imply that establishing a restaurant’s identity through design is stronger than through food. Note however that *Priciness* differed between categories in both classifications.

3. CONCLUSIONS

This article has presented results from a survey of 112 Singaporean restaurants focussing on the sonic environment. We have employed established methods for psychoacoustic descriptors (such as *Loudness*; Chalupper & Fastl 2002), quality assessment (such as *Pleasantness*; Axelsson et al. 2010), and physical factors (such as *Occupancy*; Lebo et al. 1994).

3.1.Contributions

We have developed a novel method to determine relative *Priciness* in a sample of restaurants. Contributing to theory building, we have advanced a typology of designed and non-designed sonic elements that might be useful for analysing and describing restaurant soundscapes.

Results from the correlation analysis revealed significant associations between psychoacoustic, physical, and perceptual features in the surveyed restaurants. These have been discussed in Section 2.3. The main results were that:

- the louder restaurants in the survey had rougher sound and larger variations in noise levels. They were more crowded, had more sounds from people than from nature, and were rated as more unpleasant;
- the more expensive restaurants were less loud and had visually better environments; and
- the more pleasant restaurants had fewer sounds identified with people or machine sources.

These results indicate that sounds of nature might abate the negative influence of mechanical noises in restaurants, thus lending support to the hypothesis that sound source identification plays a crucial part in the perceived valence of soundscapes (cf. Nilsson 2007, Asutay et al. 2012). Sounds imitating nature, such as recorded bird song or water fountains (i.e. 'biophony simulacra' and 'geophony simulacra'; see Table 1) are often present in servicescapes (cf. Hellström 2003, 2011). It is an open question how effective they are in moderating perceived pleasantness in comparison with actual, real sources, or for that matter, with other sonic design elements. Humans represent another complex source of sounds in restaurants; while a background din of voices might lead to negative appraisal, the occasional laughter and a sustained vocal communication comfort would be positive.

One distinction made in the typology (see Table 1) concerns interior design materials impacting on acoustics. In the survey, this aspect was investigated through a linguistic analysis of free-form "architecture & materials" annotations made on site. A predictive model gave support to the classification in categories of *Design Style* and *Food Style*. Analysis of variance revealed significant differences between categories in terms of loudness, quality, and price levels for both types of classifications.

A post-hoc contrast analysis suggested a simplified classification, with *Bars & Buffets*, *FastFood*, and *Dining* places comprising one group, and *Cafés* and *Hawker* stalls another. More research is needed to investigate this scheme further. It could be that restaurants of the first kind are more elaborate in terms of interior design in general, including acoustic elements, which leads to loudness attenuation and more pleasant environments. While many Western-style fast-food franchises (e.g. McDonalds) have ceiling panels that are acoustically absorbent, Asian-styled hawkers and cafés in Singapore, which might in other aspects be comparable, often employ very basic interior designs that are rarely favourable for acoustics.

Thus, the psychoacoustic and perceptual differences that the present survey has uncovered might be especially pronounced in Singapore.

3.2.Implications and Limitations

Researchers might consider developing the protocol for annotating sound sources used in this study into a more targeted tool for empirical studies of restaurant soundscapes. Such a tool could be implemented on a handheld device and integrate audiovisual data capture, on-board calculation of psychoacoustic descriptors, and ratings of environmental quality, food, and service: a merge of *NoiseTube* (Maisonneuve, et al. 2010, 2014) and *buUuk* (Buuuk 2014).

Our survey of restaurants in Singapore has revealed that less loud restaurants had higher prices, and that higher prices were not associated with lower occupancy (if anything, rather the opposite). Moreover, sonic quality in the surveyed restaurants was significantly much worse than visual quality. For managers and acoustic designers, these findings point to an opportunity. Firstly, there is more room for improvement of the soundscape in restaurants than of the corresponding visual environment. Secondly, a reduction in ambient noise levels is likely to lead to higher environmental quality ratings, both visual and sonic, and might at the same time be a justification for an increase in menu prices. Thirdly, these changes can be made while maintaining, or even augmenting, the level of patronage. This three-point action plan leads not only to more customer satisfaction, but also to larger gross margin: two incentives for managers to make the necessary investments.

The analysis we have presented was based on results from Singapore, which has climatic, cultural, economic, and other specific characteristics. The conclusions are thereby limited in generalisability, and whether they can be extended to other locale remains to be investigated.

In fine, we would like to suggest that a considered selection of interior design materials for restaurant construction and renovation can, in addition to improving the acoustic and visual environment, support the overall perception of the environment in terms of design style and food style, thus strengthening the brand identity of the establishment as a whole.

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Table 1. A typology of acoustic design elements in restaurants.

<i>intention</i>	<i>source</i>	<i>category</i>	<i>inside</i>	<i>from outside</i>
<i>non-designed</i>	technological	broad (spatially and temporally)	HVACs, fans	traffic, railroads, industry
	human	point-like (spatially and temporally)	coffee grinders, dish washers	car horns, aircraft
		voices	conversation, laughter, singing	-
	natural	handled objects	cutleries, chairs scraping the floor	construction work
		biophonies	caged birds	birds, insects
		geophonies	-	wind, rain, waves, streams, thunder
<i>designed</i>	active	music	moozak, live music, biophony simulacra e.g. recorded birdsong	loudspeakers
		informational maskers	pink noise	geophony simulacra, e.g. fountains
	passive	enclosure materials	walls, floors, ceiling	built-up sound barriers, mounds, greenery, forests
		interior design materials	tablecloth, curtains, carpets	

Table 2a. Statistics for acoustic and psychoacoustic descriptors in 112 restaurants. *LAeq* = equivalent A-weighted SPL (dB); *LCeq* = idem C-weighted; *N50* = median *Loudness* (*sone*); *S50* = median *Sharpness* (*acum*); *R50* = median *Roughness* (*asper*); *F*50* = median *Fluctuation** strength (magnitude, see Section 2.2.2; *N*₁₀₋₉₀ = ‘loudness variability’, the difference between 10th and 90th percentiles of *Loudness* envelope; *S*₁₀₋₉₀ idem of *Sharpness*; *R*₁₀₋₉₀ = idem of *Roughness*; *F**₁₀₋₉₀ = idem of *Fluctuation** strength.

	<i>LAeq</i>	<i>LCeq</i>	<i>N50</i>	<i>S50</i>	<i>R50</i>	<i>F*50</i>	<i>N</i> ₁₀₋₉₀	<i>S</i> ₁₀₋₉₀	<i>R</i> ₁₀₋₉₀	<i>F*</i> ₁₀₋₉₀
<i>mean</i>	70.2	76.1	20.8	1.27	0.0527	38	6.97	0.268	0.0707	9.52
<i>SD</i>	4.74	4.41	6.81	0.084	0.0097	11.6	3.42	0.0815	0.0193	3.26
<i>median</i>	70.3	76.2	19.5	1.26	0.0524	34.7	6.2	0.26	0.0657	8.79
<i>min</i>	57.3	66.5	8.91	0.935	0.0319	22.6	1.82	0.148	0.0402	4.17
<i>max</i>	81.9	88.6	49.8	1.53	0.0911	88.9	26.4	0.885	0.169	21.1

Table 2b. Statistics for physical features and perceptual ratings in 112 restaurants. For *Priciness* and *Occupancy*, see Section 2.2.3. Perceptual ratings as in the *Swedish Soundscape Quality Protocol* (Axelsson et al. 2011).

	<i>Priciness</i> (bx)	<i>Occupancy</i> (%)	<i>Pleasantness</i>	<i>Eventfulness</i>	<i>Sonic Quality</i>	<i>Visual Quality</i>	<i>Nature</i>	<i>Human</i>	<i>Traffic</i>	<i>Fans</i>	<i>Other noise</i>
<i>mean</i>	1.42	52	-0.13	0.21	2.90	3.42	1.28	3.85	1.83	2.20	3.09
<i>SD</i>	0.46	96	0.66	0.63	1.01	1.09	0.63	0.90	1.22	1.17	1.30
<i>median</i>	1.38	38	-0.141	0.271	3	4	1	4	1	2	3
<i>min</i>	0.00	2	-1.79	-1.51	1	1	1	2	1	1	1
<i>max</i>	2.53	100	1.45	1.73	5	5	4	5	5	5	5

Table 3. Cross-correlation matrix for multimodal measurements in 112 restaurants, showing statistics (Pearson's r or Kendall's tau) with associated probability (** $p < 0.001$, * $p < 0.01$, * $p < 0.05$). For clarity, only correlations with $p \leq 0.05$ are included. $N50$ = Loudness, $S50$ = Sharpness; $R50$ = Roughness; $F*50$ = Fluctuation* strength. (bx) = Box-Cox transformed variables; (tau) = Kendall's tau, used for non-parametric correlations where normality of distributions could not be assumed.

	Psychoacoustic Descriptors						Physical Features		Ratings of Quality				Sound Sources			
	L_{Aeq} (bx)	$N50$ (bx)	$S50$	$R50$ (bx)	$F*50$ (bx)	Loudness Variability (bx)	Price Index (bx)	Occupancy (bx)	Pleasantness	Eventfulness	Sonic Quality	Visual Quality	Nature	Human	Traffic	Fan
$N50$	0.82 $p=0^{***}$															
$S50$ (tau)																
$R50$	0.56 $p=0^{***}$	0.71 $p=0^{***}$														
$F*50$																
Loudness Variability	0.55 $p=0^{***}$	0.70 $p=0^{***}$		0.62 $p=0^{***}$												
Prices		-0.26 $p=0.062^{**}$			0.26 $p=0.055^{**}$											
Occupancy	0.31 $p=0.0091^{**}$	0.27 $p=0.045^{**}$		0.24 $p=0.011^{*}$		0.32 $p=0.0049^{**}$	0.19 $p=0.046^{*}$									
Pleasantness	-0.21 $p=0.023^{*}$	-0.26 $p=0.063^{**}$				-0.20 $p=0.035^{*}$										
Eventfulness	0.23 $p=0.014^{*}$			0.19 $p=0.049^{*}$					-0.21 $p=0.024^{*}$							
Sonic Quality (tau)	-0.15 $p=0.042^{*}$	-0.16 $p=0.023^{*}$		-0.14 $p=0.047^{*}$					0.46 $p=0^{***}$							
Visual Quality (tau)		-0.19 $p=0.082^{**}$				-0.16 $p=0.02^{*}$	0.26 $p=0.0021^{**}$	-0.16 $p=0.025^{*}$	0.39 $p=0^{***}$		0.41 $p=0^{***}$					
Nature (tau)	-0.16 $p=0.037^{*}$	-0.20 $p=0.09^{**}$						-0.26 $p=0.0087^{***}$				0.25 $p=0.026^{**}$				
Human (tau)	0.28 $p=8.2e-05^{***}$	0.24 $p=0.01^{**}$				0.22 $p=0.018^{**}$		0.36 $p=0^{***}$	-0.19 $p=0.079^{**}$		-0.16 $p=0.046^{*}$	-0.21 $p=0.098^{**}$	-0.32 $p=0.0017^{**}$			
Traffic (tau)							-0.15 $p=0.041^{*}$					-0.18 $p=0.028^{*}$	0.32 $p=0.0023^{**}$			

<i>Fan</i> (<i>tau</i>)				0.21 p=0.0028**				-0.20 p=0.0054**			-0.17 p=0.027*			0.28 p=0.00052** *	
<i>Othernoise</i> (<i>tau</i>)		0.17 p=0.016*						-0.24 p=0.00055** *		-0.17 p=0.032*				0.16 p=0.0044*	

Table 4. Types of restaurants in the survey, by *Design Style* and *Food Style* categories.

	<i>Chinese</i>	<i>MixFusion</i>	<i>OtherAsian</i>	<i>Western</i>	sum
<i>Bar&Buffet</i>	0	4	2	1	7
<i>Café</i>	6	5	3	11	25
<i>FastFood</i>	3	5	2	11	21
<i>Hawker</i>	5	13	4	0	22
<i>Dining</i>	7	4	12	14	37
sum	21	31	23	37	112

Table 5. Multiple analysis of variance (MANOVA) in restaurants categorised by *Food Style* and *Design Style*. For variable names, see Table 2 and Sections 2.1 and 2.2. Effect size is Cohen's d with pooled standard deviation estimate.

	<i>Food Style</i>			<i>Design Style</i>		
	<i>F</i>	<i>p</i>	<i>effect size</i>	<i>F</i>	<i>p</i>	<i>effect size</i>
<i>LAeq</i>	2.99	0.034*	0.08	2.16	0.079.	
<i>N50</i>	1.86	0.14		2.8	0.030*	0.10
<i>S50</i>	0.222	0.88		1.31	0.27	
<i>R50</i>	2.16	0.098.		1.79	0.14	
<i>F*50</i>	1.82	0.15		1.26	0.29	
<i>N₁₀₋₉₀</i>	0.952	0.42		0.317	0.87	
<i>Priciness (bx)</i>	4.63	0.0044**	0.12	19.4	6.3e-12***	0.43
<i>Occupancy (bx)</i>	0.903	0.44		2.22	0.072.	
<i>Pleasantness</i>	0.121	0.95		1.61	0.18	
<i>Eventfulness</i>	0.619	0.60		2.21	0.073.	
<i>Nature</i>	0.867	0.46		4.24	0.0032**	0.14
<i>Human</i>	0.627	0.60		3.25	0.015*	0.11
<i>Traffic</i>	1.55	0.21		4.12	0.0039**	0.14
<i>Fan</i>	6.02	0.0008***	0.15	1.52	0.20	
<i>Othernoise</i>	0.303	0.82		0.187	0.94	
<i>Sonic Quality</i>	0.205	0.89		3.12	0.018*	0.11
<i>Visual Quality</i>	0.0258	0.99		5.61	0.0004***	0.18

Figure 1a. Mean frequencies, with 95% confidence intervals, of six types of interior design materials (see legend) in 112 restaurants, by categories of *Food Style*.

Figure 1b. Mean frequencies, with 95% confidence intervals, of six types of interior design materials (see legend) in 112 restaurants, by categories of *Design Style*.

Figure 2a. Means and 95% confidence intervals for selected features of 112 restaurants, by categories of *Food Style*. *Chin* = *Chinese*; *MixF* = *MixFusion*; *Asia* = *OtherAsian*; *West* = *Western*; *LAeq* = on-site A-weighted SPL (dB); *N50* = median *Loudness* (*sone*). For other variables, see Sections 2.1 and 2.2.

Figure 2b. Means and 95% confidence intervals for selected features of 112 restaurants, by categories of *Design Style*. *BB* = *Bar&Buffet*; *Café* = *Café*, *FF* = *FastFood*; *Hawk* = *Hawker*; *Din* = *Dining*; *LAeq* = on-site A-weighted SPL (dB); *N50* = median *Loudness* (*sone*). For other variables, see Sections 2.1 and 2.2.

Figure 3. Plot of 112 Singaporean restaurants by selected features. X-axis = *Sound Level (LAeq)*; Y-axis = *Quality* (mean of z-scaled *Pleasantness*, *Sonic Quality*, and *Visual Quality*); Symbol size = *Priciness*. Symbol shapes code *Design Styles* and colours code *Food Styles*; see legend. The two ellipses have radii representing the 95% confidence intervals around the means of the corresponding measures, respectively, for two contrast groups defined post-hoc: *Western Bar&Buffet*, *FastFood*, and *Dining* places (black, upper left); and *Chinese*, *MixFusion*, and *OtherAsian* places in design styles *Café* and *Hawker* (purple, lower right).