Proceedings of the 3rd International Conference on Music & Emotion (ICME3), Jyväskylä, Finland, 11th - 15th June 2013. Geoff Luck & Olivier Brabant (Eds.)

PHYSIOLOGICAL MEASURES REGRESS ONTO ACOUSTIC AND PERCEPTUAL FEATURES OF SOUNDSCAPES

PerMagnus Lindborg[*,†]

[*] School of Art, Design, Media, Nanyang Technological University, Singapore
[†]Department of Speech, Music and Hearing, KTH Royal Institute of Technology, Sweden
permagnus@ntu.edu.sg

Abstract

There is no exact model for the relationship between the autonomic nervous system (ANS) and evoked or perceived emotion. Music has long been a privileged field for exploration, while the contribution of soundscape research is more recent. It is known that health is influenced by the sonic environment, and the study here presented aimed to investigate the nature and strength of relationships between soundscape features and physiological responses linked to relaxation or stress. In a controlled experiment, seventeen healthy volunteers moved freely inside a physical installation listening to soundscape recordings of nature, urban parks, eateries, and shops, reproduced using 3D ambisonic techniques. Physiological responses were continuously captured, then detrended, downsampled, and analysed with multivariate linear regression onto orthogonal acoustic and perceptual stimuli features that had been previously determined. Measures of *Peripheral Temperature* regressed onto *SoundMass*, an acoustic feature, and onto *Calm-to-Chaotic*, a perceptual feature, in each case with a moderately sized effect. A smaller effect was found for *Heart Rate* onto *VariabilityFocus*, an acoustic feature, and for *Skin Conductance* onto the interaction between the acoustic features. These relationships could be coherently accounted for by neurophysiological theory of how ANS activation leads to emotional relaxation or stress. We discuss limitations of the present study and considerations for future soundscape emotion research, as well as more immediate practical implications.

Keywords: physiology, acoustic features, soundscapes

1. Introduction

Generally below the level of consciousness, the autonomic nervous system (ANS) is part of an organism's system to control organs and body functions through neuronal (rapid, precise, differentiated) and hormonal (slower and more diffuse modification of metabolic functions) activity levels, effectuating adaptive responses to various environmental demands (e.g. Kreibig 2010). Depending on the organism's needs and desires, ANS elicits quick response mobilisation, "fight-or-flight", via the sympathetic nervous system (SNS), or a "rest and digest" response via the parasympathetic nervous system (PNS). These two subsystems are continuously modulating bodily vital functions, usually in antagonistic fashion, to achieve homeostasis, i.e. trying to maintain a relatively constant inner environment for the organs to function properly, and assure the survival of the organism.

When SNS is activated, stimulating signals are sent to arouse heart and respiratory activity; constrict peripheral blood vessels (i.e. diverting blood away from the skin as well as from the gastro-intestinal tract); dilate blood vessels in muscles and prepare stockpiled energy for utilisation; and induce auditory and visual exclusion (i.e. reducing the range of sensation, such as in "tunnel vision" or temporary hearing loss). Such responses were first described by Cannon (1929). When PNS is activated, dampening signals are sent to calm the activity of heart and lungs; relax the muscles to release blood; and broaden the range of audiovisual sensation. If relaxation follows arousal, ANS stimulates glands to increase sweat production in order to reduce internal body temperature. Even though it is to a larger extent than the other physiological responses here considered open to conscious control, respiration activity is mostly involuntary. Breathing onset rate and air flow rate increase under SNS activation; however, the amplitude range of a breath sequence decreases. The inverse happens when respiration is influenced by PNS dampening. It is important to recall that the brain has evolved to produce integrated responses rather than modify functions one by one. As pointed out by Coutinho and Cangelosi (2011), neurobiological models of emotion focus not only on how ANS controls body activity but also on how afferent signals, going from organs back to the brain, bias feeling as well as cognition, in a process of peripheral feedback (Dibben 2004). Comprehensive arrays of physiological measures would be needed to map such regulation patterns.

People are typically not aware of ANS-influenced physiological changes as such, but have a rich vocabulary to describe their inner state in terms of evoked emotion, or 'feeling', which is to some degree captured with self-reports, e.g. using semantic or other scales. In addition, a person's inner state might be indirectly detected via self-reports of perceived qualities pertaining to stimuli. Correlating objective physiological measures with self-reported psychological measures is therefore a highly important method for cross-validation of emotion constructs. Yet another way to detect ANS responses is by observation of a subject's behaviour. Certainly self-report is useless to capture delicate involuntary mental states, such as distraction, bliss, or fascination. A limitation of the objectivity of physiological measurement is that directed attention can influence the readings, as evidenced by e.g. biofeedback training or mediation.

There is no consensus on the exact relation between ANS activity and evoked or perceived emotion (Kreibig 2010). Music has for a long time been a privileged resource for studying such relationships (see e.g. Friberg, Schoonderwaldt & Hedblad 2011, Juslin & Sloboda 2010). In the context of listening, Iwanaga & Moroki (1999) showed that heart and respiration activity were affected by music stimuli classified as either 'exciting' or 'sedative' . Khalfa and co-workers (2008) also used repertoire pieces classified as either 'sad' or 'happy' (in original as well as structurally modified versions) and found that skin conductance and blood pressure increased more during happy music than during sad. They pointed out that while happy music is arousing and perceived as pleasant, sad music is much less arousing but still perceived as rather pleasant, which is paradoxical. There is evidence that artificially induced physiological arousal or relaxation moderates the intensity of the emotion evoked by a musical stimulus (Dibben 2004). This could indicate that ANS influences perceptual processes at a pre-cognitive emotional processing stage (e.g. Juslin & Västfjäll 2008).

Many studies have mapped relationships in the communication between a transmitter's intended emotion and a listener's perceived or evoked emotion. However, intent is a moot point when considering emotion in relation to soundscapes since they are unintended (or sometimes half-designed, e.g. servicescapes) in comparison to music. What is more, sound is only one aspect of *place*, albeit a crucial one. Where music transports the listener to a domain of imagined and abstract places, listening to soundscape recordings transports the listener to remembered and physical places. That soundscape quality influences health, in particular cardiovascular diseases, has been shown in extensive research projects (e.g. Berglund et al. 2006, Davies et al. 2009). Using physiological measures and films as stimuli, Ulrich et al. (1991) found that subjects could recuperate from induced stress more quickly through watching and hearing a filmed natural environment, than through a filmed urban environment. The study compared heart rate, skin conductance, and self-report responses. Placing subjects in different physical environments, Hartig and co-workers (2003) compared blood pressure response with self-reported stress recovery and directed attention restoration. The diastolic pressure levels were lower, recovery from stress more complete, and restoration faster in people sitting in a room with tree views compared to people in a viewless room. Likewise for people walking in physical environments, such as a nature reserve and an urban area, the former induced greater stress reduction, as indicated by lower blood pressure levels. Letting subjects listen to recordings of pleasant and unpleasant soundscapes, Hume & Ahtamad (2013) found different levels of heart and respiration activity. The decrease in heart rate was greater during more unpleasant soundscapes, while the rise in respiration rate was greater during more pleasant soundscapes. Such findings give insight in how the sonic environment affects health. The importance for urban planners and acoustic designers to create accessible and tranquil places, where city dwellers can recuperate, is underlined by several authors (e.g. Andringa 2009, Hellström 2011, 2012).

2. Experimental method

Aiming to investigate how physiological responses might be influenced by different sonic environments, an experiment was designed. As stimuli, 12 ambisonic recordings of Singaporean soundscapes were selected. Aspects of their acoustic features had been previously computed and perceptual quality rated in a separate study (Lindborg 2012, 2013). The selection was influenced by considerations of how a soundscape can represent a physical environment in the absence of other sensorial information. There are three recordings each from environments loosely categorised as nature, urban parks, eateries, and shops. As a whole, the set represents quotidian Singaporean environments, while each recording has high degree of intra-stimulus homogeneity. Since physiological responses evolve over time-scales ranging from quasi-instantaneous nervous reactions to very slowly accumulated metabolic adaptation, the duration of each experimental stimulus is paramount. In the present study it is 90 s, which is typical, according to a review (Kreibig 2010).

Figure 1 shows the 12 soundscapes plotted in the *SoundMass* - *VariabilityFocus* plane (SM-VF), introduced in the study mentioned above. Two orthogonal dimensions, derived from a Principal Component Analysis, explain 76.2% of the variability in a large set of low-level features (Lartillot 2010). SM describes both loudness and spectral shape: negative values for 'loud, earthy, narrow-range' sounds and positive values 'soft, evanescent, broad-range' sounds. VF indicates the dominant register of amplitude pulsation: negative values describe

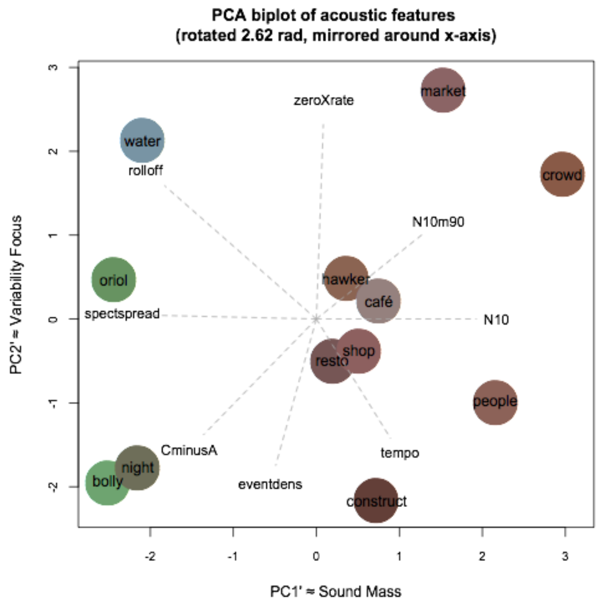

Figure 1. Soundscapes in SM-VF

'thumping, booming, machine-like' sounds and positive values 'chirpy, sizzling, whizzing' soundscapes. Serendipitously, the stimuli are well spread out in SM-VF, with two in each quadrant and four near the centre (Lindborg 2013).

Figure 2 shows the 12 stimuli in the *Pleasant ness* - *Eventfulness* plane (PL-EV). The axes are the orthogonal dimensions of perceived qualia, explaining 73.0% of the variability in ratings on the "eight adjectives" scales section of the Swedish Soundscape Quality Protocol (Axelsson et al. 2010, 2011).

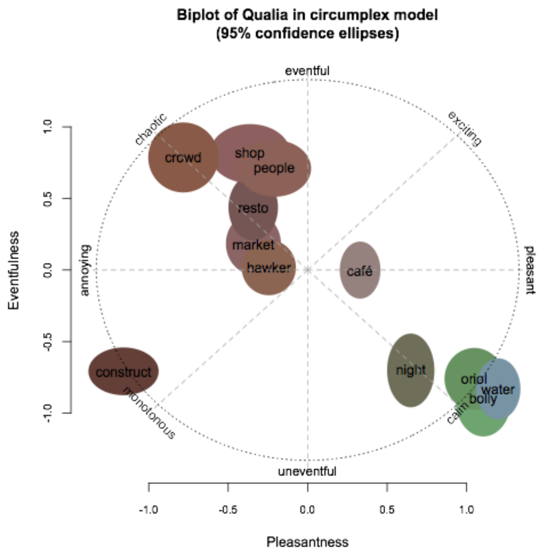

Figure 2. Soundscapes in PL-EV. The radii of ellipses correspond to 95% confidence intervals.

Noting that 11 out of 12 soundscapes are close to the "\" diagonal, for the purpose of the present study, a single derived bipolar dimension was introduced, tentatively labelled *Calm-to-Chaotic* (CaCh). Values were calculated by rotating PL-EV by -π/4 rad and keeping only the Y' axis. Table 1 lists the stimuli features used in the present study, i.e. SM, VF, and CaCh.

Table 1. Derived acoustic features (SM and VF) and perceived qualia (PL and EV), which were replaced with a *Calm-to-Chaotic* (CaCh) dimension.

	SM	*VF*	*PL*	*EV*	*CaCh*
1:market	1.53	2.73	-0.34	0.18	0.37
2:hawker	0.36	0.48	-0.24	0.02	0.19
3:construct	0.73	-2.17	-1.16	-0.71	0.32
4:café	0.75	0.21	0.33	0.00	-0.23
5:bolly	-2.51	-1.95	1.11	-0.90	-1.42
6:night	-2.15	-1.77	0.65	-0.70	-0.95
7:resto	0.19	-0.50	-0.34	0.44	0.55
8:shop	0.51	-0.38	-0.36	0.81	0.83
9:oriol	-2.44	0.47	1.05	-0.76	-1.28
10:water	-2.09	2.13	1.20	-0.83	-1.44
11:crowd	2.97	1.73	-0.78	0.79	1.11
12:people	2.16	-0.99	-0.21	0.71	0.65

17 healthy volunteers, 10 female, participated in the experiment, one by one. Age ranged between 20 and 53 years; median age was 26 years. The experiment was explained to each participant and a general health check was conducted. No participant reported feeling unwell or in an unusual emotional mood, and none had eaten a large meal, exercised heavily, or smoked in the hour preceding the experiment. Blood pressure was measured and no participant's results were unusual for them. One participant was on prescription for a blood pressure controlling medicine, and one participant was knowledgeable about having below-average pressure. The participant then filled out a 'general participant data' (GPD) form including daily habits in terms of work & study, sleep & rest, sport, art, music, games & TV, and socialising. Lastly, they completed the Ten-Item Personality Index (TIPI) and the Profile of Mood States for Adults (POMS). These data revealed nothing remarkable and will not be further discussed. Each participant received a cinema voucher as a token of appreciation.

A great number of psychophysiological measures can potentially provide evidence of SNS and PNS activity. In the present study, a ProComp Infiniti biofeedback system (Thought Technology 2011) was used to capture and transmit responses by WiFi to a computer. Five sensors were placed on the participant following the manufacturers instructions.

- EKG electrodes were placed on the participant's forearms, with the negative lead on right, and positive and ground leads on the left arm. EKG measures cardiovascular activity. SNS activation leads to an increase in heart rate, whereas PNS dampens it. The raw response is measured in micro-volts (μV) and sampled at 2048 Hz.
- A *Thoracic Respiration* (TR) sensor was strapped around the chest of the participant. The response is captured as a relative measure and sampled at 256 Hz.
- *Skin Conductance* (SC) was captured by sensors on the proximal phalanxes of the second and fourth finger. SNS activation stimulates secretion from sweat glands, which increases the skin's electrical conductivity. The response is measured in micro-Siemens (μS) and sampled at 256 Hz.

- *Peripheral Temperature* (PT) was measured by a termistor attached to the third finger of the left hand. PT will vary according to the amount of blood perfusing the skin, which is influenced by SNS. As a person gets stressed, the fingers tend to get colder. The response is measured in degrees Celsius (˚C) and sampled at 256 Hz.
- A *Blood Volume Pulse* (BVP) sensor was attached at the tip of the left hand index. The sensor uses photoplethysmography, i.e. infra-red light detection of skin colour. Changes are due to blood flow variation and indicate SNS activation levels. The response is captured as a relative measure and sampled at 2048 Hz.

The participant was blindfolded, and instructed to keep the left arm relaxed at the side of the body or slightly bent at the elbow, and to remain standing or walking throughout the experiment. Participants could freely move within a triangular area (side=6m), demarcated by a string at chest-height, inside the *WBS* 3D audio installation at IMI, NTU (Lindborg 2011). This rig consists of 9 full-range loudspeakers mounted in a prism shape at three different heights, enabling 3D reproduction of ambisonic recordings at the same Sound Pressure Level as at the original location. The data smoothing method assured that occasional jerky physical movement would not invalidate measurements. However, on two separate occasions, participants needed to be briefly reminded not to hold the left arm in a lifted-up position, e.g. supported by the right arm, or resting on top of the head. When the participant was ready, the experiment started. A 60 s baseline in silence was followed by a 'warm-up' stimulus of 90 s for the participant to get used to the situation. These data were not used in the analysis. Then the 12 soundscape stimuli, each 90 s long, were played back in randomised order. Finally, the fourth stimulus was repeated as a 'control'. To clarify, if we label the stimuli with numbers 1...12 and do not randomise, the sequence following the baseline would be: {8, 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 4}. Note that the soundscape presented in the eighth position in the stimulus sequence was identical as the one used as 'warm-up'. Total duration of the experimental session was 60+14*90 seconds = 22 minutes.

3. Data analysis

Commercial software (Thought Technology 2011) was used to visualise several potentially useful 'virtual channels' derived from the raw signals. A set of 31 channels was selected, downsampled to 256 Hz, and exported to R for further analysis. Smoothing of data was made by computing the running median, with window size determined

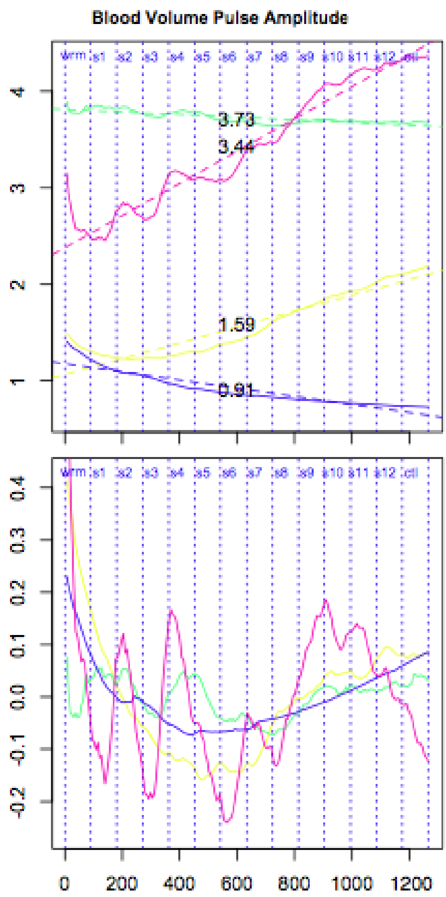

Figure 3. Examples of raw (left) and detrended responses (right). The dashed detrending lines in the left plot all coincide with a horizontal line at y=0 in the right plot. X-axes unit is seconds. The vertical lines represent stimuli onset time. Note that the plots show raw data, and that soundscapes were presented to each participant in a different order.

by Turlach's method. Each channel was then further downsampled to 5 Hz, to yield 450 data points for each 90-second stimulus. In the present analysis, five psychophysiological response channels are considered: *Skin Conductance* (SC, μS), *Peripheral Temperature* (Temp, ˚C), *Blood Volume Pulse Amplitude* (BVPA, relative), *Heart Rate by EKG* (BPM, beats/minute), and *Mean Thoracic Respiration Amplitude* (TRA, relative). Data were stored in an array containing 535,800 values. In order to minimise the influence of long-term signal variation on time-scales longer than the stimuli, linear regression de-trending was applied to each signal channel of the whole session (excepting baseline, but including 'warmup' and 'control'). The residual fluctuation around the regression line was assumed to be related to the physiological response to the soundscape. See Figure 3 for an illustration of the data transformation.

The variations in a channel signal can be attributed to various causes. During an experiment, a participant goes through metabolic, biological, and cognitive processes that have nothing to do with the sound stimuli. A certain amount of the variation will be caused by fatigue, hunger, distraction, and so forth. What we are interested in is that part of the variation which is caused by an ANS-induced response to the soundscape. A great number of techniques can potentially provide evidence of ANS activity. Table 2 presents an overview of the physiological measures used in the present study; the body function of which they register the activity; how such functions and organs are hypothesised to be controlled by ANS; and what emotional state the measures might thereby typically indicate.

Table 2. Hypothetic relations between physiological measure, ANS activity, and emotional state.

measure	body function	SNS activation causes:	PNS dampening causes:	physiological measure *increase* indicates:
BPM	heart rate	increase	decrease	stress
BVPA	peripheral blood flow	decrease	not innervated (increase)	relaxation
TRA	respiration amplitude	decrease	increase	relaxation
SC	sweating	increase	not innervated (decrease)	stress
Temp	peripheral temperature	decrease	not innervated (increase)	relaxation

4. Results

Table 3 presents the main results for 12 soundscape stimuli across 17 participants: mean (with confidence interval) and slope (Pearson's *r*) of detrended responses in 5 physiological channels.

Table 3. Main results.

	SC		*Temp*		*BVPA*		*BPM*		*TRA*	
	m ±ci/2	*r*	m	*r*	m	*r*	m	*r*	m	*r*
1:market	-0.036 ±0.076	-0.561	0.058 ±0.18	-0.978	0.014 ±0.066	-0.913	-0.115 ±0.64	0.653	0.011 ±0.019	0.196
2:hawker	-0.023 ±0.073	-0.951	-0.046 ±0.26	0.962	-0.058 ±0.078	0.849	0.109 ±0.81	-0.94	0.006 ±0.034	-0.889
3:construct	-0.057 ±0.077	0.623	0.075 ±0.21	-0.896	-0.050 ±0.05	-0.782	0.077 ±0.44	0.273	-0.009 ±0.019	0.726
4:café	0.019 ±0.11	0.639	0.125 ±0.22	-0.99	0.041 ±0.059	0.309	0.342 ±0.41	-0.365	0.002 ±0.018	-0.837
5:bolly	-0.031 ±0.10	0.853	0.167 ±0.20	0.936	0.056 ±0.064	0.898	-0.067 ±0.62	0.939	0.015 ±0.025	0.441
6:night	0.028 ±0.10	0.592	-0.055 ±0.35	-0.935	-0.020 ±0.09	-0.95	0.045 ±0.52	-0.833	-0.012 ±0.022	-0.881
7:resto	0.009 ±0.081	0.077	-0.072 ±0.19	-0.814	0.020 ±0.06	-0.984	0.53 ±0.57	-0.791	0.026 ±0.034	-0.673
8:shop	0.026 ±0.094	0.698	-0.062 ±0.25	0.949	-0.005 ±0.075	0.957	0.000 ±0.63	0.933	0.000 ±0.05	-0.894
9:oriol	-0.051 ±0.10	-0.471	0.144 ±0.26	0.998	0.029 ±0.051	-0.616	-0.46 ±0.50	0.229	-0.013 ±0.023	-0.723
10:water	-0.009 ±0.13	-0.801	0.079 ±0.19	0.866	0.002 ±0.068	0.963	-0.348 ±0.47	-0.922	-0.004 ±0.044	0.882
11:crowd	0.000 ±0.10	0.852	0.09 ±0.25	-0.955	-0.017 ±0.067	-0.844	-0.124 ±0.68	0.956	-0.024 ±0.024	0.924
12:people	0.009 ±0.091	-0.901	0.104 ±0.31	-0.766	-0.004 ±0.084	-0.932	-0.234 ±0.46	0.836	-0.013 ±0.033	-0.816

5. Analysis and Discussion

A multivariate linear regression analysis was performed with the 10 derived physiological responses as dependent variables (stratified), and with 2 acoustic (with interaction) and 1 rated feature describing the stimuli. Four relationships were significant at the alpha=0.05 level. They are illustrated in Figure 5.

- *Temp.r* onto *SM* (ß=-0.475, p=0.018*)
- *Temp.m* onto *CaCh* (ß=-0.410, p=0.038*)
- *BPM.r* onto *VF* (ß=-0.163, p=0.037*)
- *SC.r* onto *SM:VF* interaction (ß=0.185, p=0.0088**)

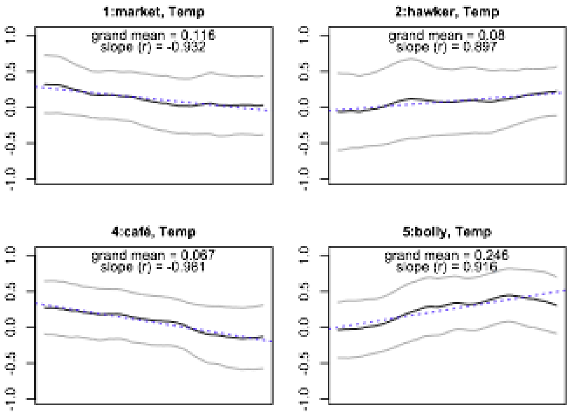

Figure 4. *Peripheral Temperature*: mean across participants (black) with confidence interval curves (grey), and linear regression of the means over time (dashed blue line). Y-axis unit is Δ˚C (distance to detrending line) and time is on the x-axis.

The change in *Peripheral Temperature* was negatively correlated to *SoundMass*, with a moderately sized effect of almost half a standard deviation. In other words, while being in 'loud, earthy, narrow-range' soundscapes such as the urban environments *11:people* and *12:crowd*, participants responded with a lowering of peripheral temperature. This is an indicator for SNS activation which typically leads to emotional stress. Also, temperature was lower the more chaotic the soundscape was, such as in *7:resto* and *8:shop*. Conversely, while being in 'soft, evanescent, broad-range' sonic environments such as the rural parks *5:bolly* and *9:oriol*, participants responded with an increased peripheral temperature. This is an indicator for reduced SNS activation (and possibly of PNS dampening) which typically leads to emotional relaxation.

A closely related aspect of *Peripheral Temperature*, the mean, was negatively correlated with the *Calm-to-Chaotic* rating, and of a comparable effect size. In other words, while being in calm soundscapes, participants responded with a higher average peripheral temperature, linked to ANS-induced relaxation in the same way as above. Conversely, while being in chaotic soundscapes, they responded with a lower temperature, which is linked to stress.

The change in *Heart Rate* (BPM) was negatively correlated to *VariabilityFocus*, with a small effect size of 0.16 standard deviations. In other words, while being in soundscapes where the amplitude variation was mainly in the low register, be it a machine-dominated street environment such as *3:construct* or a rural park with some machinery such as *5:bolly*, participants responded with an increase in heart rate. This is an indicator for SNS activation which typically leads to emotional stress. Conversely, while being in soundscapes where amplitude variation was mainly in the high register, be it in an almost pristine natural environment such as 10:water or in an urban 'old-style' marketplace such as *1:market*, participants responded with a lowering of heart rate, an indicator for PNS dampening which typically leads to emotional relaxation.

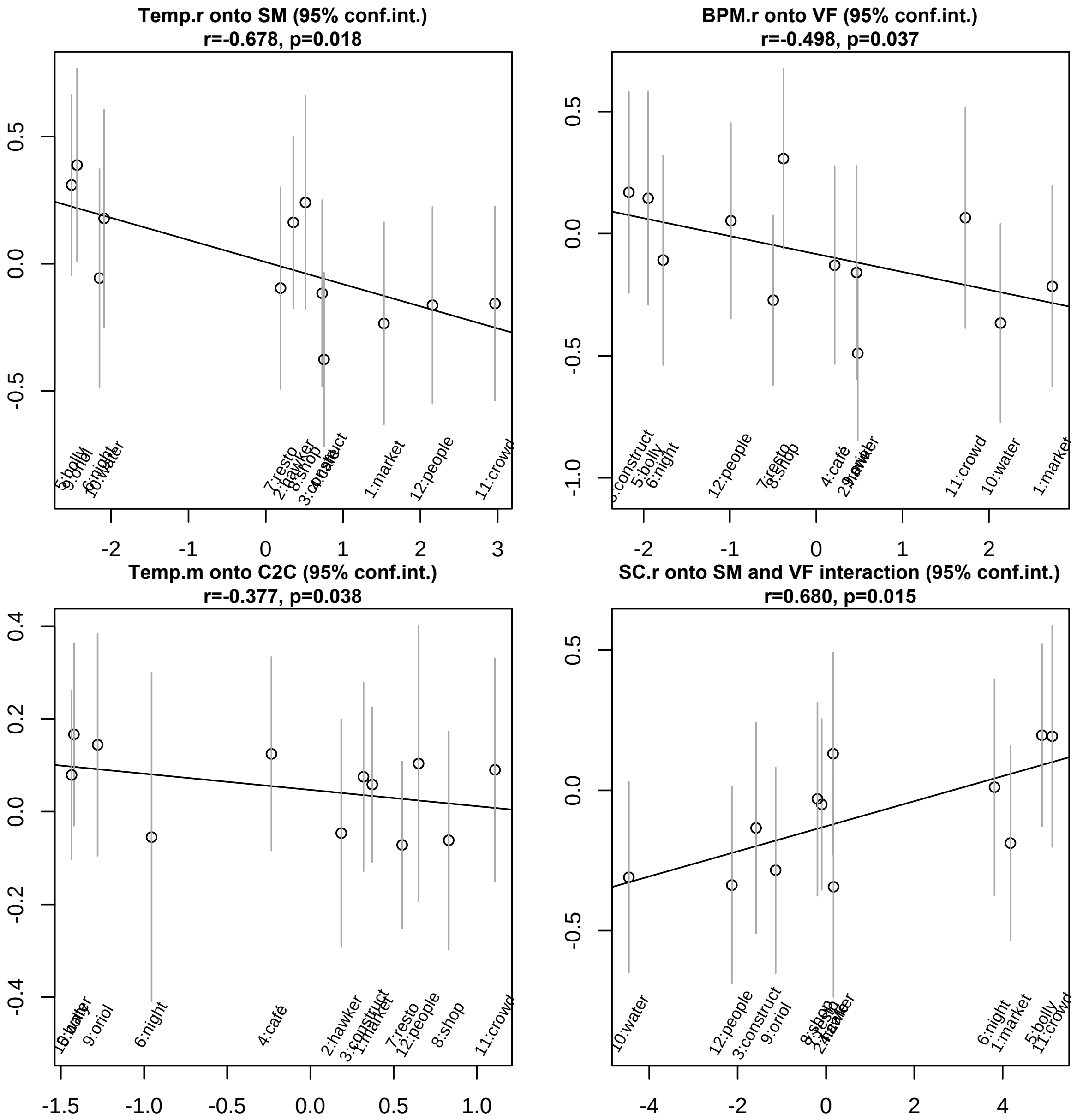

Figure 5. Significant regressions of physiological responses (y-axes) onto acoustic and perceptual features of soundscapes (x-axes).

Lastly, there was a significant interaction effect of *SoundMass* and *VariabilityFocus* on the way *Skin Conductance* changed during soundscape exposure, with a small effect size of 0.18 standard deviations. This interaction expresses the acoustic differences relative to the diagonals of the SM-VF plane. Low values are for soundscapes on either extreme on the "\" diagonal, and high for those on the "/". In somewhat loose terms, an increase in SM:VF interaction expresses high-VF soundscapes getting more massive, and low-VF ones becoming less massive. At the same time, high-SM sounds lower their VF, while less-massive sounds increase it. Such differences were positively correlated with an increase in *Skin Conductance*, an indicator for SNS activation which typically leads to emotional stress. We are not able at this point to describe in simple words what is meant by this interaction effect of acoustic features. More research is needed to investigate such interaction effects, and to identify the acoustic features that best predict emotional responses to soundscapes.

6. Conclusion

We have presented an empirical study of physiological responses to soundscapes. From a review of research in neurophysiology, music emotion, and soundscape perception we identified a set of hypothetical patterns of how autonomic nervous system responses relate to emotional states. Our aim was to investigate the nature and strength of such relationships in the context of soundscapes. A controlled experiment yielded evidence of significant regressions between peripheral temperature, heart rate, and skin conductance onto soundscapes described by acoustic and perceptual features. The results support the assumption that sonic environments induce involuntary nervous responses in ways that are congruent with results and models from research in music emotion.

Because the autonomic nervous system is complex, including peripheral feedback, accumulation, and long-term adaptation, looking for linear relationships between stimuli and physiological responses may not be the best way to create models for the prediction of emotional responses to acoustically rich sounds. Coutinho & Cangelosi (2011) criticise generalisations of results in the linear paradigm, and instead endorse connectionist models such as recurrent neural networks to model temporal development of sound perception. Further, an important aspect of soundscapes that we have not addressed is that they exist in three spatial dimensions; auditory scene analysis is key to a parsimonious description. Yet another limitation is that sound is but one aspect of place, and so a truly ecologically valid investigation must take multisensorial integration into account. Bringing these perspectives together in a model for soundscape emotion is a theme for future research.

Considering the practical implications of this research, it must be underlined that people do perceive differences in soundscape quality, and that their physiological responses are affected by the sonic environment. The present study has a limited scope but clearly highlights the existence of direct relationships between soundscapes and factors known to bear upon people's health. Singapore's transformation over barely two generations into an affluent, densely populated, air-conditioned, and traffic-dominated city-state has brought many societal changes that are laudable, but has also had negative effects, and the deterioration of soundscape quality represents one of the unknown knowns. The biological functioning of people living through such radical environmental changes remains abiding. The onus is on decision-makers to take soundscape research into serious consideration when determining cost-efficient and sustainable urban development.

References

Axelsson, Ö., Nilsson, M. E. & Berglund, B. (2011). *The Swedish Soundscape Quality Protocol.* Version of March 2011.

Axelsson, Ö., Nilsson, M. E. & Berglund, B. (2010). A principal components model of soundscape perception. *Journal of the Acoustical Society of America*, 128(5).

Cannon, W. B. (1929). *Bodily changes in pain, hunger, fear, and rage.* Appleton-Crofts.

Coutinho, E. & Cangelosi, A. (2011). Musical Emotions: Predicting Second-by-Second Subjective Feelings of Emotion From Low-Level Psychoacoustic Features and Physiological Measurements. *Emotion*, 11(4), 921–937.

Coutinho, E. & Cangelosi, A. (2010). Computational and psycho-physiological investigations of musical emotions. Unpublished manuscript.

Dibben, N. (20040. The Role of Peripheral Feedback in Emotional Experience with Music. *Music Perception: An Interdisciplinary Journal*, 22(1).

Friberg, A., Schoonderwaldt, E., & Hedblad, A. (2011). Perceptual ratings of musical parameters. In von Loesch, H., & Weinzierl, S. (Eds.), *Gemessene Interpretation - Computergestützte Aufführungsanalyse im Kreuzverhör der Disziplinen* (pp. 237-53). Mainz: Schott.

Hartig, T., Evans, G. W., Jamner, L. D., Davis, D. S., & Garling, T. (2003). Tracking restoration in natural and urban field settings. *Journal of Environmental Psychology*, 23(2), 109–23.

Hellström, B. (2012). Acoustic design artifacts and methods for urban soundscapes: a case study on the qualitative dimensions of sounds. *Proceedings of InterNoise*, New York City.

Hellström, B. (2011). Modelling the Shopping Soundscape. *Journal of Sonic Studies*, 1(1).

Hume, K. & Ahtamad, M. (2013). Physiological responses to and subjective estimates of soundscape elements. *Applied Acoustics*, 74(2), 275–81.

Juslin, P. & Sloboda, J. (2010). *Handbook of Music and Emotion*. Oxford Press.

Juslin, P. & Västfjäll, D. (2008). Emotional responses to music: The need to consider underlying mechanisms. *Behavioural and Brain Studies*, 31, 559 – 621.

Khalfa, S., Mathieu, R. Rainville, P., Bella, S. D., Peretz, I. (2008). Role of tempo entrainment in psychophysiological differentiation of happy and sad music? *International Journal of Psychophysiology*, 68, 17–26.

Kreibig, S. D. (2010). Autonomic nervous system activity in emotion: A review. *Biological Psychology* 84, 394–421.

Lartillot, O. (2011). *MIRtoolbox 1.3.2*. Available at http://www.mathworks.com/matlabcentral/fileexchange/24583-mirtoolbox (May 2012).

Lindborg, PerMagnus (forthcoming). Perception of urban soundscapes is mediated by personality traits.

Lindborg, PerMagnus (2012). Correlations between personality traits and physiological and perceptual responses to soundscapes. In Cambouropoulos, Tsourgas, Mavromatis, & Pastiadis (Eds.) *Proceedings of ICMPC-ESCOM 2012*, Greece.

Thought Technology (2011). *ProComp Infiniti hardware manual*.

Ulrich, R. S., Simons, R. F., Losito, B. D., Fiorito, E., Miles, M. A., & Zelson, M. (1991). Stress Recovery During Exposure to Natural and Urban Environments. *Journal of Environmental Psychology*, 11(3), 201–30.