The City Soundscape and the Brain

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Abstract

In this paper we explore the possibilities that portable Electroencephalography (EEG) technology offers in order to understand the behaviour of pedestrians in a specific nocturnal urban aural environment. Previous EEG research conducted in urban design has shown links between environmental cues and mood-enhancement (Aspinall et al., 2013). In the current pre-pilot project we recorded EEG data of stationary participants while they were exposed to urban soundscapes along a chosen pathway. Our intention was to investigate links between these soundscapes and the impact they have on the listeners' emotional state. Analysis of the data revealed probable evidence that the distance between the sound source and the listener generates feelings of discomfort. More particularly proximity of the sound source showed rise in frustration. Based on our findings we propose the design of a responsive brain interface. The interface calibrates the listeners' aural habitat in real time attempting to reduce the pedestrians' frustration levels, thus enhancing their aural experience. The paper finally discusses theories of environmental psychology, neuroscience, sound perception and affective computing.

Keywords: EEG, urban design, urban sounds, emotions, affective design, responsive design

1. Introduction

The emergence of brain representation technologies helps us relate observed behaviours to specific brain activity (Damasio 1999, p.12). Previous studies have shown the implications of electroencephalography (EEG) technology for spatial analysis, revealing evidence on the benefits of moving through parkland (Aspinall et al 2013). On a more speculative level we were involved with the creation of a reactive arts installation, employing mobile EEG technology to explore links between sound-generating electronic devices and a performer's emotions (Brain Drain 2014).

Emotions are coupled with the body and its biological processes,which are briefly summarized in happiness, sadness, fear, anger, surprise, disgust, calm and tension. These biological processesinclude the regulation of the physiological responses of the body, in other words the body's homeostasis (Damasio 1999, p.28). Damasio (1999) defines emotions as classifiers of body and brain responses.

Affect also relates to the body activity of emotions (Wetherell 2012, p.12). Thisallows us to use the terms "affective" and "emotional" interchangeably (Picard 1997, p. 24).

Architectural phenomenologist Juhani Pallasmaa (2005) has pointed out the importance of the aural qualities of space. Embracing his ideas, we emphasize on the sound qualities of urban spaces, an element frequently neglected by designers. We focus on "acousmatic hearing"running our tests during night hours and obliging our participants to have their eyes closed. Sounds are more audible during nighttime (Howard 2012). In addition acousmatic hearing shifts the experimentees' attention from any visual stimuli to the aural qualities of space only (Schaeffer 1966 in Kane, 2007).

The study presented here investigates the impact of sounds on stationary pedestrians in a specific urban environment. A location with rich variations in sound qualities and interesting pedestrian networks was chosen, in the center of Edinburgh.Our goal was twofold; we firstly intended to reveal links between sound environments and the emotions they elicit and secondly we used that knowledge towards the development of a responsive,affective computing applicationwhich attempts to improvein real-time the aural experience of users in urban spaces. According to Professor of Architectural Computing Richard Coyne (2010), users calibrate and re-calibrate digital devices under different contexts. It is through this dynamic calibration that users tune spaces so that they meet the users' emotional circumstances and needs (Coyne 2010). We adopt Coyne's theory approaching our proposed affective computing application as a calibration device. Thiscalibration device adapts the aural conditions of the environment in real-time to the users' frustration levels thus, enhancing the users' experience.

2. Calibrating sound and emotions

Contemporary developments in neuroimaging technologies offer further insight intoways that environments impact on people's brain activity (Lengen and Kistemann, 2012). These new techniques provide us with detailed examinationof the structure and the function of the brain. Specific brain activities can then be correlated with observed behaviours (Damasio 1999, p.12).

People perceive their environment through its physical aspects and through the emotional responses it evokes(Lengen and Kistemann, 2012). Certain physiological processes are involved in the generation of an emotional response, explains Neuroscientist Antonio Damasio (1999).Such physiological processes includecommunication among different regions of the brain but also communication between the brain and the rest of the body. This physiological activity is responsible for the production of one's affective state (Damasio 1999, p.46).

The field of environmental psychology is concerned with the emotional responses that physical environments elicit. Psychologists Mehrabian and Russel (1974) claim that any emotional human responsecan be described by 3 variables; pleasure, arousal, dominance and their variations, regardless of the type of environment or the sense triggered (p.14).Boredom for example can be described as aresponse, which is low on pleasure, arousal and dominance. On the contrary, excitement registers high levels of pleasure, arousal and dominance. Anxiety is classified as low on pleasure and dominance while high on arousal. Finally relaxation shows low arousal levels but rates high on pleasure and dominance(Thayer 1967; 1970, in Mehrabian and Russell, 1974, p.83).Pleasure, arousal and dominance are also closely associated with the physiological response mechanism of the body(Mehrabian and Russell 1974, p.17).

Physiological signals carry affective information from which we can infer emotional responses. Nowadays wearable EEG technology offers the possibility for physiological signals to be inputted to a computer system (Picard 1997).Aspinall et al (2012) at the University of Edinburgh have conducted one of the first studies that register emotional responses in an outdoor environment, using low-cost mobile electroencephalography (EEG) technology, the Emotiv EPOC EEG headset. Together with the headset they used Emotiv's Affective Suite application which filters and translates raw EEG signals to 4 affective states: engagement, frustration, meditation and excitement (long-term and short-term). Their research revealed evidence, which supports reduction in frustration levels for walkers that shift from busy urban environments to green spaces.

Using the same portable EEG technology we discover links between urban sounds and the frustration levels that stationary pedestrians exhibit. More specifically close proximity to sound sources indicated higher frustration levels.Proximity, distance and territoriality are considered important factors in the examination of the effects of the environment on human emotions (Mehrabian and Russell, 1974, p.4).

Anthropologist Edward T. Hall(1969, p.40) explains that people have distance receptors –eyes, ears, nose- and immediate receptors –touch, sensations from skin, membranes and muscles-. He specifically differentiates between sound and vision. Visual information, he explains, is more focused and precise while sound information is more vague especially when the stimulus source is at a distance (Hall 1969). In general the larger the distance between the stimulus object and the person,the bigger the decrease in the object's details and the information it carries. Inversely when the distance is minimized the information rate increases (Mehrabian and Russel 1974, p.83).

Hall introduced the theory of proxemics to explain “man's use of space” (Hall 1969, p.95). He distinguishes among 3 categories within proxemics one of which, the pre-cultural, relates to physiological responses (Hall 1969, p.95). Men like animals, have a territorial perception of space that defines a range of distances from one another (Hall, 1969). According to Hall, there are 4 types of distances observed in people: intimate distance, personal distance, social distance and public distance. Intimate distance describes the closest distance between 2 people; the two human bodies can be overwhelmed from the heightened sensory inputs. Personal distance is defined as the distance of “non-contact”; it is a protective boundary, like a sphere, surrounding the organism and protecting him from others (Hall 1969, p.112). Social distance defines the “limit of domination”; it is the boundary, which ranges between the personal distance and the social distance (Hall 1969, p.114). Finally, the public distance is outside of any boundary of interaction. When shifting from one mode of distance to the other, significant sensory transitions take place (Hall 1969).

Spatiality and distance are also important elements in hearing and sound localization. Factors that help uslocate sound are head tracking, the first-arriving sound waves or the direct sound waves when being in a reverberant environment. Welocalize moving sound sources more successfully than stationary ones (Rumsey and McCormick 2013, p.38). Sound localization entails perception of distance.Distance perception in hearing refers to the distance between the listener and an individual sound source (Rumsey and McCormick 2013, p.39).

The participantsduring our experiments were obliged to have their eyes closed while listening to the urban soundscapes. Schaeffer describes the acousmatic hearing as a purely auditory experience (1966).Acousmatic sounds shift the attention from any visible or tactile cues of space to hearing only, ignoring the source of the sounds (Schaeffer, 1966).According to French Composer Michel Chion(1994, p.11)acousmatic "indicates a noise which is heard without the causes from which it originates being seen". When vision is involved in hearing, "much of what we though we were hearing, was in reality only seen, and explained by the context" (Schaeffer 1966 in Kane 2007). In reflective environments, such as urban environments,the size of the space and the distance between the listener and the surfaces can be determined quite successfully even when using the auditory sense alone(Rumsey and McCormick 2013).

Sound stimuli generate various physiological reactions. When sounds are characterized as sudden, loud, dissonant, or fast in tempo, they cause sensations of unpleasantness or arousal(e.g., Berlyne 1971; Burt et al. 1995; Foss et al. 1989; Halpern et al. 1986, in Juslin et al., 2008).Our perceptual system constantly observes for changes or events in our surrounding environments. Sudden, loud, fast sounds are perceived as auditory changes. These auditory changes evoke high levels of arousal urging the listener to direct their attention to these particular sound stimuli. Finally sensory dissonance initiates a sense of danger(Ploog 1992 in Juslin et al. 2008).

Studies have shown that listeners prefer music stimuli that induce optimal arousal levels (Berlyne 1971 in Juslin et al. 2008). We can infer from that, that the same would apply for sounds in general.Of course, what is considered optimal is not the same for all listeners(McNamara & Ballard 1999 in Juslin et al. 2008) and does not apply to all contexts(North & Hargreaves 1997 in Juslin et al. 2008).

This paper suggests the creation of a responsive affective computing application, which intends to reduce the pedestrians' level of frustration. Frustration in terms of physiology relates to high levels of arousal (Hokanson 1964). Practically we could say that our application attempts an optimization ofthe pedestrians' arousal levels, therefore enhancing their aural experience (Juslin et al. 2008). The application runs on a laptop and it communicates via Open Sound Control Protocol (OSC) with the portable EEG headset.When digital devices or portable computers relate to or influence emotions Professor of Media Arts and Sciences, Rosalind W. Picard refers to them as a type of affective computing (1997, p.3). The affective application we propose calibrates in real-time the sound environment surrounding the pedestrians (Juslin et al. 2008). We think of this application as a digital device, which adapts to the users' corresponding needs in a particular context (Coyne 2010). Professor of Architectural Computing Richard Coyne (2010, p.26) identifies calibration as an on-going dynamic process, which depends on different contexts each time and requires re-calibration when these contexts change. When the tuning involves digital devices, such as our affective brain control interface, then tuning becomes electronic, even automatic. According to hardware hacker Nicolas Collins (2006 in Coyne 2010, p.35) tuning then includes "multiple Stages of amplification, filtering and frequency shifting".

3. Method

In the current project we tested pedestrians' emotional responses to particular urban nighttime soundscapes. We chose an urban path in the center of Edinburgh city, the Middle Meadow Walk. The Middle Meadow Walk crosses one of the central parksin the city. It links the University of Edinburgh and the Old Town with quiet south residential areas. The path is surrounded with buildings of the University of Edinburgh, a renovated and newly built high class housing quarter, "The Quarter Mile", with coffee shops, a big supermarket and a hotel. At the bottom of the path a wide green park area spreads. The environment selected combines a variety of different pedestrians such as students, tourists, locals, residents, and shop owners. It is also important to mention that alongside the pedestrian pathway is a long cyclist's lane. We particularly selected this path because of the high variety of the emerging sound qualities and the highly interesting transitions in the aural environments along its way. We focused on 5 nodal locations along the path, which portray these transitions.

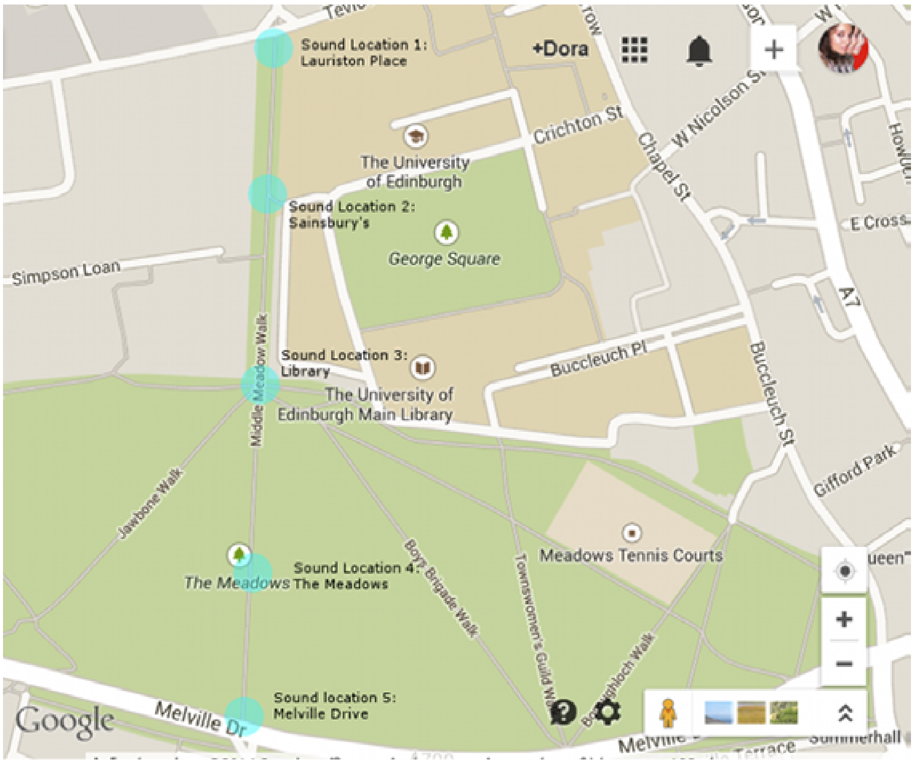

Figure 1. Map of the Sound Locations of the study, The Meadows, Google map, Access: 6.6.2014

In the map above you can see the 5 Sound Locations marked on the map. The locations are:

1. Lauriston Place, facing the entrance to The Meadows on Middle Meadow Walk (MMW)
2. In front of Sainsbury's, a little further down MMW
3. At the entrance to the Meadows, near the University Library
4. In the middle of the Meadows
5. At the southern end of MMW, facing Melville Drive

We did binaural recordings of 2 minutes duration each[1], on these 5 locations. All five recordings were done on March the 30th, 2014 between 8pm and 9pm. Equipment used was a pair of DPA microphones with a windshield and a homemade separator - the microphones were spaced to simulate a binaural recording 'head' - and a Sound Devices 744.

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[1] Apart from the recording for Sound Location 4 which lasts for 2'30''.

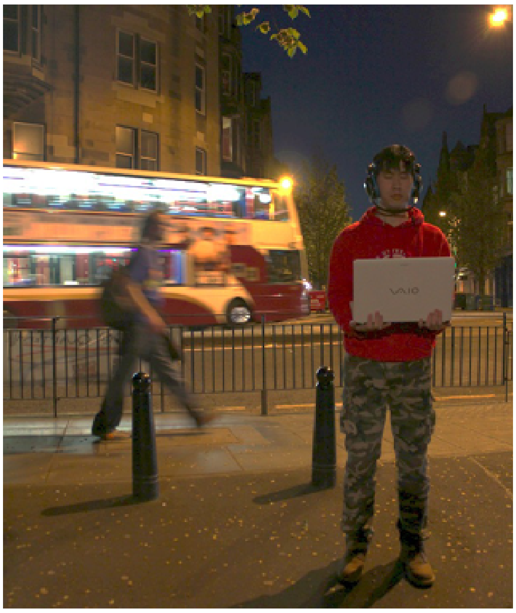

Figure 2. Sound Location 1.

Figure 3. Sound Location 2.

Figure 4. Sound Location 3.

Figure 5. Sound Location 4.

Figure 6. Sound Location 5.

3.1. A description of the sound recordings

Sound Location 1

This location is on the top of the path, on Lauriston Place, which is a very central road. The sound environment there is quite noisy with loud cars and buses passing by, people dragging their suitcases to close hotels, others coming out from the local bars and walking their way home down the Meadow Walk. This location proved to be quite exhilarating in a situation of intentional, concentrated listening. During the amount of traffic noise was quite astounding, amplified by the reflections off house walls, which surround the area. In the spectrogram below, the fairly massive noise floor up to about 1.8kHz is clearly visible, representing the constant rumble of street traffic. Most of the low-revving engine sounds (due to traffic lights nearby, where cars would stop and start) take place at the very bottom end of the frequency spectrum, which display the high sound pressure levels in that range.Generally, thicker broadband peaks (vertical lines) are passing cars. The much extended frequency range is due to wheel on road surface noise, and possibly higher engine revolutions. Thinner vertical lines represent the sounds of people walking by closely.

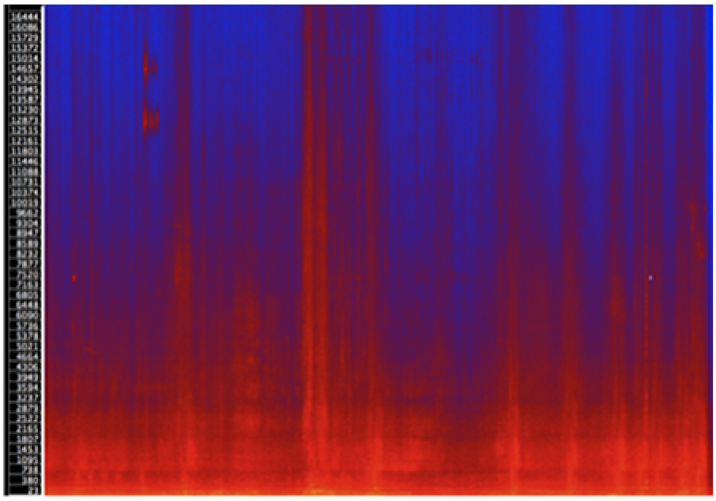

Figure 7. Spectrogram of Sound Location 1.

A closer look illustrates the low-range frequency behaviour of an accelerating engine close by. At the opposite end of the spectrum, we can find some incredibly high-pitched sounds that still stem from street traffic, such as screeching brake discs, further illustrating how this occupies considerable amounts of the overall sound space.

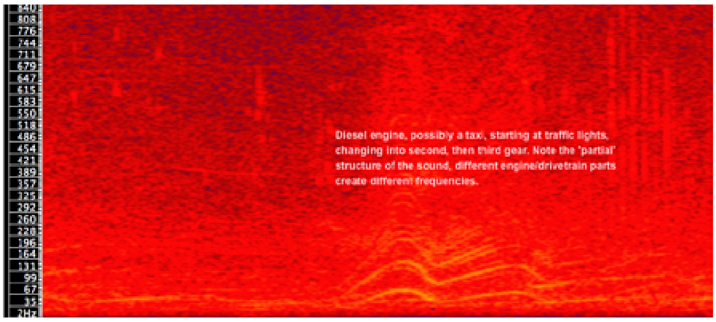

Figure 8. Accelerating engine.

Sound Location 2

Moving further down, from Lauriston Place, just in front of the Quarter Mile residential block and “Sainsbury’s” supermarket is where our second recording was made. There is a resting point for pedestrians and a small crossroad, which leads to George square where a complex of University Buildings including the Main Library of the University of Edinburgh are. Mainly students and bikers pass by. In comparison to the previous Sound Location, here we see a distinctly reduced low-end/low-mid noise floor, as roadside traffic sounds become slightly more distant (both in terms of engine and road surface sounds). At the same time, passers-by, either on foot or on bikes stand out much more discretely generating at the same time a broadband frequency range.

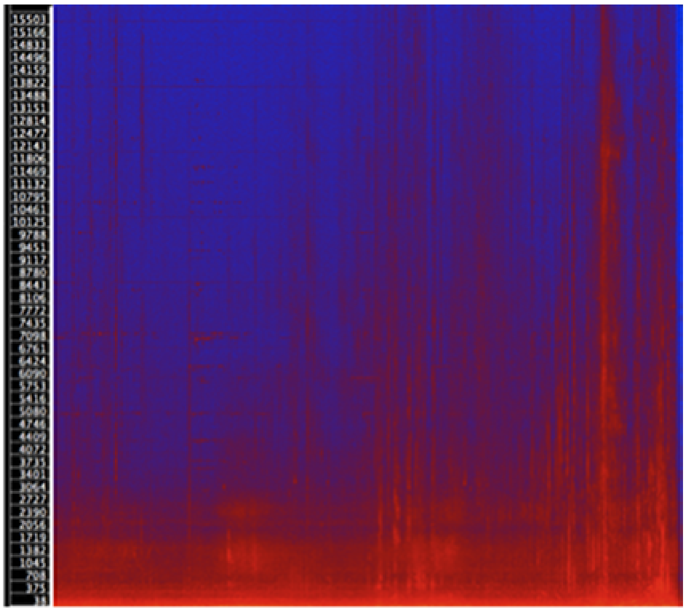

Figure 9. Spectrogram of Sound Location 2.

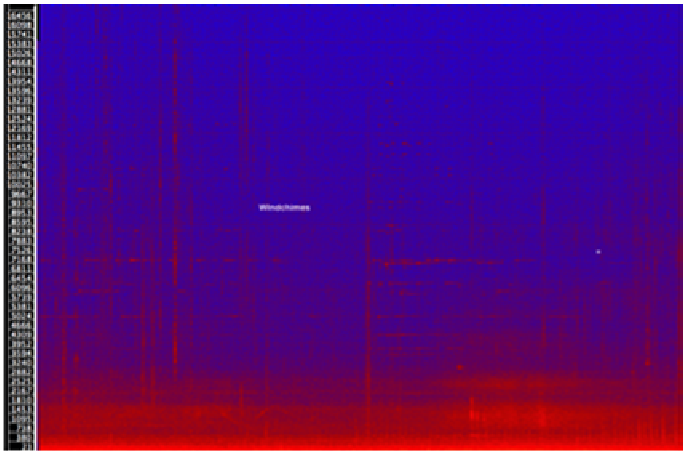

Figure 10. The Wind chimes.

Noteworthy is the sound of wind chimes present in the area, likely coming from someone's balcony. Naturally, they populate the high-frequency range, and while they are not being perceived as an incredibly loud sound source, they do provide a discernible, ever-present background (due to their frequency area not being very populated by other sounds, and their discrete onsets), and become the 'theme' of the soundscape.

Sound Location 3

This recording was made on the big cross section of the Middle Meadow Walk and the North Meadow Walk, which is adjacent to the Main Library. As we move further and further lower on our selected path, the ambient environment becomes quieter. The sound of passers-by becomes more discrete over the backdrop of distant traffic noise. While close-up engine sounds are less of a factor here, we now get to hear more wind, as the area is more open and exposed, and the road on the southern end of The Meadows becomes audible - thus, the noise floor is quite similar to the previous recording. From this point further, the green park area spreads. Quite dominant is the constant hum of a nearby generator, its fundamental frequency suggesting a pitch between F-sharp and G, which would tally with the European standard 50 Hz AC hum that equates to a G (possibly, the actual fundamental lies here. The other partials indicate (roughly) the pitches D (a fifth above) and G.

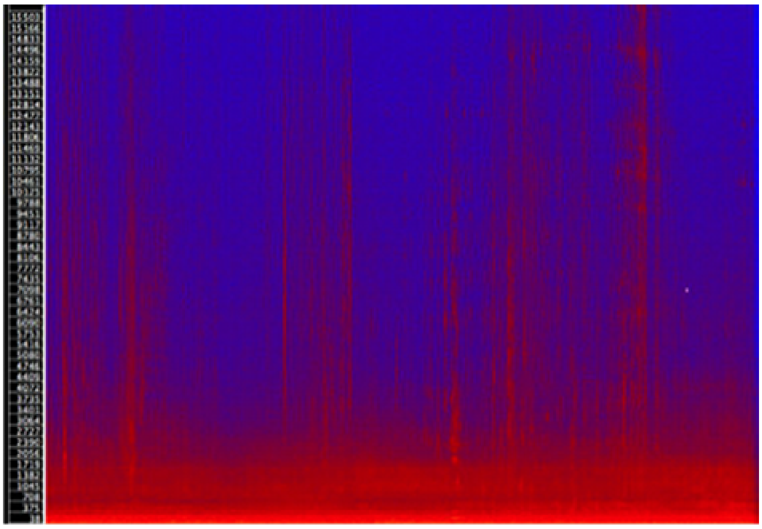

Figure 11. Full frequency spectrogram of Sound Location 3.

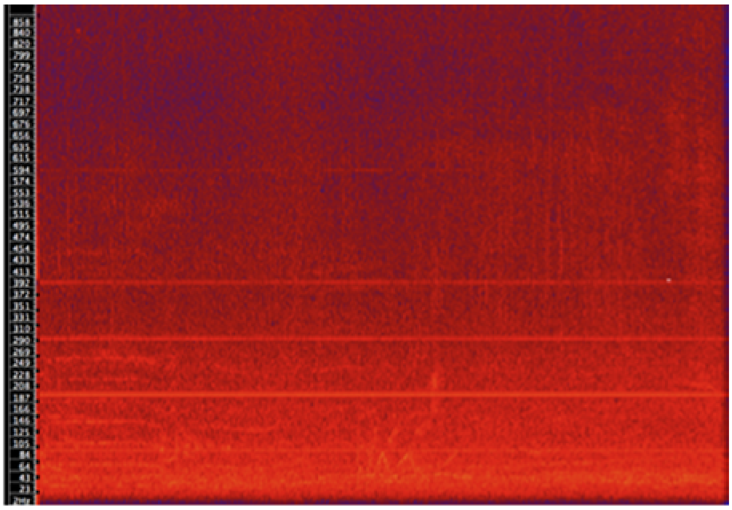

Figure 12. Spectrogram of humming sound.

Sound Location 4

This sound recording was made in the park zone. This spot is isolated from any near buildings and the number of people that walk by or cycle by is reduced. Here again the spectrogram is less crowded than before. We have again a fairly dense low end and low mid range. That still stems from traffic noise from Melville Road but at a distance, however there is now also wind noise, visible in the upper mids. But with fewer passers-by we get less of the thin vertical lines except for two people fairly near the end, which, due to the altogether less crowded soundscape, stand out much more. The wind noise is more dominant in this sound file. With fewer passers by we get less of the full frequency discreet sound events.

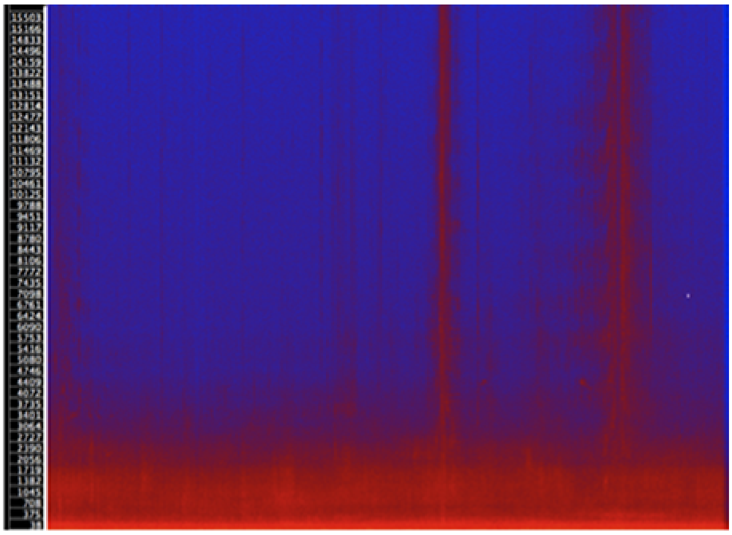

Figure 13. Full frequency spectrogram of Sound Location 4.

Sound Location 5

Our final recorded urban soundscape is on Melville Drive, at the far bottom of the Middle Meadow Walk. Melville Drive is a street,less central than Lauriston place, and with a higher speed limit during the night as the traffic lights adapt to the pedestrians' flow. To us, Melville Drive felt louder than the more crowded Lauriston Place where the generally higher noise floor is likely to lead to some amount of desensitization. Cars pass by speeding and it is worth mentioning that there is a Child Hospital near by, so ambulances are quite common to drive on that road as well. The spectrogram resembles that of Lauriston Place more closely as we're near a fairly busy street once again. As there are fewer cars and fewer buildings that would reflect the traffic rumble it's a bit less dense than the Lauriston Place spectrogram. Very few passers-by were present, so we get a fairly pure image of traffic sound here.

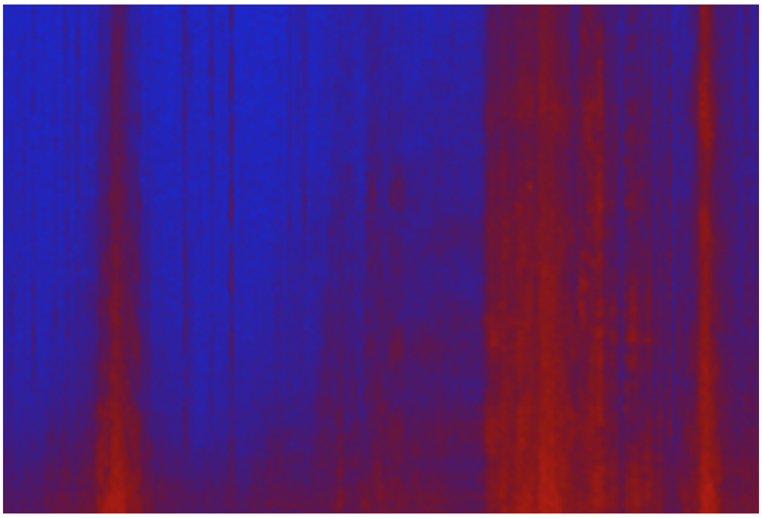

Figure 14. Full frequency spectrogram of Sound Location 5.

3.2. The experiment

Our experimentation consisted of two Stages. During the first Stage we recorded EEG data while participants were exposed to the 5 sound recordings. We then analyzed the recorded data in order to find correlations between the sound characteristics and sound events and the participants' emotional state. During the second Stage of the experimentation we tried to implement our findings and conclusions from Stage one, in order to process the recorded sounds in real-time so that the sound environment calibrates according to the emotional state of the participants.

Figure 15. Emotiv EPOC headset.

More specifically, in Stage one we used the sound recordings and ran pre-piloting experiments in order to test the physiological reactions of the participants to the sounds. Our experiments took place on location –the Middle Meadow Walk- and between 8:00pm and 9:00pm. We measured the physiological responses of the participants using a novel, low-cost commercial portable EEG (electroencephalography) headset, the EPOC EEG headset. The headset has been successfully validated against a medical grade headset (Badcock et al 2013, Aspinall et al 2012, Debener et al 2012).The headset consists of 16 sensors (14 plus 2 reference points), which record the EEG data from the participant's brain.

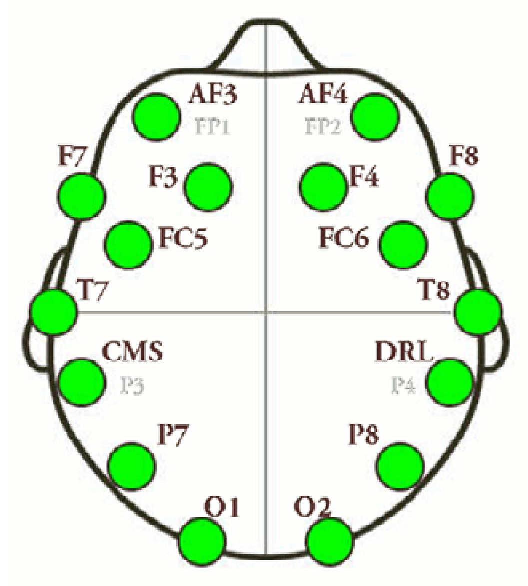

Figure 16. Positions of the Emotiv EPOC sensors[2].

The Research team of Emotiv EPOC has developed the Emotiv EPOC control panel, an application that among other suites includes the Affective suite, which we used for the purposes of our experiments. The Emotiv's Affective suite filters and translates raw EEG signals to four variables indicating 4 affective states: excitement (long-term and short-term), frustration, engagement and meditation. The values range from 0 (minimum) to 1 (maximum).

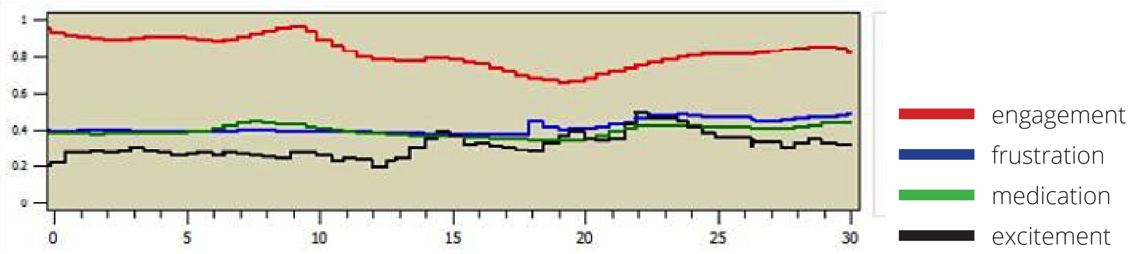

Figure 15. Representation of the affective suite variables.

A USB wireless receiver links the EEG headset to the Emotiv EPOC control panel application. Another application available from the Emotiv EPOC Company, the Mind your OSCs, sends out the affective suite values for each of the affective parameters, mapped in a range between 0 and 1 via Open Sound Control (OSC) communication protocol. We sent out the

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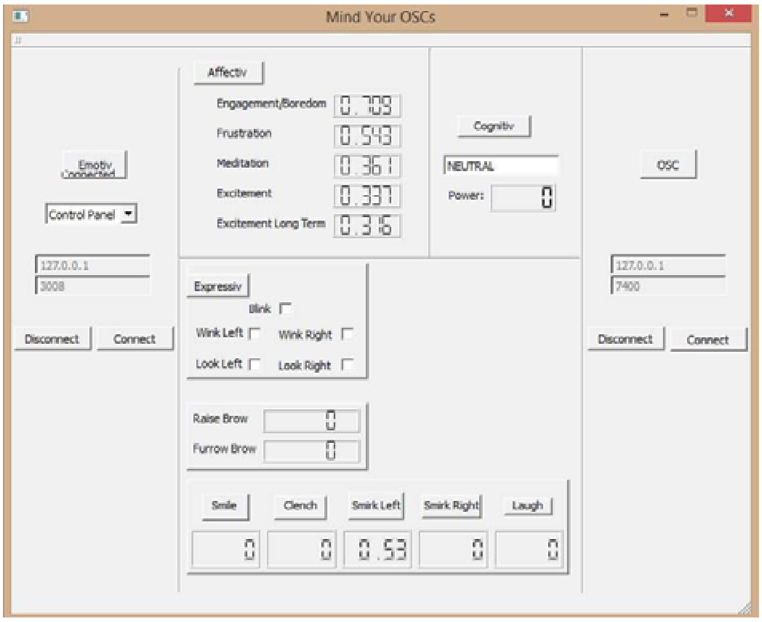
[2] Available at http://neurofeedback.visaduma.info/emotivresearch.hm

OSC messages to a custom application[i] we developed inthe visual programming language Processing[3] in order to save the affective suite parameters in a txt file.[4]



127.0.0.1
3008

Engagement/Boredom 0.709
Frustration 0.543
Meditation 0.361
Excitement 0.337
Excitement Long Term 0.316

NEUTRAL
Power: 0

127.0.0.1
7400

Blink ☐
Wink Left ☐ Wink Right ☐
Look Left ☐ Look Right ☐

Raise Brow 0
Furrow Brow 0

Smile	Clench	Smirk Left	Smirk Right	Laugh
0	0	0.53	0	0

Figure 16. Mind your OSCs reading the affective suite parameters in values between 0 and 1.

We tested 10 participants for Stage 1 and 4 of them also continued withStage 2. All participants had their eyes closed. At this point we should note that we accompanied the participants therefore there were no health and safety issues involved.

Our experiments included a laptop, a wireless EEG headset, a pair of earphones and a pair of ear defenders. The users of the experiments listened to thesound recordings and they wore ear defenders to avoidany interference with external sounds.

Below you can see a visual description of the setup that we used.

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3. Open source visual programming language Processing, available at www.processing.org

4. We also recorded raw EEG data using the Research Edition software of Emotiv EPOC, Testbench. However we did not use for the purposes of this paper.

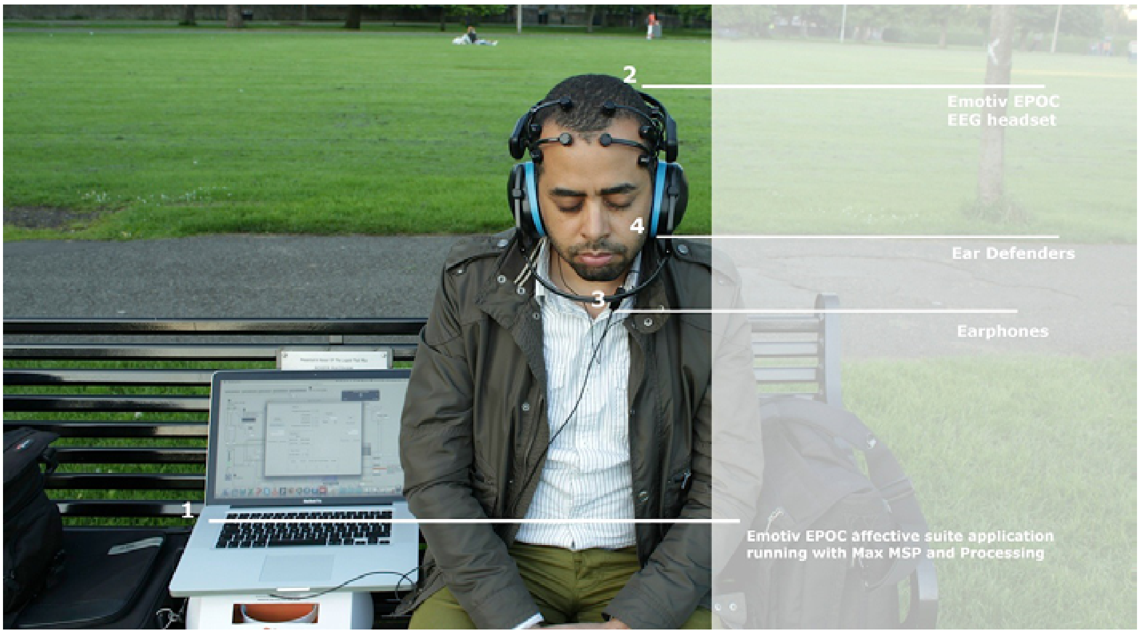


Figure 17. The setup of our experiment.

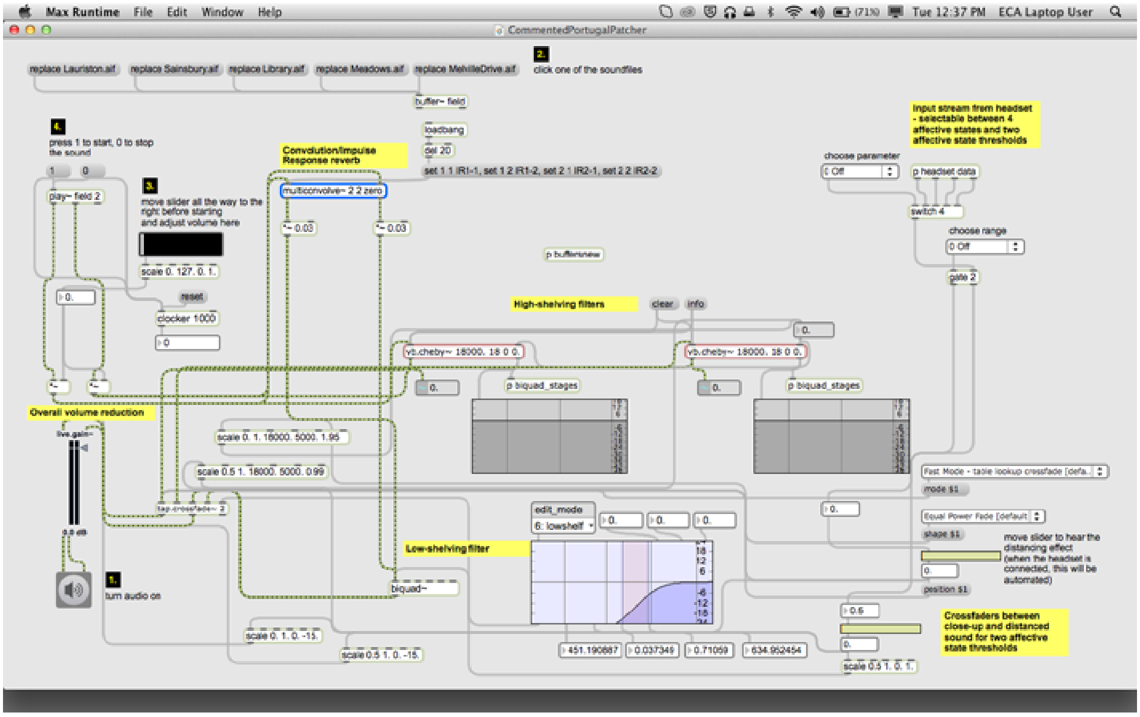
Running the Stage 1 experimentation sessions and analyzing the data that we retrieved we noticed that frustration levels would rise when sound sources approached the participants, which formed our hypothesis.

In Stage 2 we decided to focus on the creation of an application that would in real-time adjust the proximity of the sound sources. Our intension was to create a brain interface, which would calibrate the aural environment of the user in real-time, according to the levels of frustration that the users experienced. When the frustration levels would rise, the sound sources would become more distant, in an attempt to reduce frustration. For the purposes of this paper the application processes the pre-recorded sounds in a real-time mode. We then ran a second set of experiments trying to prove our hypothesis.

3.2. A proximity adaptive brain controlled interface

In order to process the sounds we created a Max/MSP patch. Having looked into into theories of distance perception (Rumsey and McCormick, 2013, p.39) and sound propagation (Simon Fraser University, 2014), in the sound design the following measures were implemented to create an impression of increasing distance between listener and sound sources:

- An overall reduction of volume
- A reduction of high-frequency content
- An increase in reverberation (which also decreases localization in the stereo field)
- A small reduction of lower-midrange frequencies, due to ground effect



1. turn audio on

2. click one of the soundfiles

3. move slider all the way to the right before starting and adjust volume here

4. press 1 to start, 0 to stop the sound

move slider to hear the distancing effect (when the headset is connected, this will be automated)

Figure 18. Snapshot of the proximity adjustment Max/MSP.

3.2. Description of the distancing patch

All 4 affective parameter values are streamed from the headset to Max/MSP. For our experiments we are occupied only with inputting the affective state of frustration. Frustration values range from 0 to 1. These values then are linked to cross faders running between close-up and distanced sounds. The higher the frustration levels the further the sound scene distances.

In terms of the signal flow, two channels of binaurally recorded sound files run through a pair of parallel high-shelving filters (one for each channel) with a variable cutoff frequency starting at 18Hz for the 'dry' signal, into an equal power cross fader and the master output gain control. Parallel to this, the signals of the same two channels run through a stereo convolution reverb, into a single low-shelving filter whose cutoff frequency is fixed at around 450Hz, with a Q of 0.71, into the cross fader, and then into the master output gain control. Regarding the distancing effects a progressive reduction of high-frequency content - and to a lesser degree low- to low-mid-frequency content – is implemented as the soundmoves further away from the listener (Farnell, 2010; Rumsey and McCormick, 2013). While high-frequency attenuation is commonly used to create a sense of distance to sound sources in audio engineering, in line with natural frequency behaviour in similar scenarios, the reduction in low- and low-mid frequency content alludes to the ground effect where Stage cancellations between direct signals and those reflected from theground can result in losses in that area of the spectrum (Rumsey and McCormick, 2013). At the same time an increase in reflections is employed to represent sound distancing in an urban environment (Rumsey and McCormick, 2013). The stereo image is progressively narrowing, as precise directional information of sound sources become blurred with increasing distance (Raffaseder, 2010, p.125). Finally, the overall loudness is reduced, as sound pressure decreases over distance (Farnell, 2010, p.80). Generally, the patch has been designed to work with a variety of (often unpredictable) source material from urban sound environments, and could also work with real-time audio input. The latter has yet to be tested. To achieve as much flexibility as possible, certain compromises had to be made where the fine-tuning of the parameters is concerned - the goal being to strike a good balance in sound behavior for differing scenarios.

4. Discussion

The current project investigates links between urban sounds and pedestrians' affective states. In order to pursue our research we set up an experimentation process, which involved 2 Stages. Firstly we ran experiments where participants ' EEG data were registered while they listened to pre-recorded sounds from a specific urban path. After the first session of experiments ended we inferred from the results that the proximity of the sound sources to the listener could be a potential factor for the configuration of the listener's frustration levels.In order to investigateour hypothesis we created at a second stage a responsive brain application, whichadjusts the proximity of the sound sources according to the listener's frustration levels. More particularly the sounds distance from the user as the frustration levels of the user increase.

We should underline that our research is currently at a pre-piloting Stage. The number of experiments is limited and the method of data registration is still being formulated in order to become more efficient. So far we have been recording data both directly from the EEG headset in a txt file but also viaan observation method.

4.1. Experiments: Stage 1.

In Stage 1 for every sound recording we marked the EEG affective values first at equal time intervals– at 30”, 1’, 1’30”, 2’ for the recordings at Sound Location 1,2,3 5 and at 30”, 1’, 1’30”, 2’, 2’30” for the recording at Sound Location 4-.We decided to focus on the affective parameter of frustration, as we were interested in investigating probable factors in the sound environment that cause negative feelings to pedestrians. We also observed that the affective parameter of frustration showed interesting fluctuations in the recorded values when the sound sources proximity oscillated.We then marked the frustration values at time instants, for which we estimatedthat sound sources were at close proximity to the listener. These instantsare as follows:

a. Sound Location 1: 25”, 36”, 48”, 56” and 1’15”,
b. Sound Location 2: 1’ 06”, 1’15”, 1’45”, 1’51”, 1’58”,
c. Sound Location 3: 8”, 14”,1’12”, 1’20”, 1’45”,
d. Sound Location 4: 2”, 1’09”, 1’32”, 2’15”,
e. Sound Location 5: 6”, 10”, 30”, 1’18”, 1’34”, 1’45”, 2’

For every participant we calculated their average frustration levels for every sound recording and the total average frustration level for all 5 recordings together,both at equal intervals and at close sound proximity instances. We also calculated the overall total average deriving fromall participants for all 5 recordings together again at equal intervals and at close sound proximity instances. We then compared the EEG results between the two different time intervals. The results showed that the frustration levelsrecorded at close proximity instances were slightly higher than the frustration levels recorded at equal time intervals, reinforcing our initial assumption.

Chart 1. Average frustration levels of each participant for all 5 sound recordings registered at equal intervals and at close proximity time instants.

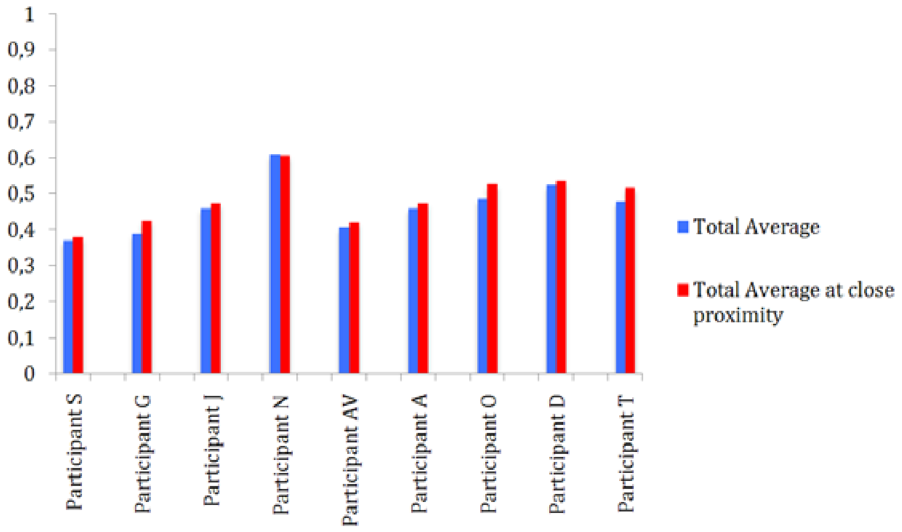
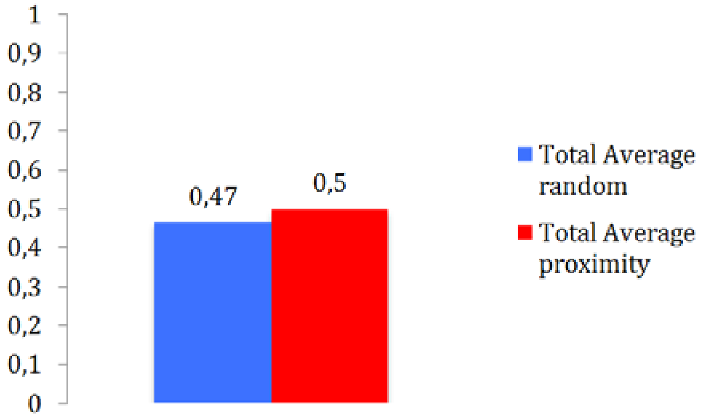


Chart 2. Average frustration levels of all participants for all 5 sound recordings registered at equal intervals and at close proximity time instants.



4.2. Experiments: Stage 2.

We then incorporated this inference regarding links between proximity of sounds andfrustration in the development of a responsive brain-controlled application. The application adjusts the proximity of the sounds according to the frustration levels of the experimentee. More specifically, when frustration rises the distance between the listener and the sound sources becomes larger. We then proceeded with testing the application with4 participants from Stage1. The setup conditions of the experiments were exactly the same only now the pre-recorded sounds adjusted in real-time to the users' frustration levels. We wanted to see whether distancing the sound scene would reduce the levels of frustration that the experimentees experienced.

We recorded the EEG frustration levels at the same close proximity time instants that we used in Stage 1- Sound Location 1: 25", 36", 48", 56", 1.15", Sound Location 2: 1.06", 1.15", 1.45", 1.51", 1.58", Sound Location 3: 8", 14", 1.12", 1.20", 1.45", Sound Location 4: 1.09", 1.32", 2.15", Sound Location 5: 6", 10", 30", 1.18", 1.34", 1.45", 2'-.

4.3. Comparing frustration levels between Stage 1 and Stage 2

We then compared the EEG frustration values recorded at close proximity instances between Stage1 and Stage 2.

Chart 3. Comparing the average frustration levels of all 4 participants for every sound recording between Stage 1 and Stage 2.

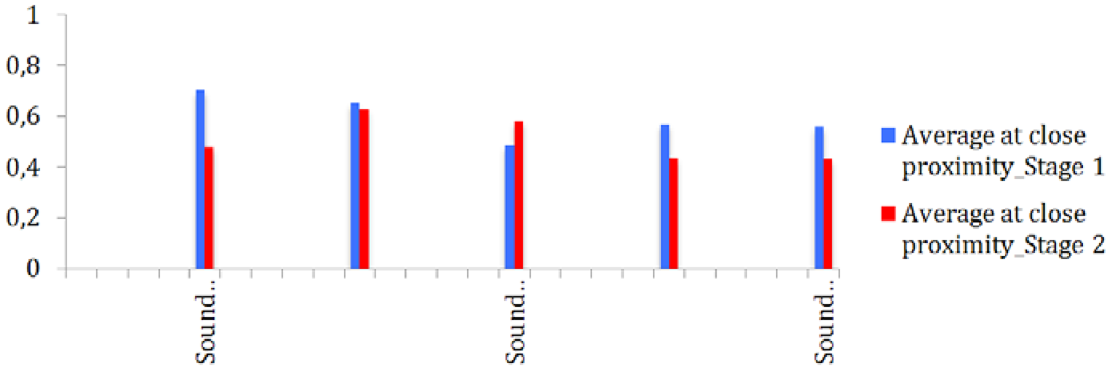
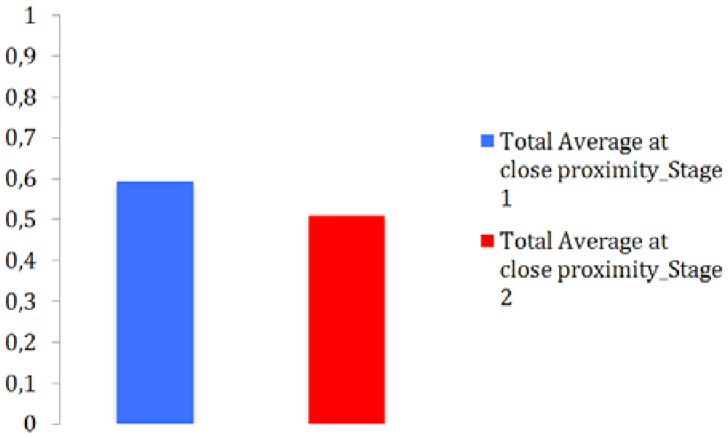


Chart 4. Comparing the total average frustration levels of all 4 participants for all sound recordings between Stage 1 and Stage 2



The results show that on average our application manages to decrease the frustration levels of the participants from a total average of 0.6 to a total average of 0.51. When looking analytically at each sound recording, we see that the frustration levels for all participants drop when using our application, except for sound location 3 for which the frustration levels increase.

Table 1. Comparing the frustration levels of each of the4 participants for everysound recording between Stage 1 and Stage 2.

Sound location 1	Stage 1	Stage 2	Change	Sign	Standard Deviation
Participant G	0.402	0.384	Reduction	(-)	
ParticipantA	0.569	0.391	Reduction	(-)	
ParticipantO	0.832	0.286	Reduction	(-)	
ParticipantAV	1	0.849	Reduction	(-)	0.25
Sound location 2					
ParticipantG	0.519	0.311	Reduction	(-)	
ParticipantA	0.476	0.793	Increase	(+)	
ParticipantO	0.604	0.465	Reduction	(-)	
ParticipantAV	1	0.928	Reduction	(-)	0.29
Sound location 3					
ParticipantG	0.396	0.325	Reduction	(-)	
ParticipantA	0.239	0.672	Increase	(+)	
ParticipantO	0.342	0.563	Increase	(+)	
ParticipantAV	0.966	0.758	Reduction	(-)	0.19
Sound location 4					
ParticipantG	0.375	0.361	Reduction	(-)	
ParticipantA	0.67	0.476	Reduction	(-)	
ParticipantO	0.371	0.363	Reduction	(-)	
ParticipantAV	0.86	0.548	Reduction	(-)	0.09
Sound location 5					
ParticipantG	0.44	0.351	Reduction	(-)	
ParticipantA	0.416	0.447	Increase	(+)	
ParticipantO	0.488	0.404	Reduction	(-)	
ParticipantAV	0.886	0.529	Reduction	(-)	0.08

In table 1 we can see analytically for each of the 4 participants and for each of the 5 sound recordings, the levels of frustration in Stage 1 and Stage 2, whether a reduction or an increase was noted and the standard deviation for the frustration values in Stage 2. We notice that the frustration values drop in most cases for 3 out of the 4 participants. The experimentation sessions during Stage 1 and Stage 2 were carried out on 2 different days. Thus the discrepancy detected could be interpreted as a random event; participant A could have had high levels of arousal on the day of the experiment, prior to our actual testing.Since the experiments take place on location and taking into account the fact that Edinburgh has cold temperatures during springtime and especially during night hours, this could have been another reason that arousal was high for that specific participant.

Our findings underpin our hypothesis; proximity of the sound sources to the listener affects her levels of frustration. This outcome encourages us to continue our investigation with more participants.However we ran a Wilcoxon signed rank test but the conclusions were inconclusive. A bigger sample size will give us more valid statistical results.

Moreover we would like to note that the EPOC EEG headset would at times not stream data, which then led to repeating the experiment or having a partial data set. Additionally in terms of future improvements, our recording methods were not very accurate when it came to the synchronization of the sound files with the EEG recordings with a divergence of a couple of seconds.

We are also considering improving our Max/MSP proximity adjusting application. Customization of the processing parameters for each sound file separately and application of different urban reverberation settings to the audio signal could improve the proximity and distancing effect that we aimed for.

Most importantly though we should take into account some aspects of "distance hearing" that we missed in our analysis. In order for a listener to determine correctly the distance between the sound source and the auditory event, familiarity with the audio signals is necessary. For example the distance of human speech, which is a sound familiar to us, can be perceived successfully regardless of its loudness. On the contrary when unfamiliar sound sources are away more than 3m from the listener the auditory distance perception depends on the loudness only, generating discrepancies at the identification of the distance of the sound source (Blauert 1997, p.45). This could have led into a misinterpretation of the sound scene and our hypothesis, as proximity might have been confused with loudness.

When people, such as our participants, listen to binaural recordings while deprived of any visual cues they usually "localize the sound scene behind them", which is an automatic assumption the brain does when not able to see the sound sources (Rumsey and McCormick, 2013, p.38).It is also possible that the signal processing applied in our applicationinstead of altering the distance perception, it might have yielded a sense of unfamiliarity to the participants, as the sound scene would suddenly distance from the user's ears.

5. Conclusion

The current project investigates links between urban sound environments and pedestrians' emotions. We recorded 5 specific locations along a pathway, which crosses a central park of Edinburgh. Participants listened to the 5 sound recordings with their eyes closed while we were tracking their affective state with the aid of portable EEG technology. Our findings showed that frustration levels increased when the proximity of the sound sources was close to the listeners. We used this information for the purpose of creating an affective brain application, which would calibrate the sound environment according to the pedestrian's emotional state. Our aim was to enhance the aural experience of pedestrians in urban environments, by reducing their frustration. Higher frustration levels would cause the recorded sound scene to distance further from the listener. The results indicated that the average level of frustration could be reduced when using our proximity adjustable application. Effectively our application manages to calibrate the aural environment of the stationary pedestrians successfully, enhancing their experience.

We should underline at this point that the experimentation we described in this paper was only a pre-pilot, which we used to get an initial understanding firstly of urban sound perception in relation to emotional response and secondly to gain technical experience for further research.

Understanding how pedestrians respond emotionally to their urban sound environment gives us useful information regarding spatial behavior. As Mehrabian and Russell (1974) wrote, physical stimuli, which relate to feeling pleasurable and aroused, generate behaviours of preference and avoidance in the environment. We could assume then that negative feelings, such as frustration would produce avoidance behaviours. Predicting and understanding such spatial behaviours could play an important role in the urban design process.

However for future work, as Picard mentions in her book on Affective Computing (1997), it is important to customize an affective interface to the specific metrics of a person, as it is difficult to assume that all people react emotionally exactly the same way. At this point the use of questionnaires and the implementation of a machine-learning algorithm could help us in future developments understand the precise aspects of the urban sounds that reduce or increase frustration and also help us calibrate our application to the needs of a particular individual.

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REFERENCES

Aspinall, Peter, Mavros, Panagiotis, Coyne, Richard and Jenny Roe. “The urban brain: analysing outdoor physical activity with mobile EEG”British Journal of Sports Medicine (2013): accessed June 5, 2014, doi: http://dx.doi.org/10.1136/bjsports-2012-091877

Badcock, Nicholas, Mousikou, Petroula, Mahajan, Yatin, de Lissa, Peter, Johnson, Thie and Genevieve McArthur. “Validation of the Emotiv EPOC(®) EEG gaming system for measuring research quality auditory ERPs”, PeerJ1 (2013): e38, accessed 10 May 2014, doi: 10.7717/peerj.38.

Blauert, Jens, Spatial hearing: the psychophysics of human sound localization, (Massachusetts: MIT Press, 1997), 45.

“Brain Drain”, last modified April 25, 2014, https://dmsp.digital.eca.ed.ac.uk/blog/braindrain2014/.

Chion, Michel, Audio-Vision: Sound on Screen, (New York: Columbia University Press, 1994), 11.

Collins, Nicolas, Handmade Electronic Music The Art of Hardware Hacking, (New York, London: Routledge, 2010)

Coyne, Richard, The tuning of place: sociable spaces and pervasive digital media, (Cambridge, Massachusetts: MIT Press, 2010), 20-35.

Damasio, A, The feeling of what happens: Body and Emotion in the Making of Consciousness, (Florida: Ecco Press, 1999), 12-46.

Debener, Stefan, Minow, Falk, Emkes, Reiner, Gandras, Katharina and Maarten de Vos, “How about taking a low-cost, small, and wireless EEG for a walk?”,Psychophysiology 49 (2012): 1617-1621, accessed April 2014, 2014, doi:10.1111/j.1469-8986.2012.01471.x

Farnell, Andy, Designing Sound (Camrbidge: The MIT Press, 2010), 80.

Hokanson, Jack E., and MichaelBurgess. “Effects of physiological arousal level, frustration, and task complexity on performance.”The Journal Of Abnormal And Social Psychology 68 (1964): 698-702, accessed June 2, 2014.doi:10.1037/h0049340.

Hall, Edward T., The Hidden dimension of space (New York: Anchor books Edition, 1966), 40-116.

Howard, Ian Porteus, Perceiving in Depth, Volume 3: Other Mechanisms of Depth Perception. (New York: Oxford University Press, 2012), 281.

Jusling, Patrick N. and Daniel Västfjäll. “Emotional responses to music: The need to consider underlying mechanisms”, Behavioural and Brain Sciences31 (2008): 559-575, accessed May 20, 2014, doi:http://dx.doi.org.ezproxy.is.ed.ac.uk/10.1017/S0140525X08005293.

Kane, Brian. “L’ObjetSonoreMaintenant: Pierre Schaeffer, sound objects and the phenomenological reduction”, Organized Sound 12(2007): 15-24, accessed April 15, 2014, doi: http://dx.doi.org/10.1017/S135577180700163X.

Lengen, Charis and Thomas Kistemann, “Sense of place and place identity: Review of neuroscientific evidence”, Health and Place 18 (2012): 1162-1171, accessed June 6, 2014, http://www.sciencedirect.com/science/article/pii/S1353829212000275

Mehrabian, Albert and James A. Russell, An Approach to Environmental Psychology(Cambridge: The MIT Press. 1974), 3-83.

Pallasmaa, Juhani, The Eyes of the Skin. Architecture and the Senses.(New York: John Wiley, 2005).

Picard, Rosalind W., Affective Computing(Cambridge Massachusetts: MIT Press, 1997)

Rumsey, Francis and Tim McCormick, Sound and Recording: An introduction (Abingdon, UK: Focal Press, 2013), 38-39.

Raffaseder, Hannes, Audiodesign (München: Carl HanserVerlag, 2010), 125.

Schaeffer, Pierre, Traité des objetsmusicaux, (Paris: Le Seuil, 1966)

“Simon Fraser University,Sound Propagation”, last modified 1999, http://www.sfu.ca/sonic-studio/handbook/Sound_Propagation.html#section_3

Wetherell, Margaret, Affect and Emotion: A New Social Science Understanding(London: SAGE, 2012), 12.

Third-party externals used in the Max/MSP patch

“ESB-Objects for Max/MSP, vb.cheby”, http://www.esbasel.ch/Downloads/MaxMSP-Objects.htm.

“University of Huddersfield Repository,The HISSTools Impulse Response Toolbox: Convolution for the Masses”, last modified 2012, http://eprints.hud.ac.uk/14897/.

“University of California at Berkeley Department of Music, OSC-route”, last modified 2014, http://cnmat.berkeley.edu/patch/4029.

“74objects, TapTools”, http://74objects.com/taptools/.

---

i

```
import oscP5.*;
import netP5.*;
float excitement;
float boredom;
float engagement;
float frustration;
float meditation;
OscP5 oscP5;
PrintWriter output;
void setup() {
oscP5 = new OscP5(this, 7400);
// Create a new file in the sketch directory
output = createWriter(“testing.txt”);
}
void draw() {
int m = millis();
//output.print(m,”excitement=”++ “,”+);
output.println(“time=” + hour()+”:”+minute()+”:”+second() + ” ” + “,”);
output.println(“excitement=” + excitement + ” ” + “,”);
output.println(“engagement=” + engagement + ” ” + “,”);
output.println(“frustration=” + frustration + ” ” + “,”);
output.println(“meditation=” + meditation + ” ” + “,”);
output.println(“boredom=” + meditation + ” ” + “,”);
}
void oscEvent(OscMessage theOscMessage) {
// check if theOscMessage has an address pattern we are looking for
if(theOscMessage.checkAddrPattern(“/AFF/Excitement”) == true) {
// parse theOscMessage and extract the values from the OSC message arguments
//excitement = ceil(theOscMessage.get(0).floatValue()*255);
excitement = theOscMessage.get(0).floatValue();
} else if (theOscMessage.checkAddrPattern(“/AFF/Meditation”) == true) {
meditation =theOscMessage.get(0).floatValue();
}
```

```
if(theOscMessage.checkAddrPattern("/AFF/Engaged/Bored") == true) {
// parse theOscMessage and extract the values from the OSC message arguments
engagement = theOscMessage.get(0).floatValue();
boredom = 1-engagement; //to seperate boredom from engagement
} else if (theOscMessage.checkAddrPattern("/AFF/Frustration") == true) {
frustration = theOscMessage.get(0).floatValue();
}
}
void keyPressed() {
output.flush(); // Writes the remaining data to the file
output.close(); // Finishes the file
exit(); // Stops the program
}
```

Saving the Emotiv EPOC affective suite data in a text file using OSC

Based on the ProcessingEpocOsc1 example by Joshua Madara, available athyperritual.com/blog/processing-epoc-osc/

Adjusted by Dorothea Kalogianni and Zechao Li for the purposes of Brain Drain (Digital Media Studio Project 2014, University of Edinburgh)