Thinking about sound and space

Recording people's emotional responses to spaces

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In this paper we explore what EEG techniques teach us about people's responses to environments. We explain two complementary projects: a sound art installation in which a performer was rigged up with an EEG device and required to sit for 30 minutes in a chair. Around him were positioned custom-made instruments for generating electro-mechanical sounds. A screen behind the performer showed a dynamic geometrical image that altered according to his mood state and as picked up by EEG (engagement, meditation, frustration and excitement), while a sound technologist operated the instruments. We used the same sound sources for an experiment in which we tested people's responses to sounds. We discuss the spatial implications of this work.

Keywords: *EEG, brain, sound, space*

In this paper we explore what EEG techniques teach us about people's responses to environments. At the eCAADe2012 conference Mavros and Coyne reported on their study into the implications of EEG for spatial representation (Mavros et. al., 2012). They were also able to provide further empirical evidence of the benefits of taking respite from busy urban life by moving through parkland (Aspinall et al, 2013). In this paper we'll demonstrate the outcome of a more speculative approach to using EEG in a spatial context. We connect to the interest surrounding innovative technologies for understanding the brain using a mobile electroencephalography (EEG) device for recording and visualizing some of the key frequencies propagated through the human nervous system in response to emotional stimuli.

EEG is primarily designed for the clinic and the laboratory, but this emerging technology is being deployed to make game play more responsive, for detecting people's emotional responses to movies, music, marketing campaigns and environments, and for assisted control of prosthetic devices and computers. These new techniques of brain representation can help designers understand how the behaviours we observe correspond to brain activity and even to specific regions of the brain (Damasio, 1999). The technology is new and poses challenges in terms of validation. We have been exploring how best to deploy the technology to provide meaningful results in the context of design.

MONITORING EMOTIONAL RESPONSE

Recent developments in neuroimaging technologies and computational neuroscience offer insights into some of the ways environments impact on brain activity (Lengen and Kistemann, 2012). People obviously interact with their environments through all the senses and through embodied activity, much of which is perceived as an emotional response to a place (Lengen and Kistemann, 2012). Damasio describes the physiological processes that are involved in the generation of an emotional response. Particular regions in the brain communicate with the rest of the body altering one's affective states (1999, p.46), a concern of those working in the field of environmental psychology (Mehrabian and Russell, 1974, p.3). Physical stimuli have a direct impact on people's emotions and an indirect effect on the behaviour of that person within that specific environment, inducing actions of preference and avoidance (Mehrabian and Russel, 1974, p.6).

Mehrabian and Russell summarize responses to the environment in terms of pleasure, arousal, and dominance, and variations on these (Mehrabian and Russell, 1974, p.19). All emotional reactions to any kind of situation are defined in connection with these three responsive variables: pleasure, arousal and dominance. They explain that: "the feeling of boredom or fatigue may be described as one that is low on pleasure, arousal and dominance. On the other hand excitement may be characterized as an emotional state of high pleasure, arousal and dominance. Anxiety and stress rate high on arousal but low on pleasure and dominance. Relaxation, contentment and comfort rate high on pleasure and dominance but low on arousal." (Thayer 1967; 1970, in Mehrabian and Russell, 1974, p.83). There is evidence that pleasure, arousal and dominance represent the core of any emotional human response independently of the type of the environment or the sense stimulated. These emotional response variables are also associated with the physiological response mechanism of the human body, which again is common under any stimulus-modality condition (ibid, p.17).

Wearable EEG technology offers physiological input to a computing system (Picard, 1997). Physiological signals carry affective information from which systems infer the emotional responses of those wearing the technology (ibid, p.160). One of the first studies to monitor emotional responses outdoors using mobile EEG technology was conducted at the University of Edinburgh by Aspinall et al (2012). More specifically, they used a low-cost a mobile EPOC EEG headset and a particular application (Emotiv's Affective Suite) that filters and translates raw EEG signals to four variables indicating 4 affective states: engagement, frustration, meditation and excitement (long-term and short-term). Their findings showed significant reductions in frustration when walkers transitioned from busy urban environments to green spaces.

The human sensorium is rich and varied. To simplify our test conditions we wanted our participants to have their eyes closed while listening to a repertoire of sounds. Using the auditory sense alone is what Schaeffer (1966) calls "the acousmatic experience." Acousmatic (Chion, 1994, p.11) is a word of Greek origin that "indicates a noise which is heard without the causes from which it originates being seen." The acousmatic experience shifts the attention from any visible or tactile cues in space to hearing only, without the visual distraction of attending to its source: "Often surprised, often uncertain, we discover that much of what we thought we were hearing, was in reality only seen, and explained, by the context" (Schaeffer, 1966 in Kane, 2007, p.17). There is evidence that using the auditory sense alone in reflective environments is fairly reliable when judging the qualities of a space. The size of the space, the distance between the listener and the surfaces can be estimated due to the reverberation time and the early reflection time (Rumsey and McCormick, 2013, p.39).

Researchers have identified the physiological reactions that take place when the brain responds to sound stimuli. Sound stimuli, which are sudden, loud, dissonant, or fast in tempo, cause an auditory sensation of arousal or unpleasantness (e.g. Berlyne

1971; Burt et al. 1995; Foss et al. 1989; Halpern et al. 1986, in Juslin et al., 2008). It seems our perceptual system is incessantly looking for changes or events in the environment. Change can be perceived as "sudden or extreme sounds, sounds that change very quickly, or sounds that are the result of strong force" (Juslin et al., 2008, p.564). These changes evoke high arousal, which then drives the listener to direct their attention to the particular sensory stimuli. It is important here to note that sensory dissonance implies a sense of danger and alarm (Ploog, 1992, in Juslin et al., 2008).

Berlyne (1971 in Juslin et al., 2008) has investigated properties that induce arousal in music. His findings show that listeners prefer stimuli, which provoke optimal levels of arousal. We could then generalize and assume that the same would be expected from other sounds as well. We should also bear in mind that what is considered optimal for one listener need not be the case for another, as it depends on the specific situation (North & Hargreaves, 1997, in Juslin et al., 2008), one's personality (McNamara & Ballard, 1999 in Juslin et al., 2008), and personal history.

METHOD OF STUDY

The headset consists of 16 sensors (14 plus 2 reference points), which record the EEG data from across a participant's scalp (Figure 1, 2). The research team of Emotiv EPOC developed the Emotiv EPOC control panel, an application that among other suites includes the Affectiv Suite, which we used for the purposes of our study. The Emotiv's Affective suite filters and translates raw EEG signals to four variables indicating 4 affective state: excitement (long-term and short-term), frustration, engagement and meditation. The headset has been successfully validated against a medical grade headset (Badcock et al, 2013, Aspinall et al, 2012, Debener et al, 2012).

The USB receiver links the EEG headset to the Emotiv EPOC control panel application wirelessly. We then recruited another application available from Emotiv EPOC, called Mind your OSCs. The latter sends out the affective suite values for each of the affective parameters, mapped in a range between 0 and 1 via OSC (open sound control) communication protocol. We sent out the OSC messages to a custom application we developed in a visual programming language application, Processing. The output (Figure 3) was then manipulated in real-time allowing visualisation on a screen in various formats while the affective suite parameters were saved in a txt file.

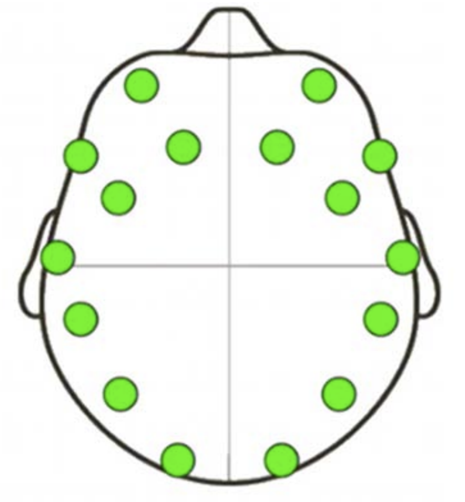

Figure 1
Screen capture of Emotive EEG contact points. The diagram indicates that all sensors are receiving data.

We created a set of 8 sound sources: 8 electroacoustic instruments. One of these was a Tibetan Singing Bowl (Figure 4). It was created from a traditional record player, a brass bowl, and a wooden paddle. A stationary microphone supports the paddle, which then touches the side of the bowl. As the turntable platter rotates, a resonating sound is generated due to friction. The sound shows continuous high frequencies representing the fundamental plus overtones. The sound is characterized by multiple transients and by grain. It also has a pulsation but overall is quite steady. The other sound sources included attachments to a piano soundboard, en electromagnetic bow, a laser pointer on a turntable, wind chimes, a light sensor phasing theremin and a foot operated piece of resonant wood shaped like a fish.

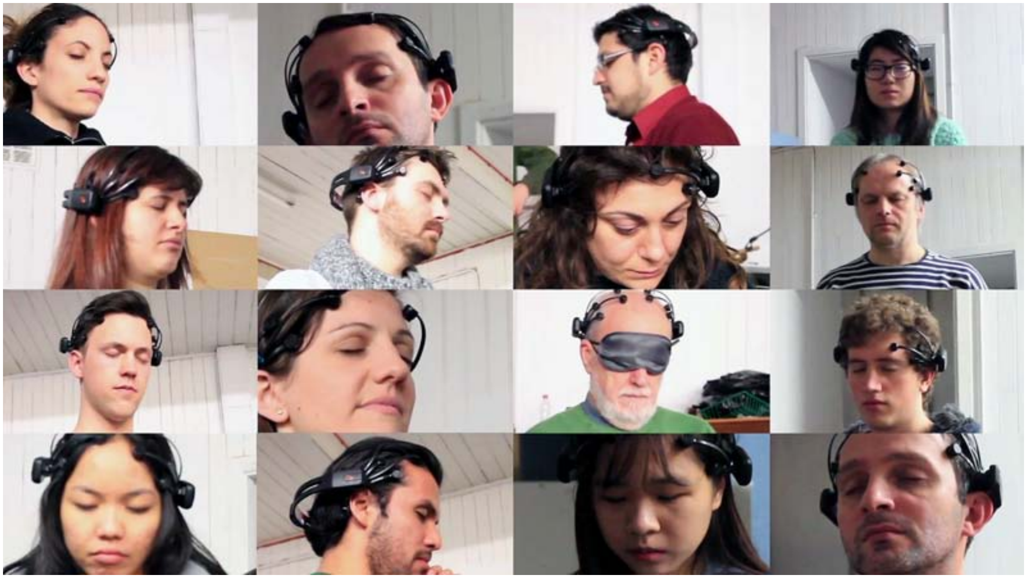

Figure 2
Participants in the study wearing the EEG headset.

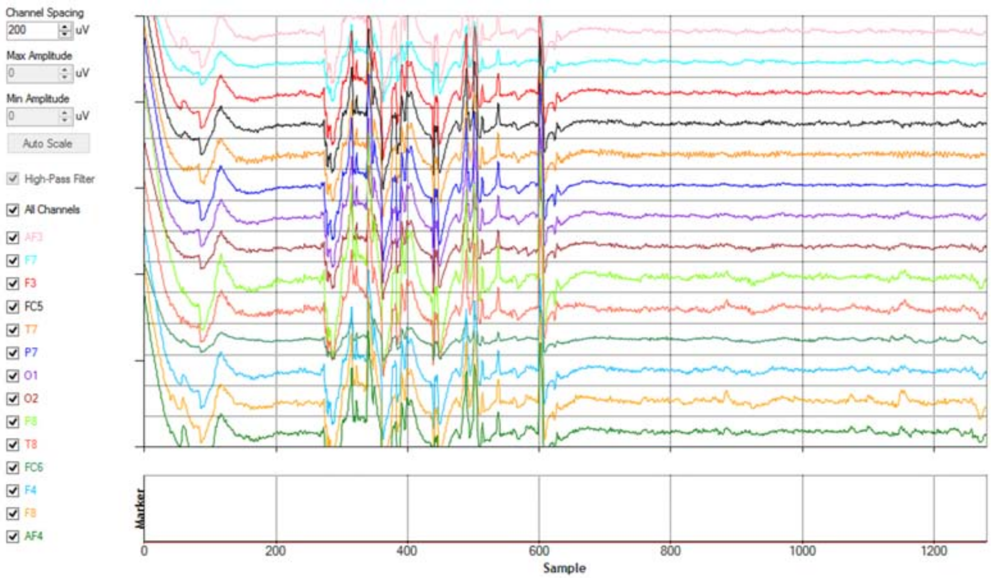

Figure 3
Raw EEG output from one of the participants in our study

We will describe the EEG performance first, and then the experimental study.

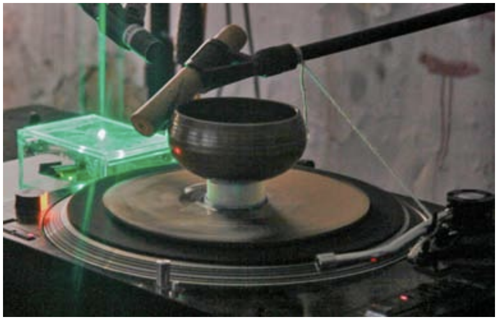

Figure 4
Tibetan Singing Bowl

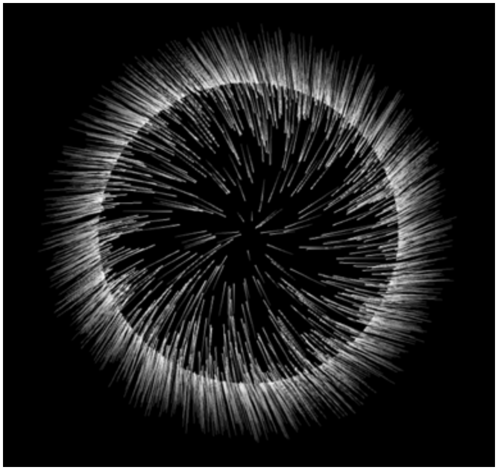

Figure 5
The hairy sphere representation (based on Noise Sphere by David Pena)

Figure 6
The EEG performance: experiencing excitement (Brain Drain, 2014).

The performance: visualising brain activity

The visuals in our installation are linked to the emotional responses of an individual designated as a performer. In real-time the performer's emotions evoked by the aural environment are used and processed in order to generate corresponding visualizations. On a technical level the EEG affective state parameters are sent to the application in Processing. Others have conducted similar research using the Emotiv EPOC headset to generate experimental art. Prominent is the work of Fraga et al (2013) from the *Instituto de Matemática e Arte de São Paulo*. Fraga et al used the Emotiv EPOC headset in order to retrieve the affective values of users so that to manipulate in real-time arts oriented virtual reality environments. We felt that it would be necessary to develop different visualization concepts in order to investigate and interpret whether people can associate with and recognize the emotions represented.

For the purpose of this investigation 3 different visualization concepts were developed. The first one employed a more organic approach. A hairy-like spherical organism continuously rotates in the digital space (Figure 5). The 4 affective states are expressed via the different behavior of the hairs of the organism. These behaviours attempt to imitate the responses of ciliated protozoa, or other familiar organic forms.

The second concept that we worked on involved simple geometrical forms, and changes in colour and size. Once again we attempted to relate these 3 parameters to expressions of engagement, frustration, meditation and excitement. For example since excitement is experienced via a sense of arousal (Thayer 1967; 1970, in Mehrabian and Russell, 1974, p.83), for our visualization we associated excitement with an effect which simulates explosion (Figure 6). The further the boxes explode the higher the values of excitement. Frustration uses a trembling effect (Figure 7). Frustration is often associated with a feeling of irritation (Oxford University Press, 2010). Therefore having a shaking geometry on the screen could represent this feeling.

Figure 7
The EEG performance: experiencing frustration (Brain Drain, 2014).

Finally the third method of representation was more numerical. We used a 5 cornered graph, in other words a radar chart (Figure 8), that adjusted to the EEG parameters in real-time. This allowed us a clearer visualization of the data that the audience would find easier to interpret. This performance raised the profile of our work, provided a vehicle for learning about and testing the technology, and provided material for the next phase of the project: the experiment with several human participants.

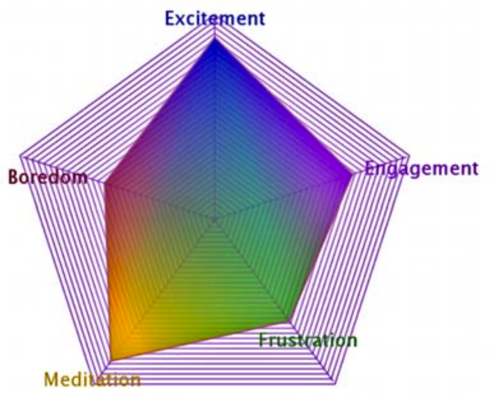

Figure 8
The radar chart representation.

The experiment: comparing responses to sound

The experiment involved 16 participants from amongst a cohort of PhD and design students. Each participant followed the same protocol over 4 days, each participant was dealt with one after the other. We spent 40 minutes with each participant. There were three phases to each encounter. Each participant was given a short questionnaire in which they were asked to describe in their own words what the 4 affective parameters (engagement, frustration, meditation and excitement) meant to them, i.e. what synonyms come to mind. We noted this in each case. Then came the fitting of the headset, and orientating the participant to the protocol. For the next phase the partipant was blindfolded, sitting in a chair in the centre of a sound environment populated by the sound sources. The experimenters played each sound in succession for 20 seconds, pausing between each. We video captured the levels of the output parameters from the screen for later analysis. After each sound was played we asked each participant which of the four parameters applied most directly to their experience while listening to the sound. They were also free to use their own words to describe how they felt during the sounds' performance.

During the analysis stage we visually inspected all of the visual output data and read off the 4 parameter values at a moment 10 seconds into the video. We selected this moment in the time sequence as that seemed to be the point at which the EEG effect was most pronounced. This is a pilot study and we selected the results from just 6 of the participants on the basis of the reliability of the recording: the sounds and the video capture were most accurately synchronised.

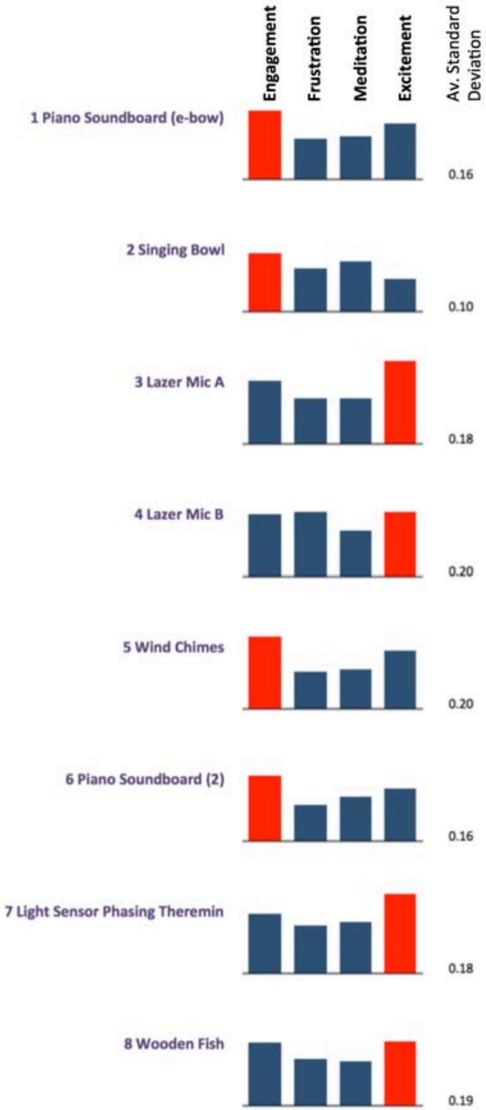

Figure 9
Average values of the 4 affective parameters for every sound object.

The results are shown in figure 9. We averaged the results from each of the participants for each of the sound sources. There was a fair degree of agreement on the EEG parameters. We have subjected the data to various tests, including a One Sample Wilkinson Signed Test. We also presented the 8 graphs to a set of people to see if they could match the sounds to the graphs, including a random set. The results of these confirmation tests are inconclusive. The experiment described by Aspinall et. al. employed a form of high dimensional correlated component regression analysis with M-fold cross-validation. This is excellent at detecting significant patterns in such data, and represents further work for our project.

A questionnaire completed by the audience members at the end of the performance indicated that most thought the mood of the sounds matched the EEG responses as displayed on the screen and most were moderately convinced we were able to display people's actual emotions using EEG.

The descriptors

Loud sounds, sounds generated suddenly, and sounds that have rapid temporal characteristics and rapid change patterns produce higher levels of arousal or feelings of unpleasentness in the listener (Berlyne 1971; Burt et al. 1995; Foss et al. 1989; Halpern et al. 1986 in Juslin et al., 2008). Low and high pitched sounds raise arousal more readily than sounds that are in the mid frequency range. Other aspects of the stimuli such as novelty, surprise, complexity, ambiquity and "puzzlingness" also influence arousal levels (Berlyne, 1971, p.69).

We infer from our table that sounds of different qualities induce different emotions. The sounds generated from the piano soundboard and the singing bowl show low levels of engagement. We carried out a spectral analysis of these sounds, which indicated that they have either a full or a middle range frequency spectrum. These sounds also exhibit slow rhythmic characteristics and soft dynamics. At the same time the sounds generated from the lazer mic set up, the wind chimes, the light sensor and the wooden fish, demonstrate high levels of excitement. These sounds have short attacks and releases, so they invoke an element of surprise. They have a moderate or fast temporal pattern. They also show rapid changes in frequency or loudness and some of them show high frequencies.

Russell has demonstrated that physiological responses of arousal, pleasure and dominance correlate with people's verbal reports. Our experiments concur with these findings. Here are some of the descriptors offered by our participants for each of the sounds.

Sound 1: "Engagement," "Meditation", "Meditation, also he knows this sound and it reminds him of Hollywood movies where people meditate (funny)"

Sound 2: "Meditation", "Close to meditation", "Meditating", " "Sleepy"

Sound 3: "Frustration", "Tense, alert, frustration", "Surprise at the beginning and then boredom", "Gunshots, fear, frustration", "Annoying"

Sound 4: "Frustrated", "Boat about to depart, nostalgic, meditation"

Sound 5: "Isolation (feeling away from reality)", "Calm," "Very relaxing," "Relaxing/meditation", "Childhood, nostalgic, old toy, meditation"

Sound 6: " "Caught her interest", "Interesting, but a bit annoying, he is trying to hear the piano also at the same time", "Death! Beethoven, frustration", "Excitement, makes you wake up and focus"

Sound 7: "Frustration at the beginning, then normal in general the frequency is annoying", "Frustration and boredom", 'Very annoying" "A lamp that doesn't work properly in a hospital, fear, frustration", "Something dominating"

Sound 8: "Claustrophobic, compressment", "Stimulating / close to excitement", "Stimulating", "Annoying but very anxious of how they produce it, where it comes from", "Something pushing and rushing you, annoying you"

DISCUSSION

Environmental psychologists affirm that environmental stimuli affect the users' behavioural patterns, as well as their emotional responses (Mehrabian and Russell,1974, p.8). The three physiological variables (pleasure, arousal and dominance) at the core of all the emotional responses, determine two main sets of behavior in space: behaviours of approach (locomotion towards the stimulus) and behaviours of avoidance (Berlyne 1971, p.78). As Mehrab and Russell explain these behaviors refer to "physical approach, work performance, exploration, and social interaction" (Mehrabian and Russell,1974, p.8). Therefore, such behaviours also have spatial implications.

Dominance and submissiveness relate to spatial concepts such as territoriality. Territoriality expresses the level of freedom for action in an environment (Mehrabian and Russell,1974, p.19). Anthropologist Edward T. Hall introduced the theory of proxemics to explain people's territoriality. He distinguishes among three categories within proxemics one of which, the pre-cultural, relates to physiological responses (1969, p.95). Human beings, like other animals, have a territorial response to space through which they establish distances from one another (ibid, p.107). Hall (1969, p.108) added that people are able to sense and perceive distance in a dynamic way. According to him, people distinguish four types of distance: intimate, personal, social and public.

Pleasant environments are known to induce better conditions for social interaction, while hostile environments on the other hand produce negative feelings. In general, environments with high arousal attract higher levels of human activity. This is also seen in buildings. Depending on the environment, people choose to be in some parts of the building while avoiding other parts (Mehrabian and Russell, 1974). People tend to seek for situations and stimuli that generate higher arousal levels (Mehrabian and Russell,1974, p.104). They also prefer environments that induce relatively complex stimuli or moderately novel ones (Mehrabian and Russell,1974, p.106).

Studies into emotion build on evidence that is sometimes difficult to capture and verify. Do researchers just see what they want to see? Confirmation bias refers in research to only seeing or selecting evidence that fits a hypothesis or a belief (Nickerson, 1998). It is common for people to want to maintain beliefs that they have adopted, and this constitutes a form of bias. In particular, people choose positive evidence, the piece of evidence that confirms their hypothesis or belief, rather than the negative evidence which disconfirms their hypothesis. People can be so affected by their expectations that they might identify patterns where they don't actually exist (Kelly, 1930 in Nickerson, 1998). This process of selectively choosing positive over negative information is unavoidable. It's a feature of human cognition over which we have little choice (ibid). In the EEG performance and our experimentation we sought to submit our outcomes and data to a range of testing, and subject the audience and our participants to a range of questionnaires, which we will report elsewhere.

CONCLUSION

A focus on the brain leads inevitably to a consideration of environment, and therefore architecture and its practices and modes of representation. Neuroscience attempts to understand the processes of cognition, while architecture is proactive and seeks to create new artefacts. Current research attempts to explore what these disciplines have to offer to each other. Neuroscience can provide a deeper understanding of how humans inhabit places, what aspects of the environment are crucial and what factors require careful architectural consideration.

John Eberhard (2009) offers an example from architectural design of natal care units in hospitals, whose design and equipment was eventually adapted to the needs of prematurely born babies rather that the needs of nurses. Neurological insights reveal that low noise and light conditions are required in order to leave the time for babies' cognitive and perceptual systems to develop at the right pace and in the right order. Such insights provided by neuroscience are subtle and implicit, nonetheless enrich the design process and outcomes. In this article, we highlight just some of the methods in exploring the relationship between brain research and architecture. In our study we focussed on sound, but there are implications for the whole sensorium and people's perceptions of space.

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