<u>RECORDING HUMAN BIOSIGNALS</u>

This document discusses the various signals, mainly electrical, which can be recorded from the human body. In particular it discusses the recording techniques and interpretation of the data. The document is designed as an aid for those wishing to sonify human performance.

<u>THE SIGNALS</u>
The signals most usefully recordable from the human body for sonification include:

Electroencephalogram EEG - brainwaves)
Electrocardiogram (ECG) - heart
Pulse rate (HR)
Electromyogram (EMG) – muscles
Electro-oculogram (EOG) – eye position
Galvanic skin response (GSR) – skin conductivity
Respiratory rate

Accelerometer (not discussed further)

<u>A DISCUSSION OF THESE SIGNALS</u>

<u>**EEG**: the EEG measures brain activity.</u> Specifically it measures the electrical potential (voltage) on the scalp which in turn relates to the activity of areas of brain more or less beneath the electrode.

The EEG is used clinically to assess brain activity in conditions such as epilepsy and behavioural disturbance. Its interpretation is subjective, but in general the findings are useful when there is a need to identify and classify abnormal activity.

It should be understood that the EEG is a very blunt tool. The idea that putting electrodes on the scalp and thereby getting some understanding of the emotions and localised brain activity in the subject is largely nonsense – despite the huge number of claims otherwise. The EEG is simply not capable of such discrimination.

A good analogy for the EEG is a football match at a large stadium. If you stand outside the stadium you can hear, from the noise the crowd makes, whether the game is in progress or not (= brain activity). You can also hear whether something dramatic has happened (= epileptic focus or similar). You can also hear the crowd singing footy songs (=synchronised brain activity such as sleep or alpha rhythm with little information content). But you can't get any detail about the game, nor about who is winning. Perhaps if the spectators sit in certain places you can figure out whether the ball is at one end or the other. And that's about it.

The EEG is like a football match – very non-specific, but useful within its limits.

The EEG recording of the brain can be subclassified into 4 main frequencies of activity (see http://en.wikipedia.org/wiki/Electroencephalography for a more detailed discussion) :

- Beta rhythm, which is fast activity commonly seen in awake, alert subjects.
- Alpha rhythm seen in resting subjects thinking about nothing much – not all subjects have alpha rhythm, and it is usually abolished by opening the eyes.
- Theta rhythm seen in drowsy subjects.
- Delta rhythm seen in sleeping subjects.

EEG recordings are plagued by **artefact**. The most common being muscle artefact from the scalp muscles, eye movement artefact (the eye is electrically charged, and it's movement is clearly visible on the EEG), and blink artefact. The other common artefact is electrode artefact from badly placed electrodes.

The voltage of the EEG is very low (10-100 microvolts) while electrical scalp noise is around 5-10 microvolts. Muscle artefact is around 50-100 microvolts, just the right range to interfere with the EEG, as is the artefact produced by blinks and eye movement.

Problems encountered when recording the EEG are mainly to do with electrode placement and skin contact. Recording techniques are discussed later, but in general EEG electrodes have to be good conductors, placed in good contact with clean skin, and held in place during the EEG recording. In practice subjects move, the electrodes slip, the scalp gets sweaty, and hair gets in the way. All this mitigates against getting accurate and useable recordings. I did EEG recordings on a regular basis for 6 years and can confirm that it takes a fair bit of practice, and – most important - attention to detail, to get reliable results.

The bottom line with successful EEG recording is that if you have good equipment and spend time getting the electrodes placed properly and securely, you will get a good recording. If you don't, then getting a good recording is a matter of chance. The commonest result of careless electrode placement is noisy, unreliable data which cannot be interpreted as anything meaningful. More to the point is that EEG data and noise look similar, and it is all too easy to process noise.

Electrode placement: There are numerous ways of placing the electrodes. Recording can be done between pairs of electrodes, or between a single electrode and the average of a bunch of electrodes, or between a single electrode and a distant point (such as the leg). Interpretation of the recordings in each case is a little different clinically, but the difference is unlikely to be significant for sonification.

Spatial localisation: Because the EEG shows activity over a large area of brain, and is commonly laced with artefact, it is not much use for localisation (this is what I did for my first research degree. Contrary to what I just said, I was able to show that you can actually localise brain activity – but only under some very special conditions which are not relevant here). Although we now know which areas of brain are active with different behaviours, most of the advances in the field have been with functional MRI and PET scanning, rather than EEG.

Magnetoencephalography uses the magnetic field of the brain – orthogonal to the electric field – to monitor cerebral activity. It does not suffer from problems associated with electrical recording, but needs expensive and specialised equipment.

Temporal EEG recordings are likely to be of more value (in sonification) than spatially localised ones. This means collecting reliable EEG data and transforming it using something like serial Fourier Transform to extract information about the power content of different frequencies over time. Whether this means anything much is unclear (in particular during a performance) but it is a technique would perhaps give something useful for sonification. In general one would expect higher frequencies to be associated with greater arousal, but because most performers don't fall asleep while playing, its use seems doubtful at best.

NOTE: My comments are of a general nature, since I have not searched the current literature on sonification. There are probably a number of reports of spatial and temporal EEG recordings being used, but they should be read critically, always asking what the data actually represents. I suspect what is sonified is mostly noise or muscle artefact rather than true EEG.

ECG measures heart activity

The ECG (cardiograph) gives a wealth of clinical information about the diseased heart, but is unlikely to say much about the normal heart. On balance one would expect performers to have normal hearts, in which case there is little of interest except perhaps the heart rate.

Heart rate increases and decreases in disease states (infection, shock, thyroid disease etc), but also in states of arousal and excitement.

The good news about ECG measurements is that they are easy to do, and the electrodes and technology is robust and reliable. ECG electrodes are sticky gel-filled pads which attach to the skin. Generally there is little problem with their use. They are robust and designed to stay on for several days.

The ECG voltage is about 10mV (10-100 times the EEG or EMG).

Pulse rate

Comments as for ECG – disease and arousal increases the pulse rate. The pulse can be measured easily using ECG electrodes, or a 'pulse oximeter' which is an infra-red device clipped over the fingernails. This is probably inappropriate for a musician.

Electromyogram (EMG)

EMG measures muscle activity. In clinical practice this is usually done with 2 layer needle electrodes inserted into the muscle, but non-invasive recording is done by attaching a gel-filled electrode to the skin.

Muscle potentials are around 50-100 microvolts. They indicate activity of the underlying muscle(s).

It would seem that the Emotiv and similar so-called brain measuring devices are actually measuring muscle activity, and the software purports to muscle activity as brain activity (for example measuring forehead muscles in a frown is inferred as indicating brain activity related to anger or concentration). These claims seem to be a superficially attractive but rather tenuous.

True EMG may seem be a useful modality for sonification, since robust electrodes can be used (ie the cardiac electrodes used for ECG), and some kind of correlation is easily made between physical activity and electrical data.

Electro-oculogram

This is a subset of the electromyogram, where the electrodes are placed around the eye. There is an electrical potential developed between the front of the eye and the retina correlated with features such as light intensity, which is of a highly specialised nature (and not much use for sonification). On the other hand the EOG can be used to measure eye tracking, blinks, and saccades (what your eyes to when they move from one object to another), which might be of value.

Eye movement can also be measured using infra-red light. This involves shining infra-red LEDs attached to some kind of spectacle frame onto the eye. The amount of reflected light from the sclera (the white bit) varies depending on where the eye is looking. This technique has been used for years, and is reasonably robust though reliability depends on the frame not slipping during data capture. In practice the glasses tend to be a bit temperamental, but they do work.

Galvanic skin response

When people are hot, sick, active, excited or anxious they sweat. Sweat is a conducting electrolyte and lowers the electrical resistance of the skin. The resistance between two electrodes can be measured easily, and is called the GSR.

During a performance the lower the GSR the higher the arousal, anxiety or excitement (or heat for that matter).

RESPIRATORY RATE

Rather like the GSR, when people are hot, sick, active, excited or anxious they breathe faster. Respiratory rate is different from the other modalities in that it is captured by measuring the amount of stretch in a band round the chest. Apart from a slight discomfort in wearing the device, respiratory rate is robust and easy to measure.

RECORDING ERRORS AND PROBLEMS

ELECTRODES: The material of which electrodes are made is very important. Electrodes need to be inert, strongly attached to their wires, robust and of very low resistance. In practice most metals react with the skin or the electrode gel, so silver or gold is used in quality electrodes. Silver is combined with chloride to make it inert, while electrodes are often gold-plated. This used to be cheap, but the price of gold has gone up and it may be expensive nowadays. (In a pinch contacts from high quality computer boards might work since they are gold-plated.)

Whatever the material, it is worth making sure the electrodes are high quality, since low quality ones (aluminium, copper, stainless steel) invariably introduce artefacts sooner or later.

The connection between the electrode and the wire is a weak point. Frequently electrodes are soldered to the wire, sometimes crimped. In either case with time the joint weakens and breaks. If possible an effective antidote to this is to attach the wire itself to the electrode to take the strain off the joint. However, this can make the electrode assembly too cumbersome to use.

Electrode wire. It is worth paying attention to the quality of the wire between the electrode and the capturing device. Wires are constantly moving, and frequently break. Single strand wire is not used at all, while multistrand wire only works if there are many small strands – and works better if string of some kind is woven into the strands. Phone and player earpiece wires live in the same harch environment, and you will notice how soft and floppy good quality earpiece wire is.

SKIN CONTACT

A lot of errors arise at the skin-electrode interface, and it is always worth spending time making sure the contact between the two is good.

Skin consists of a flexible living layer, overlaid by harder dead material (keratin) which gradually falls off in flakes (= dandruff). **Keratin** is an insulator, so increases electrode resistance (effectively the electrode goes deaf). For this reason the skin should always be cleaned before electrode contact – rubbing with a dry cotton bud or a cloth is enough, but for professional use there is a cleansing gel with small abrasive particles which ensure minimal keratin flakes on the skin surface.

Skin also has **oil** on it, secreted by the sebaceous glands. Oil is also an insulator so is best cleaned off first – acetone or alcohol will do.

The skin **sweats**, which reduces its resistance, but also makes electrodes slip. For this reason the electrode carrier needs to be robust and well attached to the body. In practice this is not an easy thing to do, and it can be expected that errors will arise during a performance as a result of shifting electrodes. Two techniques counter this – large sticky electrode pads as in ECG electrodes, or sticking the electrodes to the skin with the same glue used for sticking moustaches and beards in the theatre.

Hair is often a problem because the hairs get in the way. On the body it is easy to shave a small patch of skin, but this is not popular on the head. The only two ways to put electrodes on the scalp without shaving is to part the hair as far as possible, use a robust cradle, and plenty of electrode (conducting) gel, or alternatively use stick on electrodes as described above. The latter is preferable though time consuming both to attach and remove the electrodes.

Electrode gel is basically salt in jelly which bridges the gap between the electrode and the skin, and helps ensure good electrical contact. Some equipment is advertised as using ‘dry contact’ electrodes. In my experience this is means ‘poor contact’ electrodes, so I would prefer always to use electrode gel.

INTERFERENCE

Any wire put in an **electric field** will have a voltage induced in it (which is how transformers and radios work). The voltage is highest when the wire is an integer multiple of the wavelength, but exists for all wavelengths to some extent. If the induced voltage is high enough, it appears as noise in the signal. If the signal is small, it doesn’t take much induced voltage to add noise. Sometimes the signal is small anyway (EEG), but sometimes it is made smaller by poor quality electrode contact – which is why there is so much importance attached to electrodes.

The **placement of leads** is important. Two wires crossing each other, or running parallel, will cause interference, and the higher the frequency the more likely the interference. So spikes on a line (caused by poor electrode contact, or a high frequency such as is seen in contracting muscle) will often cause ‘crosstalk’ between leads. Leads should be well separated.

Computers are nearly always used for recording. The problem with this is that they are inherently electrically noisy machines. Wires leading to a computer can be shielded (by wrapping the conducting electrodes in a woven sheath, grounded at one end only), and this should always be done when transmitting biological signals any distance.

Radio frequency interference is common – many of the items connected to a computer use wireless transmission – mice, keyboards, headsets, internet wifi etc. Which means signal recording apparatus is bathed in a sea of potentially interfering signals. In many cases this means direct (cable) connection is preferable to wireless connection. The cabling does not have to be intrusive, since most performers don’t move far from their seats while playing.

Earth loops. All signals are transmitted relative to a ground plane (in other words there are effectively two wires involved in any data transmission, though one may be hidden as the chassis of the recording equipment). The problem is that often the so-called ground, which is supposed to be at zero volts, is anything but. For example a gadget attached to a performer might have a ground voltage which is zero with respect to the gadget, but many volts different to the computer it is attached to. This problem is avoided by having a cable shield attached at one end only (stopping the interfering waves) and one of the cable wires designated as 'signal ground'. The effect of a ground loop is an oddly high or low voltage, swamping the signal of interest.

Common mode rejection amplifiers are often used in signal recording. Despite taking precautions against interference as described above, there remain sources of interference which are impossible to remove. This nearly always includes the mains – 50 hz sinewaves from the power lines. For this reason common mode rejection amplifiers are used in quality equipment. The electronics is set up in such a way that the same signal appearing on all input lines is filtered out, and what is left is the signal used as data.

SUMMARY

In summary there are a few biological signals which can be used for sonification. The EEG is unlikely to live up to the claims for its proponents. Other modalities do indicate altered body states and could be used.

In all recordings, it is important to attend to the details of electrode placement, robustness, noise and interference. If this is done, a high quality signal can be captured reliably.

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