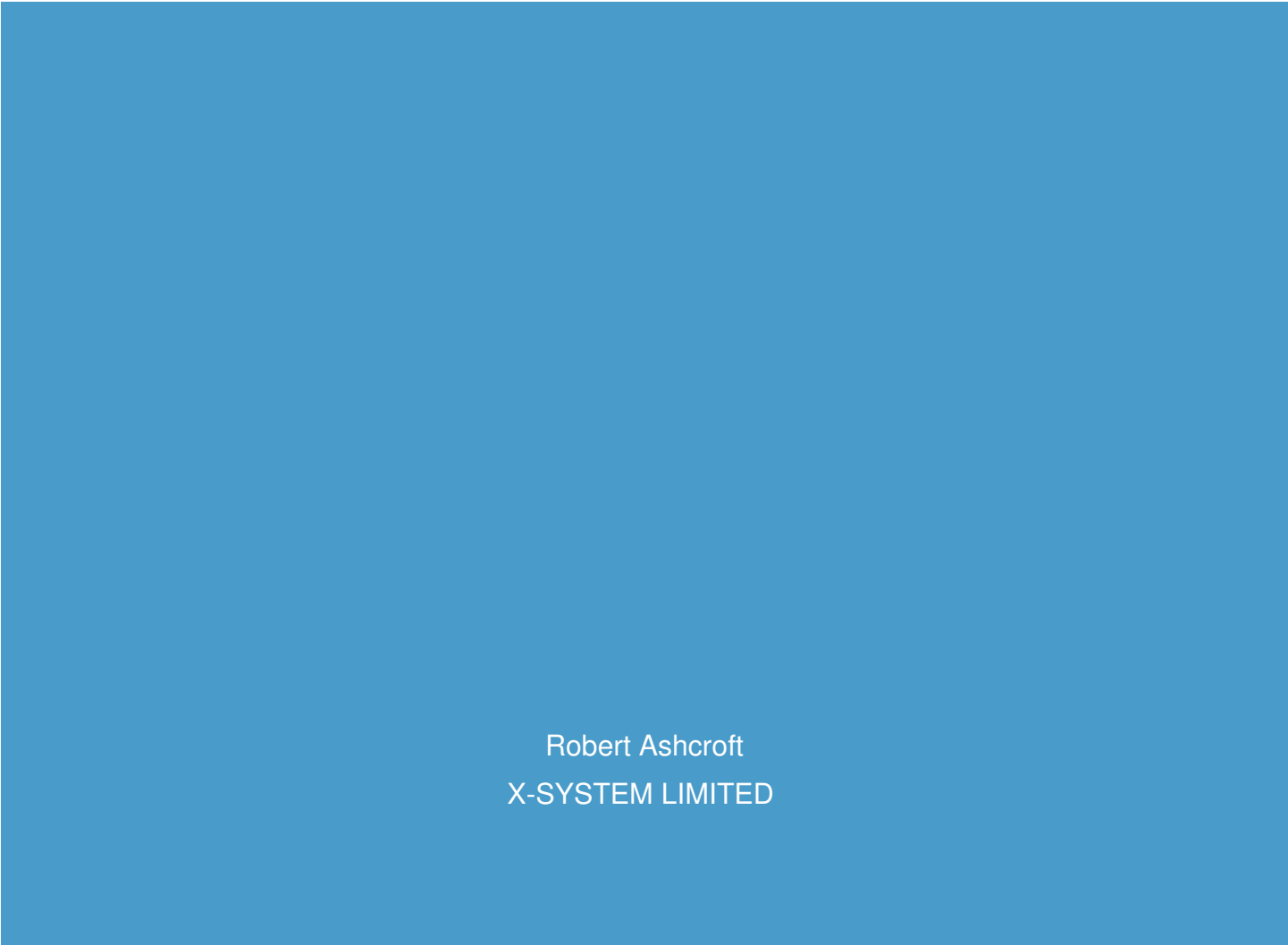




THE INNATE NEUROPHYSIOLOGICAL RESPONSE TO MUSIC



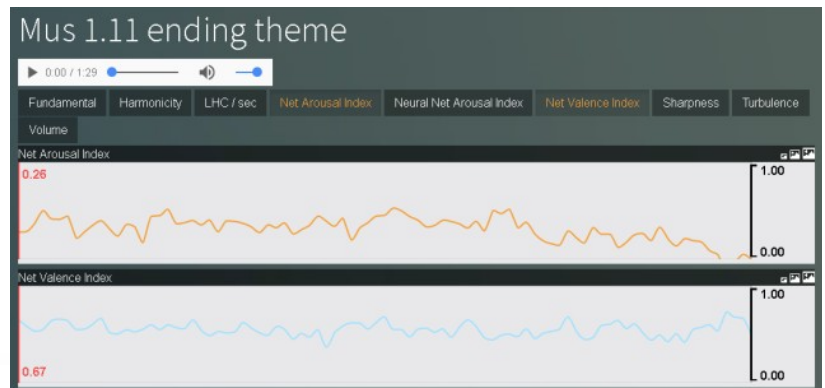
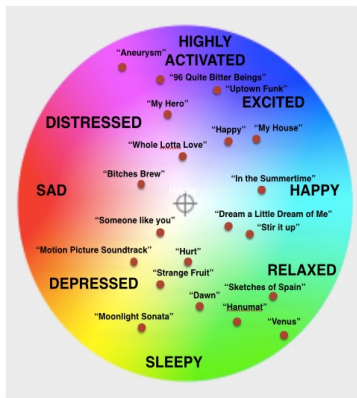
Robert Ashcroft
X-SYSTEM LIMITED

What is X-System? What can it do?

X-System technology has been developed by Professors Paul Robertson and Nigel Osborne, based on their understanding of the innate human neurophysiological response to music. It uses a purely algorithmic approach to the analysis of music of all genres and world cultures to predict its effect on the human mind and body.



X-System may be used to select music according to mood, or by its second-by-second effect on the human autonomic system (how it makes you feel).



How does X-System work?

X-System models the musical brain and predicts how its organs and pathways respond to different kinds of music.



It models the most ancient and primitive reactions to sound and to music in the *brainstem and amygdala*.

brainstem

amygdala



These reactions include:

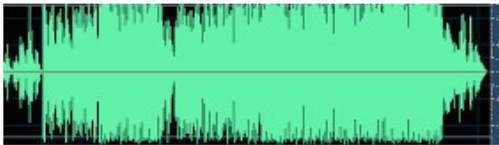
turbulence

where surges and turbulences in sound are detected by the *brainstem* and communicated as emotional information by way of the *inferior colliculus* to the *amygdala*



sharpness

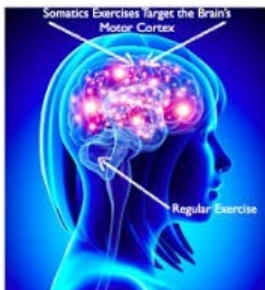
where primitive responses to high sounds, like the hissing of snakes, are communicated to emotional centres of the brain



and volume

where loudness and changes in loudness are detected by the brainstem and transmitted as

emotional information



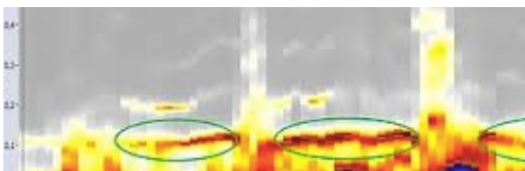
X-System models the *pre-motor* and *motor cortex*



This includes modelling of responses to:

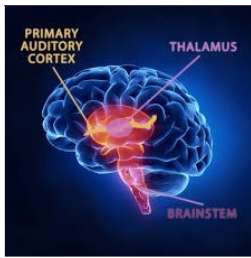
pulse

where systems of the brain concerned with movement and preparing for movement are activated by the speed of beats per minute



and rhythmicity

where the power, density and salience of rhythm not only activates movement but also

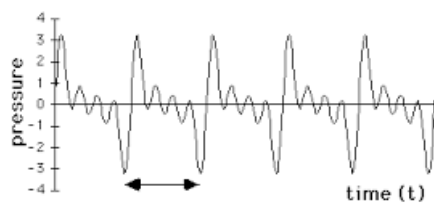


stimulates arousal and emotional change

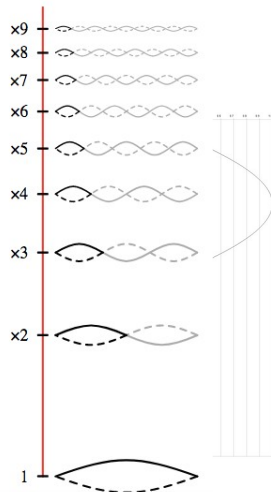
It models the primary auditory cortex and pathways to the *limbic system*

primary auditory cortex
(*Heschl's Gyrus*)

limbic system
(*amygdala etc*)



Period = $1/200 \text{ s} = 5\text{ms}$

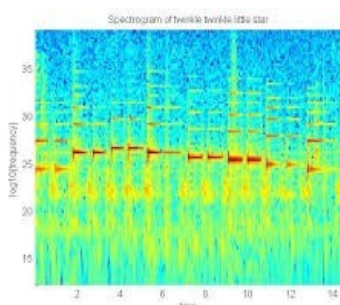


including: **fundamental detection**

where it models *Heschl's Gyrus* to establish which is the most important frequency in a single sound, note or chord.

harmonicity, where it further models *Heschl's Gyrus* to establish the vertical "harmonicity" of the spectrum of sound at any given moment. Levels of "harmonicity" are determined by how close the pattern of the spectrum of sound is to the harmonic series - the simplest pattern of sound in nature. The higher the harmonicity of a sound, i.e. the closer to the pattern of the harmonic series, the more relaxing and soothing the effect on the limbic system and emotional centres of the brain; the lower the harmonicity, the more arousing the effect. The pattern of the first six partials of the harmonic series, starting on the note C, is G C G C C E

and **linear harmonic cost**, where the system models the way that movement from one note or sound to another affects emotional centres of the brain. The more "harmonic" the step, the lower the harmonic cost and the greater the calming effect. The less "harmonic" the step, the greater the harmonic cost and the higher the arousal.



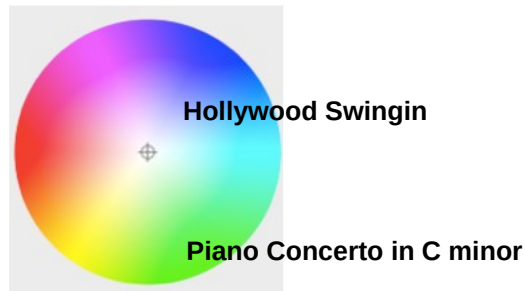
Here is a spectrogram of the first phrase of *Twinkle Twinkle Little Star*. The first four notes of the melody - CCGG (*Twinkle, twin-kle*) are very "harmonic", i.e. they fit perfectly into the pattern of the first four partials of the harmonic series - see above. The next notes - AA (*lit-tle*) do not appear until

much further up the harmonic series and are therefore less “harmonic” and a little more “arousing”. It is noticeable that the melody returns to the very harmonic G (*star*) after the disruptiveness of the two A’s

How does X-System predict arousal?

X-System combines values ← provided by its modelling of the musical brain to predict levels of *Autonomic* arousal for individual tracks

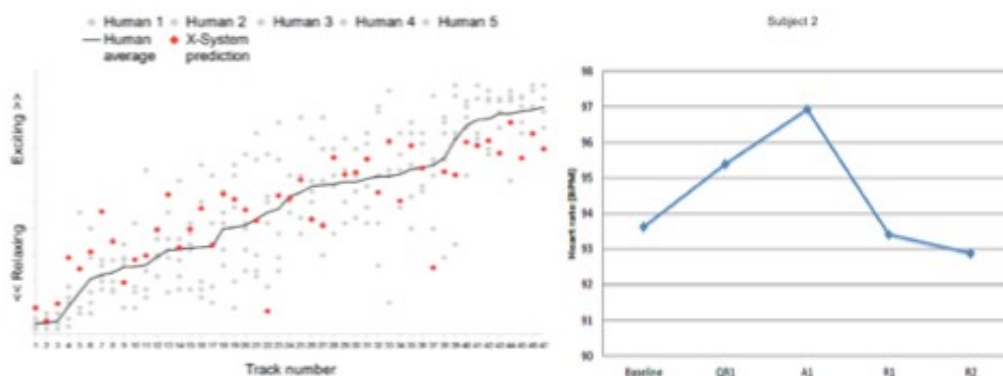
High Sympathetic Autonomic Arousal



Low Sympathetic Autonomic Arousal

For example, Kool and the Gang’s *Hollywood Swingin* is predicted to stimulate high autonomic arousal and high motor activation. The Adagio from Rachmaninov’s *Piano Concerto no 2 in C minor* is predicted to be of low arousal and generally calming.

X-System verifies these results by **subjective categorisation** and **physiological measures**

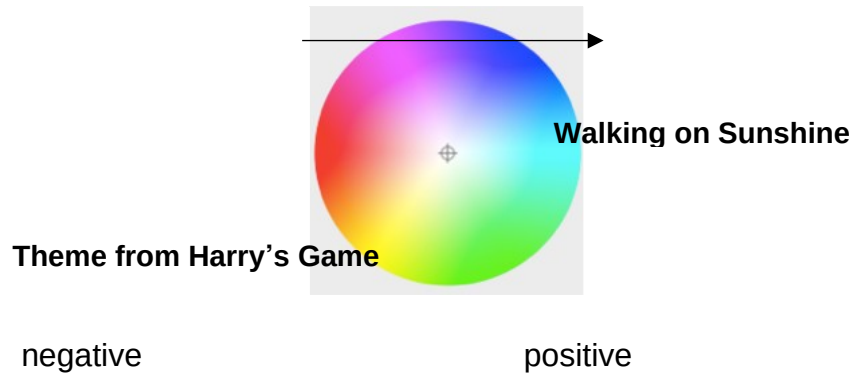


The graph on the left is an example of how X-System is better at predicting levels of arousal than experts. 47 tracks (left to right in ascending order of arousal) were categorised by 5 experts (in grey). X-System (in red) was closer to the mean than any single expert.

The graph on the right is an example of physiological measurement. In a clinical psychology experiment, subjects were “stressed” by a track of music identified by X-System as being highly arousing, and de-stressed by two tracks identified as relaxing. The graph shows data from a heart rate sensor, beginning with a baseline, then the arousing track, and then the two relaxing tracks.

How does X-System predict emotion and mood?

X-System combines these parameters to predict positive and negative moods and emotions



For example, Clannad's *Theme from Harry's Game* is predicted as "sad", and Katrina and the Waves' *Walking on Sunshine* as "happy".

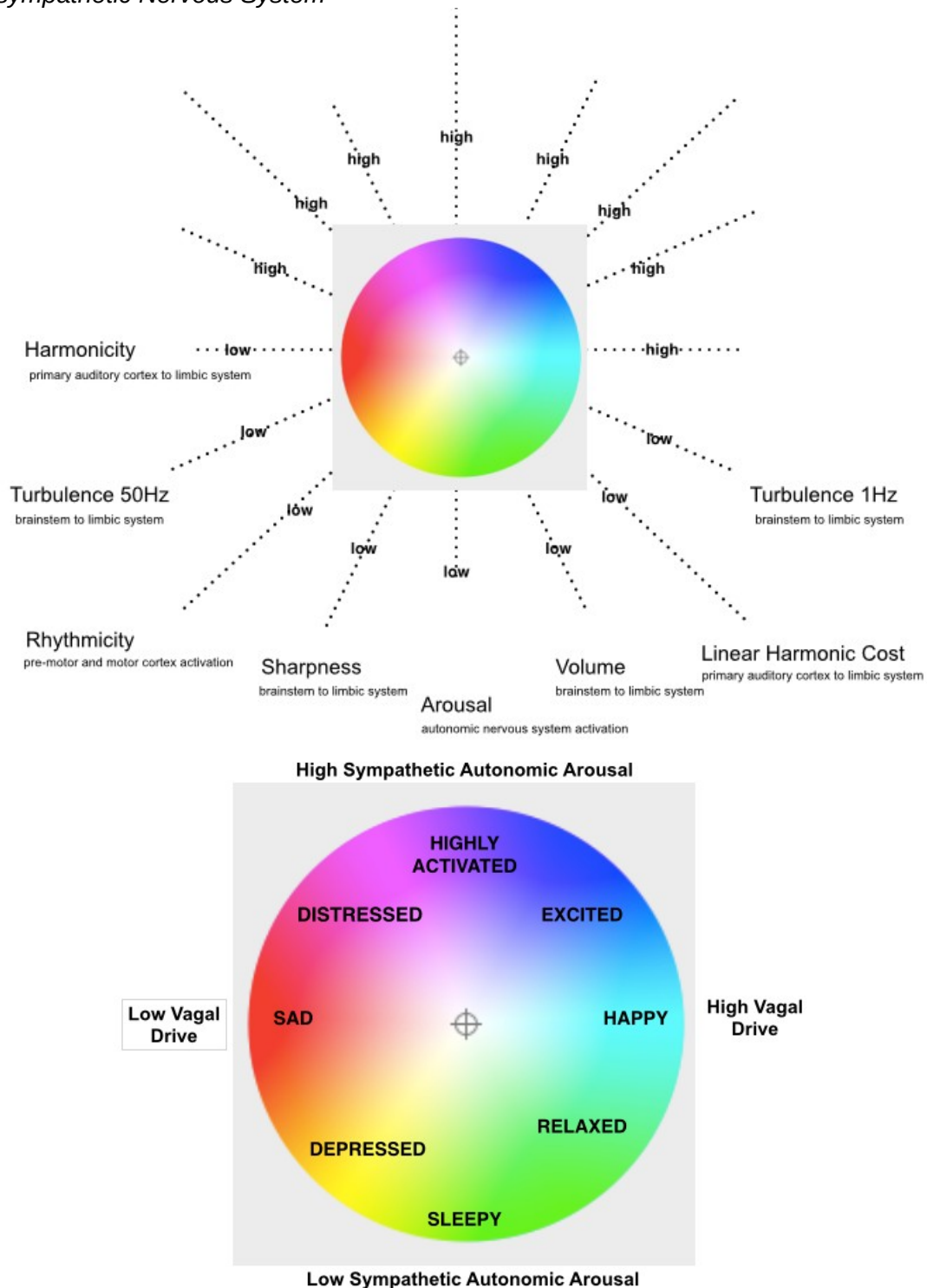
X-System verifies these results by **subjective categorisation** and by employing **neural networks** and **linear regressions**. Work has begun on **physiological verification**, using **Heart Rate Variability (HRV)** as a measure of vagal power (directly related to positive and negative emotions).

In a recent experiment involving physiological measure of HRV in the responses of 6 listeners, the total power for *Theme from Harry's Game* was 904, and the total power for *Walking on Sunshine* was 1165; this data verifies X-System's prediction.

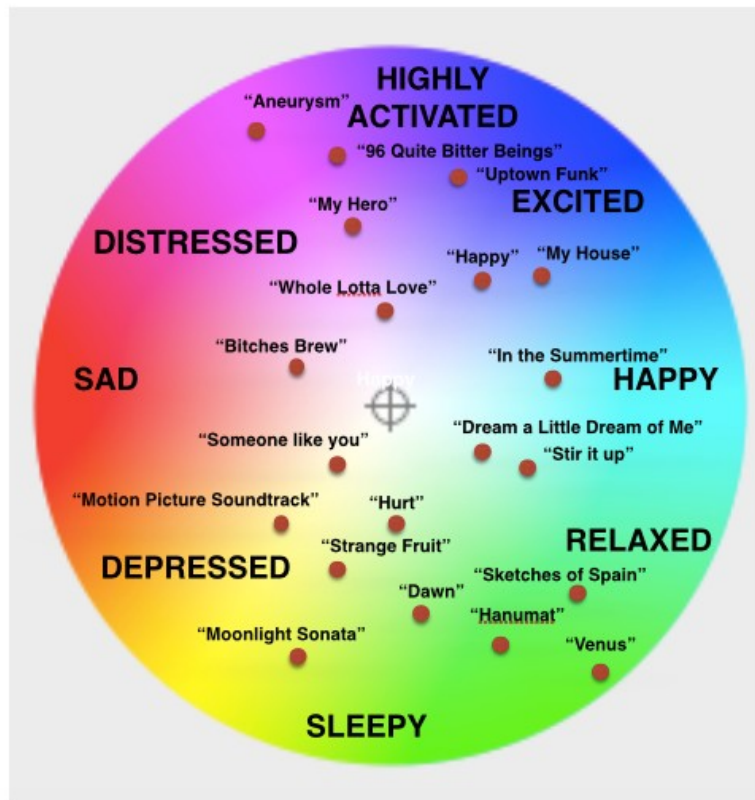


How does X-System combine arousal and mood predictions?

It combines **brain-based parameters** in a single model, with inputs from **neural networks**, **linear regressions** and **physiological measures**. Emotions and moods are ascribed to areas of the space. In the longer term, a three-dimensional model will allow for more accuracy in accommodating distinctions, for example, between tone and power in the *Parasympathetic Nervous System*



The diagram on the next page shows some examples of X-System predictions for well-known pieces of music and their locations in emotion-mood space:



Pharrell Williams' *Happy* for example is located, where it may be expected, on the borderline of "happy" and "excited". But it is also quite close to the borderline with more negative emotions. This reflects the "edgy", and for some listeners, slightly "ominous" character of the song, generated in part by its haunting, unexpected combination of minor, modal and major chords (with contradictory major and minor sevenths and even a *tierce de picardie*).

The opposite is true of Johnny Cash's *Hurt*. The sad, minor character of the verse pushes the song where it may be expected, in a negative direction. But in spite of the words, which X-System does not process, the chorus is quite bright, and this places the song as a whole at the far, negative edge of "relaxed".

This X-System prediction was verified by measurement of HRV in listeners, where the song showed a medium-to-high vagal power of 1150.

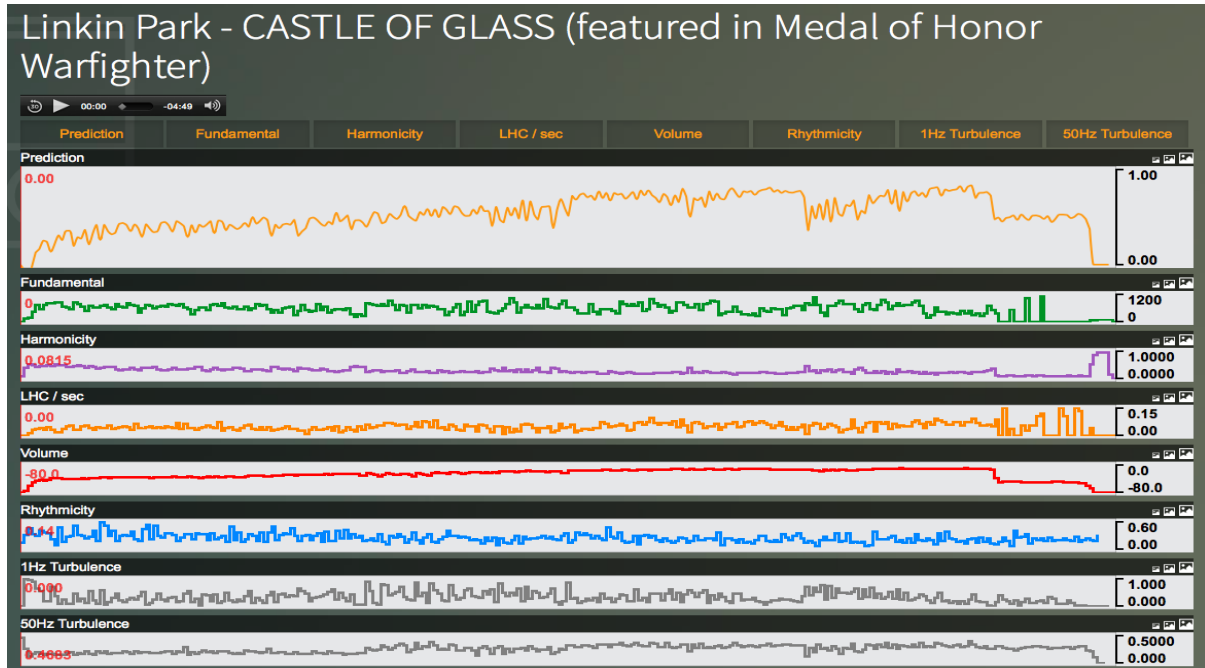
The most relaxing track in this selection of music is Gustav Holst's *Venus* from the *Planets Suite*, with the Sanskrit, Vedic chant from *Hanumat Panchashat* close by. Interestingly the *Adagio* from Beethoven's *Moonlight Sonata* is "relaxed/sleepy" but leaning towards more negative emotions. Indeed, many listeners find in it an elusive "darkness".

Nirvana's *Aneurysm* is the most arousing track, located between "high activation" and "distress". Much heavy metal music appears to play with the ambiguity between constructive and destructive high energy. Led Zeppelin's *Whole Lotta Love* is lower down the arousal scale than might be expected. This is because of the extended "abstract", Theremin section in the middle of the track.

X-System is capable of predicting arousal with high accuracy and emotion and mood with improving accuracy in all world repertoires of music.

X-System and the treatment of Central Nervous System Disorders

Because the parameters modelled by X-System are measured second-by-second, pieces of music, or segments of music, can also be matched at a more detailed level than by using the overall Arousal and Valence indices:



Using a proprietary technology to convert EEG data into its audio equivalent, X-System can be used to select music from the repertoire to entrain specific patterns of brainwave activity.

This capability is being trialled in the treatment of Central Nervous System Disorders, beginning with intractable epilepsies.