

THE INNATE NEUROPHYSIOLOGICAL RESPONSE TO MUSIC

A briefing note

Oct 2018

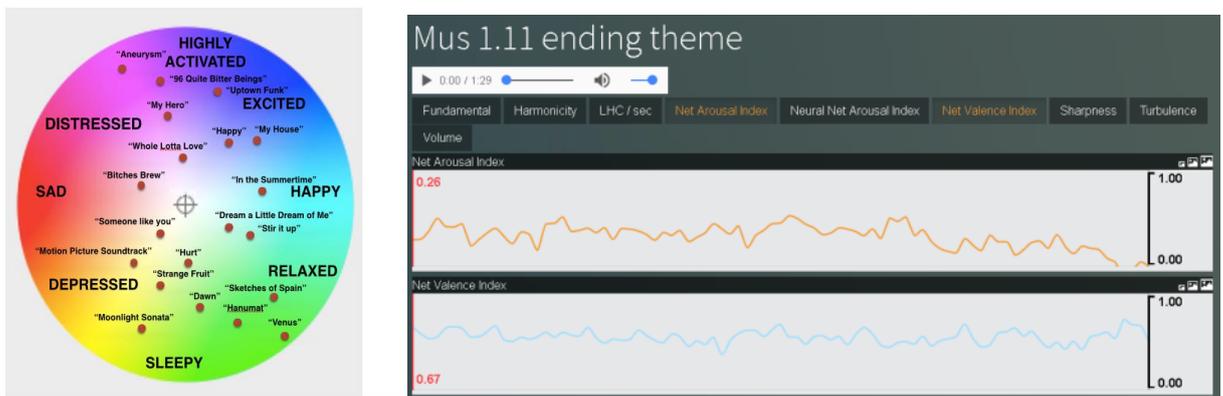
Mike Waters
X-SYSTEM LIMITED
CONFIDENTIAL

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



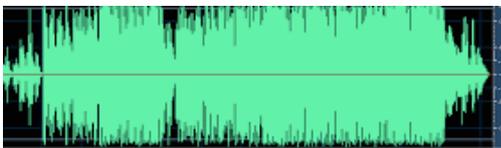
where surges and turbulences in sound are detected by the *brainstem* and communicated as emotional information by way of the *inferior colliculus* to the *amygdala*

sharpness



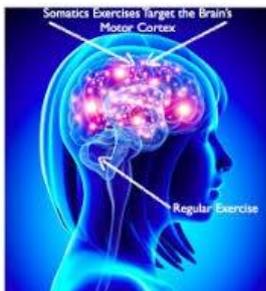
where primitive responses to high sounds, like the hissing of snakes, are communicated to emotional centres of the brain

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*



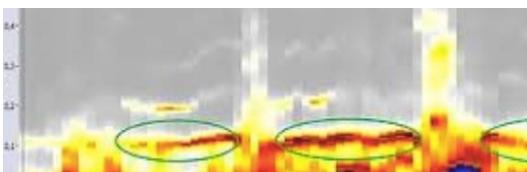
This includes modelling of responses to:

pulse



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

and rhythmicity

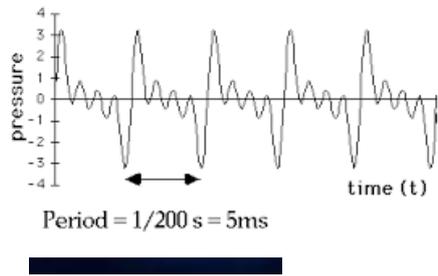


where the power, density and salience of rhythm not only activates movement but also stimulates arousal and emotional change

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

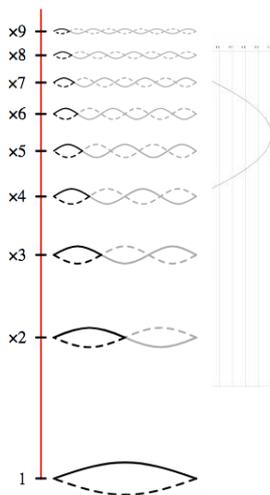
primary auditory cortex
(Heschl's Gyrus)

limbic system
(amygdala etc)



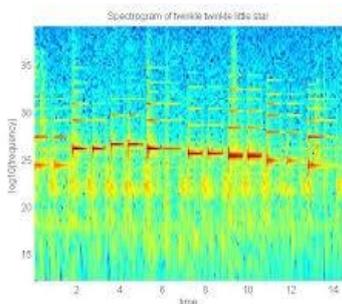
including: **fundamental detection**

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.

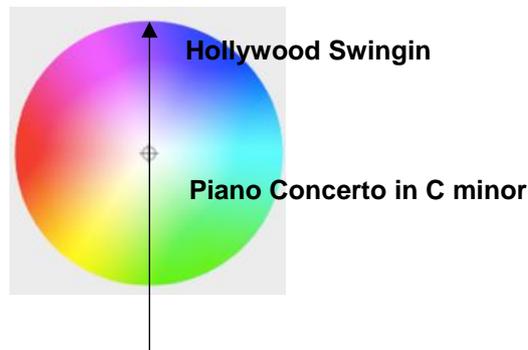


Here is a spectrogram of the first phrase of *Twinkle Twinkle Little Star*. The first four notes of the melody - CCGG (*Twin-kle, twin-kle*) are very "harmonic", i.e. they fit perfectly into the pattern of the first four partials of the harmonic series - see above. The next notes - AA (*lit-tle*) do 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

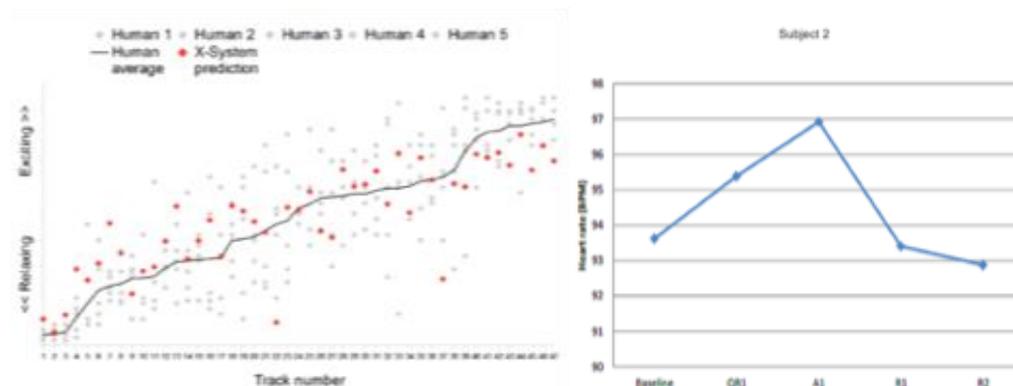
High Sympathetic Autonomic Arousal



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**

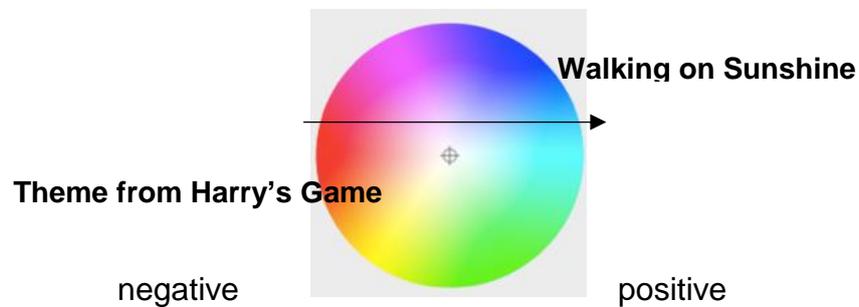


The graph on the left is an example of how X-System is better at predicting levels of arousal than experts. 47 tracks (left to right in ascending order of arousal) were categorised by 5 experts (in grey). X-System (in red) was closer to the mean than any single expert.

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?

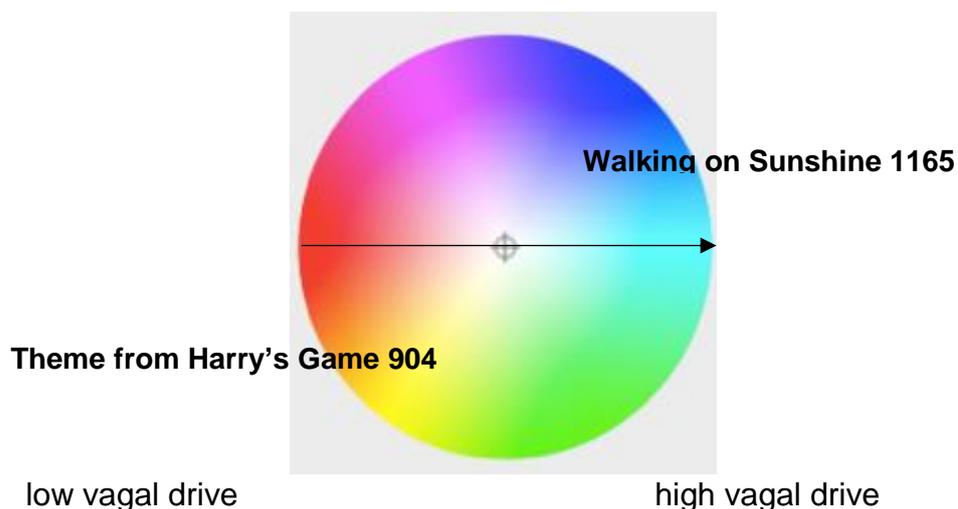
X-System combines these parameters to predict positive and negative moods and emotions



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

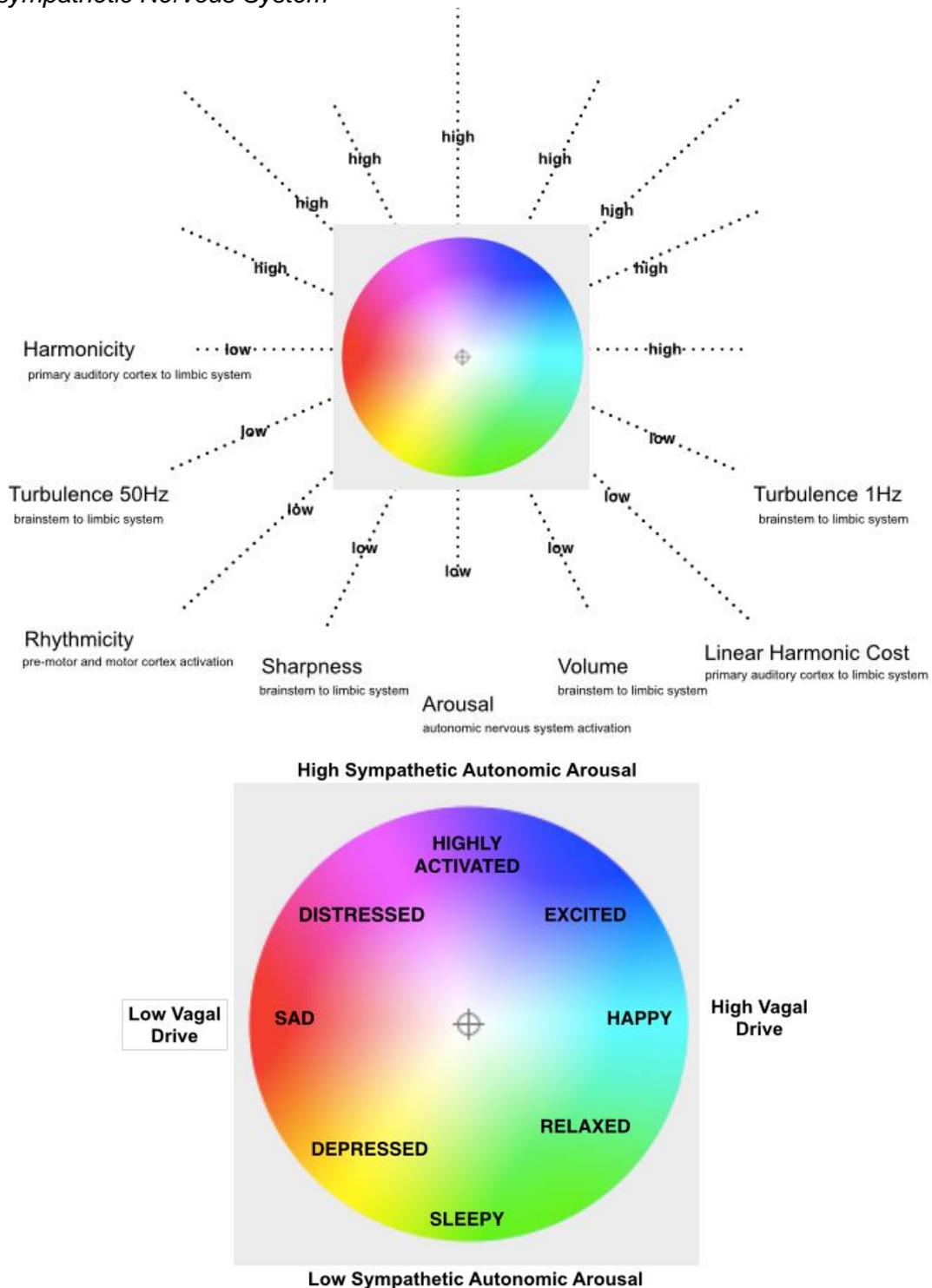
X-System verifies these results by **subjective categorisation** and by employing **neural networks** and **linear regressions**. Work has begun on **physiological verification**, using **Heart Rate Variability (HRV)** as a measure of vagal power (directly related to positive and negative emotions).

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.

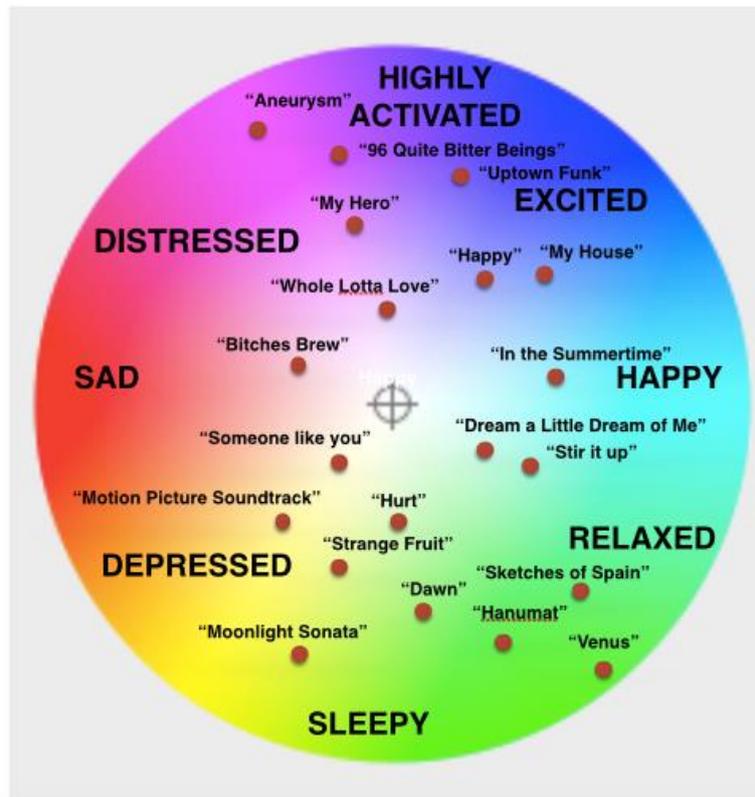


How does X-System combine arousal and mood predictions?

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.

What can X-System contribute?

Health



Medicine, where we trial X-System together with major health providers and can use X-System for self-medication of analgesia, pre and post operative anxiety relief, and aggression and psychiatric trauma reduction. It can be used to support both physical and psychiatric treatments. We welcome proposals for further trials.

Wellbeing, where X-System can be used to support self-administered relief for anxiety and stress, or motivate exercise.



Music curation and navigation



X-System permits music curation and navigation by emotional filters. It can arouse you for sport or partying, help you concentrate and focus for study, driving, or operating machinery, or help you relax for meditation, relaxation, or sleep.

Advertising

X-System can select music to build and maintain brand, organise emotional journeys for customers in ad campaigns and physical stores, and select and organise music for online presence and campaigns.



Supporting Ageing Populations

X-System has potential for treating dementia and has published a review of that. https://www.x-system.co.uk/documents/X-System_dementia.pdf.

X-System can support ageing populations. It can:



Identify music that is emotionally relevant to individuals by identifying and recording the emotional response (vagal and arousal) associated with specific tracks.

Identify music with local cultural origins to individuals or groups, by combining similar arousal levels whilst filtering on specific genres or cultures such as Gaelic, Celtic, regional or local British folk, music hall and traditional melodies.



Entrain useful levels of arousal and counter-arousal by aggregating useful tracks and arranging them in playlists by neurophysiological effect. This enables a complementary aid to proper arousal levels at appropriate times for both individual and group use.

Combine each of the above to both identify and apply suitable age-related repertoire based on composition, release or most popular track release dates.