IRIS

Below is a study from the University of London on Don Estes' actual PsiFi Sound system, which is part of each session offered at Expanded States, referred to in this report as "IRIS." Please note that this is a stand-alone study, not the immersive experience of what we offer. Those studies will be coming.

Project Report:

Impact of IRIS on Neural and Autonomic Responses

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This report presents the results of an EEG experiment which was designed to investigate the differences in brain (and autonomic) activity related to IRIS (and IRIS maximum) enabled presentation of musical excerpts, belonging to four different musical genres (classical, pop, rock and wellness), as compared to same musical excerpts but played in plain/original format. During the experiment, behavioral (participants' responses to the excerpts presented in plain, with IRIS and with its maximal variant), EG (brain activity during listening) and ECG (cardiac activity during listening) activity were recorded. In the following, we provide (i) a brief description of materials and methods including participants, stimuli, experimental procedure data collection and analysis, and (ii) experimental findings followed by discussions and a conclusion.

Materials and Methods:

Participants

Eight healthy human adults (age range from 21 years to 41 years, mean ± SD: 30 ± 7.15 years) participated in this experiment. All participants were neurologically healthy, had self-reported normal hearing, and had normal or corrected to normal vision. Written informed consent was obtained from all participants before the beginning of the experiment. All participants received a fixed financial incentive for taking part in the study. Participants were naïve to the experimental aim.

Materials

Questionnaire

All participants will complete a set of questionnaire as follows: (i) The Goldsmiths' Musical Sophistication Index (Gold-MSI) to validate participant's self-reported musicality [1], (ii) Depression Anxiety Scale short version (DASS-21; [2]) to evaluate trait anxiety and also to evaluate whether IRIS enabled effects to depend on the presence or absence of symptoms of depression and anxiety, (iii) modified Dalbert Emotions Scale (modified DES; [3]) to evaluate mood states, (iv) the State-Trait Anxiety Inventory [4] to evaluate anxiety levels and to discriminate the participants' trait anxiety (STAI-T) from her state anxiety (STAI-S), i.e. between a general anxiety level from the current anxiety level, (v) the dispositional flow trait across nine dimensions of flow experience [5], and (vi) the short version of Big-Five Personality measure (TIPI-10) [6].

Music

In the continuous experiment, we presented eight musical excerpts (Table 1), two from each of the following musical genre: (i) classical, (iii) pop, (iv) rock, and (v) wellness soundscape for relaxation. Each excerpt was presented in three different versions as follows: (i) in original, (ii) Iris enabled, and (iii) IrisMax enabled. In the on-off experiment, there were four musical excerpts (one for each genre) with 30 seconds stages of plain, followed by 30 seconds of Iris on, and then 30 seconds of IrisMax, and then the whole sequence repeated.

Table 1: Listing of musical excerpts.

Musical Genre	Excerpt	
Classical	(i)	Bochherini Minuet from Spring Quintet in E Op.13 No. 5
	(ii)	Lakmé, Act 1: "Dôme épais, le jasmin" (Lakmé, Mallika)
Pop	(i)	Can't Stop the Feeling (Soundtrack from *Trolls*)
	(ii)	I knew you were trouble (Taylor Swift)
Rock	(i)	Here comes the sun (The Beatles)
	(ii)	Supermassive black hole (Muse)
Wellness	(i)	Crystal light
	(ii)	Another farewell

Procedure

All experimental sessions were performed in a quiet preferably electrically shielded room. Participants were instructed to sit in an upright but relaxed position in front of a computer monitor and musical excerpts will be presented via an in-ear canal earphone. Before the experiment began, participants provided written informed consent. Subsequently, the EEG cap and electrodes were placed, and during this period, participants completed a set of questionnaires. Participants were subsequently informed of the task instructions by watching a short presentation on the monitor. Two separate experiments differed on the presentation style of the musical excerpts: (i) in the continuous experiment, excerpts were presented

continuously for the entire duration in one of the three formats (see later), and (ii) in the on-off experiment, excerpts have 30 seconds stages, plain, Iris on, IrisMax, repeated.

In the first experiment (i.e. continuous presentation), there were three conditions: (i) music presented in plain, (ii) music presented with Iris on, and (iii) music presented with IrisMax. For each of the there conditions, participants were presented with eight short musical excerpts belonging to the specific condition (Table 1). After listening to each musical excerpt, participants were instructed to answer the following on a 7-point Likert scale (higher values indicate higher ratings): (i) how much they liked the music, (ii) how stimulating they found the music, (iii) how absorbing they were in listening to the music, (iv) how much flow they felt while listening to the music, and (v) their overall listening experience. After each condition (i.e. after listening to the eight excerpts belonging to the specific condition), the participants completed the STAI-S, modified DES, and the state flow questionnaire. A brief break was provided between conditions. Conditions were presented in a block randomized fashion, i.e. for each block, all musical excerpts belonged to a specific condition, and the blocks were randomized across participants. In the on-off experiment, the participants were presented with four musical excerpts, but no behavioural ratings were obtained. The total duration of the complete experimental session was around 3 hours. Participants were debriefed at the end.

EEG recording and preprocessing

EEG signals were recorded by sixty-four active electrodes placed according to the extended 10-20 electrode placement system (Fig. 1). Additional electrodes were placed above and below the right eye, and at the outside corner of each eye to record vertical and horizontal eye movements, respectively. The EEG signal was amplified by a Biosemi ActiveTwo® amplifier and sampled at 512 Hz. Biosemi amplifier has two electrodes – active CMS (common mode sense) electrode and passive DRL (driven right-left) electrode – that together form a feedback loop representing the online reference (see Biosemi link, http://www.biosemi.com/faq/cms&drl.htm for details on the Biosemi referencing and grounding procedures). EEG signals were algebraically re-referenced to the average of two earlobes. A high pass filter at 0.5 Hz was applied to remove slow baseline drifts and a notch filter at 50 Hz with a 2 Hz bandwidth was applied to remove line noise. An Independent component analysis (ICA) based method was applied to the EEG data to remove large blink related artifacts. Next, the ICA cleaned EEG data were visually inspected for the identification and subsequent removal of any remaining artifacts.

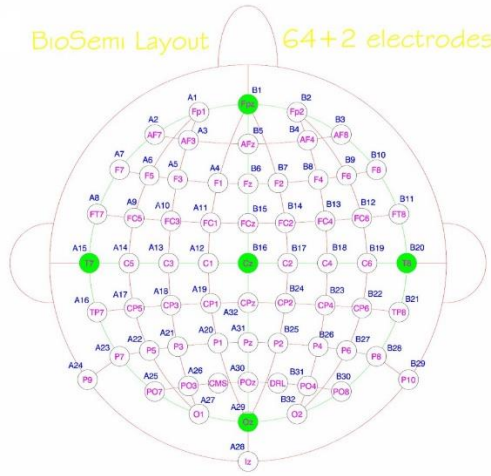

Figure 1. Electrode layout. Sixty-four scalp electrodes were placed according to the International 10-20 electrode placement systems. Electrodes were labelled according to the locations (A: anterior, F: frontal, AF: anterio-frontal, C: central, FC: fronto-central, T: temporal, P: parietal, TP: temporo-parietal, O: occipital, and PO: parieto-occipital). Odd and even number indicates electrodes from the left and right hemispheres, respectively.

EEG analysis

EEG signals were analysed primarily in terms of its constituent brain oscillatory responses. To estimate the strength of large scale brain oscillations, we calculated the power spectral density (PSD) by using Welch's method (averaged periodogram) by dividing the data (corresponding to each beat excerpt within a condition) into 2 seconds windows with an overlap of 50% (Ioannaou et al, 2015). We estimated the spectral power from 1 to 80 Hz with a step size of 0.5 Hz. The spectral power values at each electrode for each condition were averaged over classical EEG frequency bands [7]: delta (1–4 Hz), theta (4–8 Hz), alpha (8–13 Hz), beta (13–30 Hz), gamma (30–48 Hz), and upper-gamma (52-80 Hz). Spectral power values were expressed in dB by normalizing with respect to baseline values (2 sec before each excerpt).

For analyzing the signals related to the interspersed on-off condition (in which the Iris enabled excerpt was on for 30 s followed by original excerpt for 30 s), we analysed the EEG signal by Hilbert transform based amplitude envelope analysis [8, 9] in order to track the temporal dynamics of neuronal oscillations. After applying the Hilbert Transform to individual signal, we calculated the instantaneous amplitude of the filtered signal (i.e. the amplitude envelope of a specific frequency band) and this provides the time-varying nature of the strength of the chosen brain rhythms. However, for the sake of clarity and keeping the report more focused, we did not include the results of the on-off condition.

Our final EEG measure was based on frontal asymmetry which is based on Davidson's influential approach/withdrawal motivational model of emotion [10]. Left frontal activity suggests a tendency to approach or engage with a stimulus, whereas right frontal activity indicates a tendency to withdraw or disengage from a stimulus. Since frontal asymmetry is mostly reflected by the alpha-band oscillations, we calculated the frontal symmetry index based on alpha-band power over frontal electrodes [9]: the (log-transformed) alpha power over left frontal electrode regions (Fp1, AF3, F7, F3, FC1, and FC5) were subtracted from the alpha power over the right frontal electrode regions (Fp2, AF4, F8, FC2, and FC6). Since the strength of alpha oscillations as measured on the scalp is inversely correlated to the cortical excitations [11], sign and strength of frontal asymmetry would suggest the differential role of approach/withdrawal to Iris (or IrisMax) enabled presentation as compared to the presentation without it.

ECG Preprocessing and Analysis

The ECG signals were recorded in a bipolar fashion by placing two electrodes, one over the left chest and the other over the right abdomen. The sampling frequency was 512 Hz and was amplified by Biosemi® amplifier along with EEG signals. The ECG signals were processed using MATLAB® based in-house scripts for the analysis of heart rate variability (HRV) according to the recommended standards for HRV measurements [12]. The QRS complex was first identified using a QRS detection algorithm based on filter banks which enable the identification of the complex by decomposing the ECG in sub-bands with uniform frequency bandwidths [13]. The ECG data were visually inspected to assure that the R-peaks were correctly detected. Any outlier or glitch identified by studying the residuals of a forward and backward autoregressive fit and was replaced by spline interpolation [14]. Using the R latencies, the inter-beat intervals (IBI) was subsequently obtained. These values were used to estimate the heart rate (RR) and the HRV indexes [14], which included both time-domain: (i) the mean of R-R interval, (ii) the standard deviation of R-R interval,

(iii) the skewness of R-R interval, (iv) the proportion of the number of pairs of adjacent intervals differing by more than 50 ms, pNN50, (iv) the square root of the mean of the sum of the squares of differences between adjacent intervals, rmSSD; and frequency domain: (i) the mean spectral power in the LF band (0.04-0.15 Hz), (ii) the mean spectral power in the HF band (0.15-0.4 Hz), (iii) the LF:HF ratio. As stated earlier, the first four indicies are based in time domain, and the latter three indices are based in frequency domain of the heart rate variability responses [15].

Behavioural Results:

After each musical excerpt presented in three different versions, original, IRIS and IRISMax, participants provided subjective ratings of liking, stimulating, absorption, flow and listening experience; Figure 1 shows the mean ratings of these five responses.

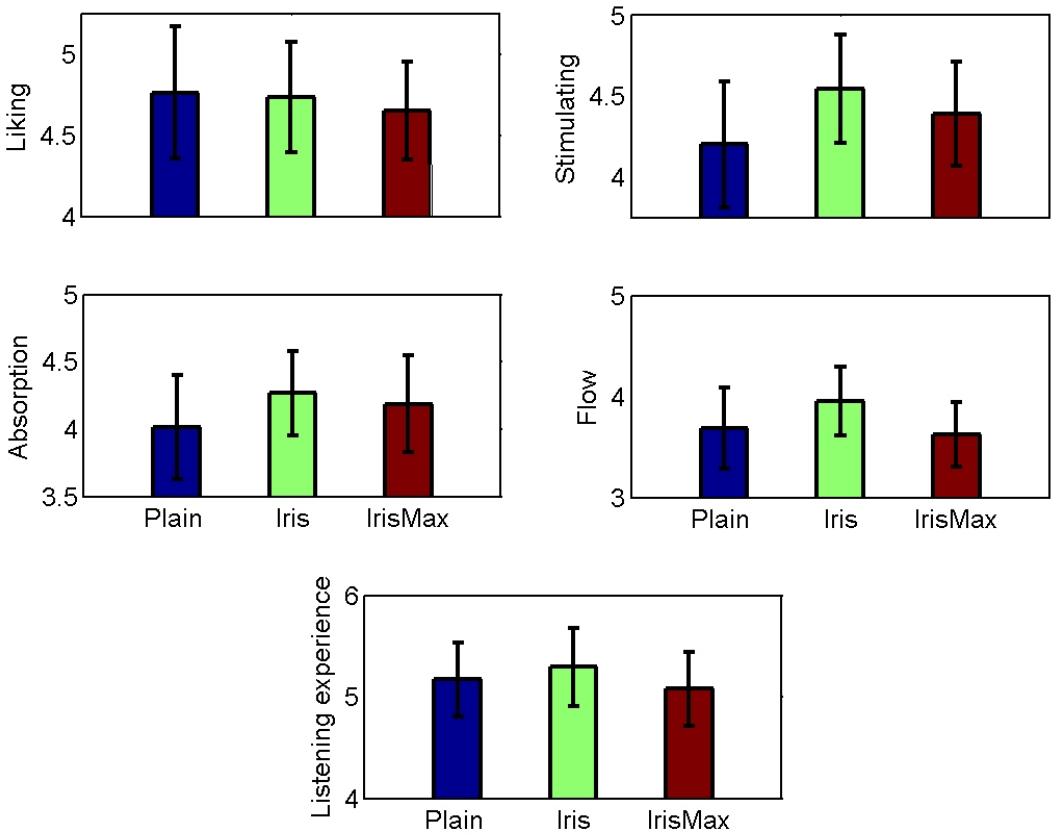

Figure 2: Behavioural ratings of music excerpts belonging to three conditions: plain/original (blue), IRIS enabled (green), and IRISMax enabled (red). Five subjective ratings are shown: liking of the musical excerpts, felt stimulation, felt absorption, felt flow experience, and listening experience (all on a 7 point scale with higher values indicating higher response). Ratings are averaged over eight musical excerpts belonging to each condition. Error bars represent s.e.m.

Across all genres and participants, the mean liking for Iris enabled excerpts (M=4.73) was comparable to plain (M=4.76) and was marginally higher than IrisMax (M=4.65). Interestingly, the participants found both Iris (M=4.55) and IrisMax (M=4.39) excerpts more stimulating than plain ones (M=4.20). Similarly, participants also reported higher absorptions for Iris (M=4.27) and IrisMax (M=4.19) as compared to plain (M=4.01). Interestingly, Iris (M=3.95) was associated with highest flow experience during music listening as compared to IrisMax (M=3.62) and plain (M=3.69). Finally, the participants rated Iris excerpts the best listening experience (M=5.30) than both plain (M=5.17) and IrisMax (M=5.08).

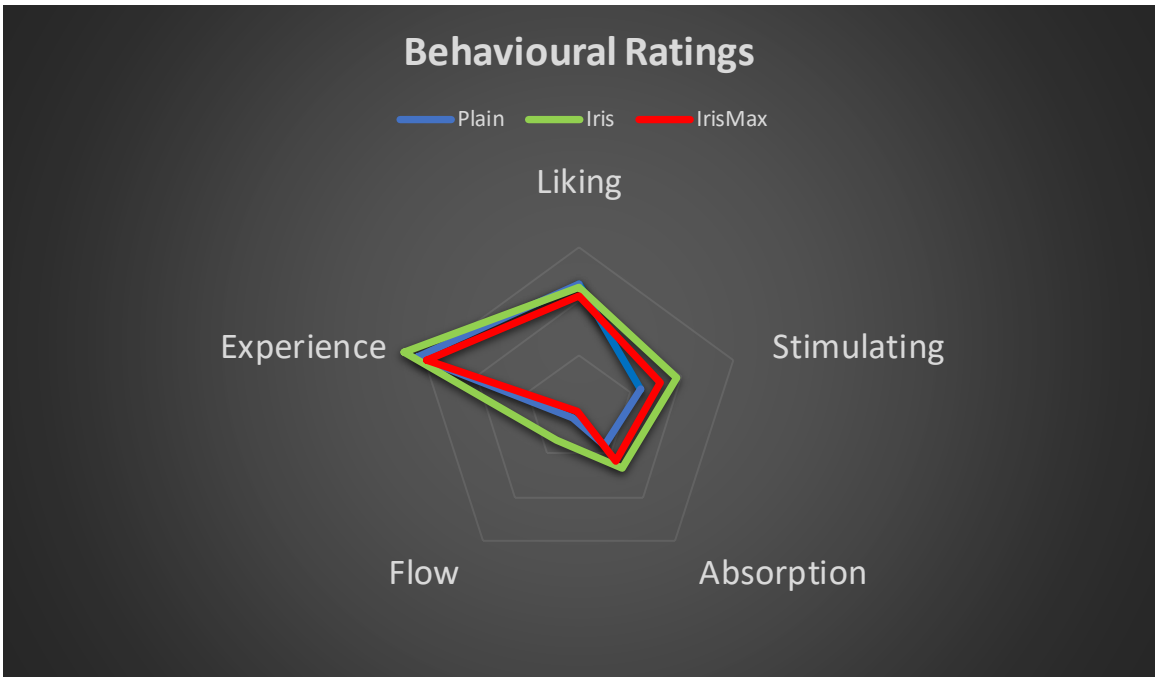

Figure 3. The radar chart of the five behavioural ratings for plain (blue), Iris (green) and IrisMax (red).

Summary of behavioural findings

(i) Iris enabled musical excerpts were rated, on average, the highest in terms of stimulation, absorption, flow experience and also in overall listening experience (Fig. 3).

(ii) The impact of Iris was found to be the largest in terms of stimulation (which is closely related to arousal, a key dimension of emotion)

(iii) Stimulation and absorptions are also the two key responses in which both Iris and IrisMax were rated higher than plain.

EEG Results:

Oscillatory correlates of Iris:

EEG signals were principally analyzed in terms of the constituent oscillatory components. Therefore, we computed periodogram (see *Methods*) and estimated spectral power in the classical EEG frequency bands. Global spectral power, i.e. oscillations averaged across all scalp electrodes, at three low to mid frequency bands, delta, theta, and alpha, are shown in Fig. 4; spectral responses are grouped according to 4 musical genre, classical, pop, rock and wellness. For very low-frequency delta band response (1-4 Hz), the largest differences were observed for rock and wellness, but in opposite directions. Theta band responses (4-8 Hz) were similar across four genres and we observed a decreasing trend from plain, to Iris to IrisMax. For alpha band response (8-13 Hz), the differences between conditions (plain, Iris and IrisMax) were more subtle, and like in delta band, the overall patterns mirrored between rock and wellness.

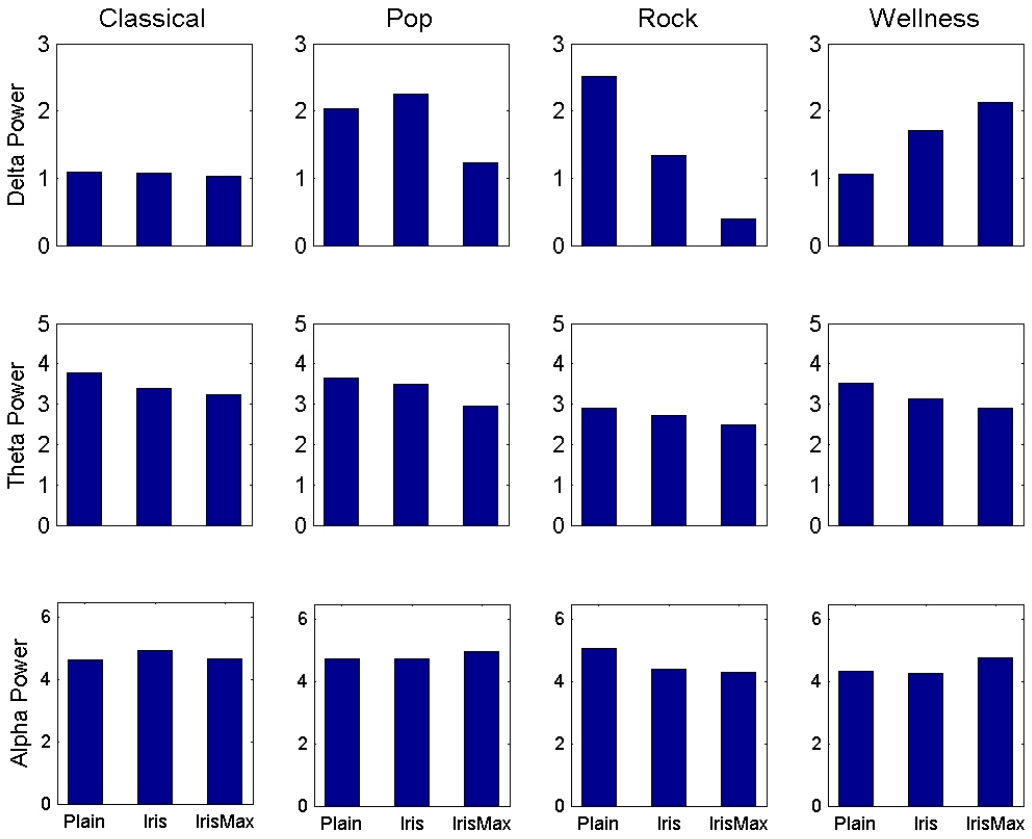

Figure 4. Mean spectral power in the delta (1-4 Hz), theta (4-8 Hz), and alpha (8-13 Hz) frequency bands during listening to musical excerpts but presented in 3 different formats: plain, Iris, and IrisMax. Results were grouped according to four musical genre: classical, pop, rock and wellness. Spectral power values were normalized with respect to baseline and averaged across all sixty-four scalp electrodes.

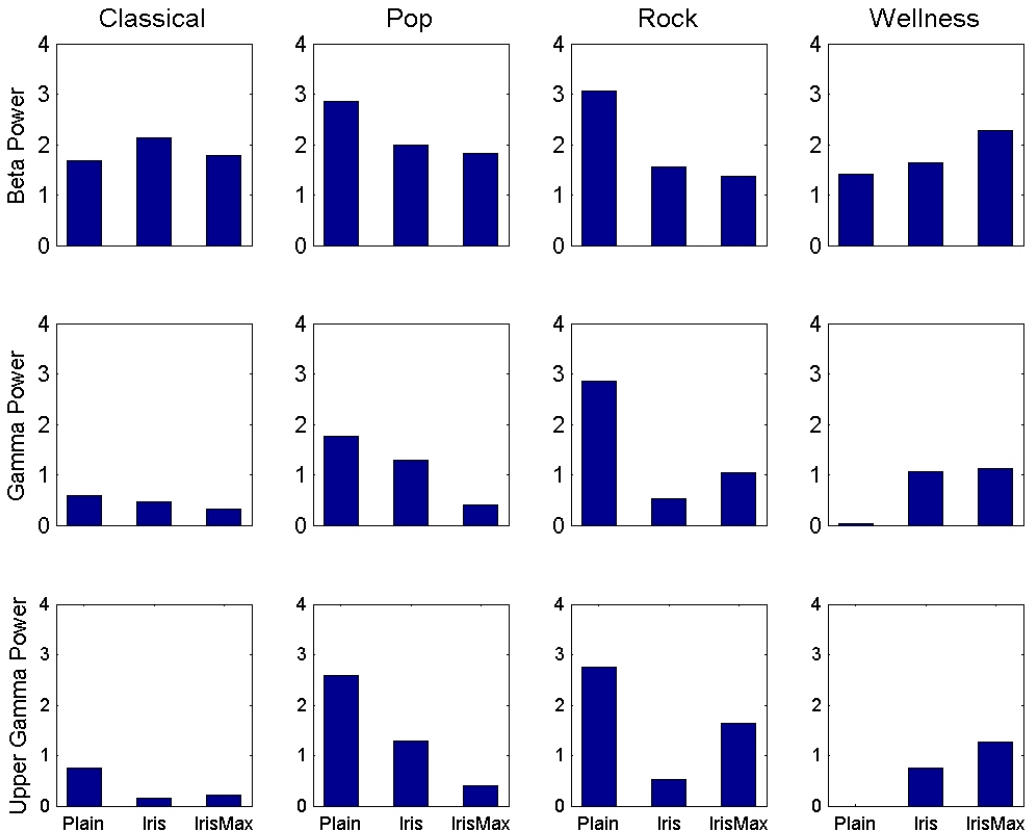

Figure 5. Mean spectral power in the beta (13-30 Hz), gamma (30-48 Hz), and upper gamma (52-80 Hz) frequency bands during listening to musical excerpts but presented in 3 different formats: plain, Iris, and IrisMax. Results were grouped according to four musical genre: classical, pop, rock and wellness. Spectral power values were normalized with respect to baseline and averaged across all sixty-four scalp electrodes.

Global spectral power, i.e. oscillations averaged across all scalp electrodes, at mid to high frequency bands – beta, gamma and upper gamma are shown in Fig. 5; spectral responses are grouped according to 4 musical genre, classical, pop, rock and wellness. The most consistent and robust (i.e. both Iris and IrisMax being considerably different than plain) findings were observed for wellness genre in higher frequency bands (i.e. both gamma and upper gamma); the effect was also observed in the beta frequency band, but to a lesser extent.

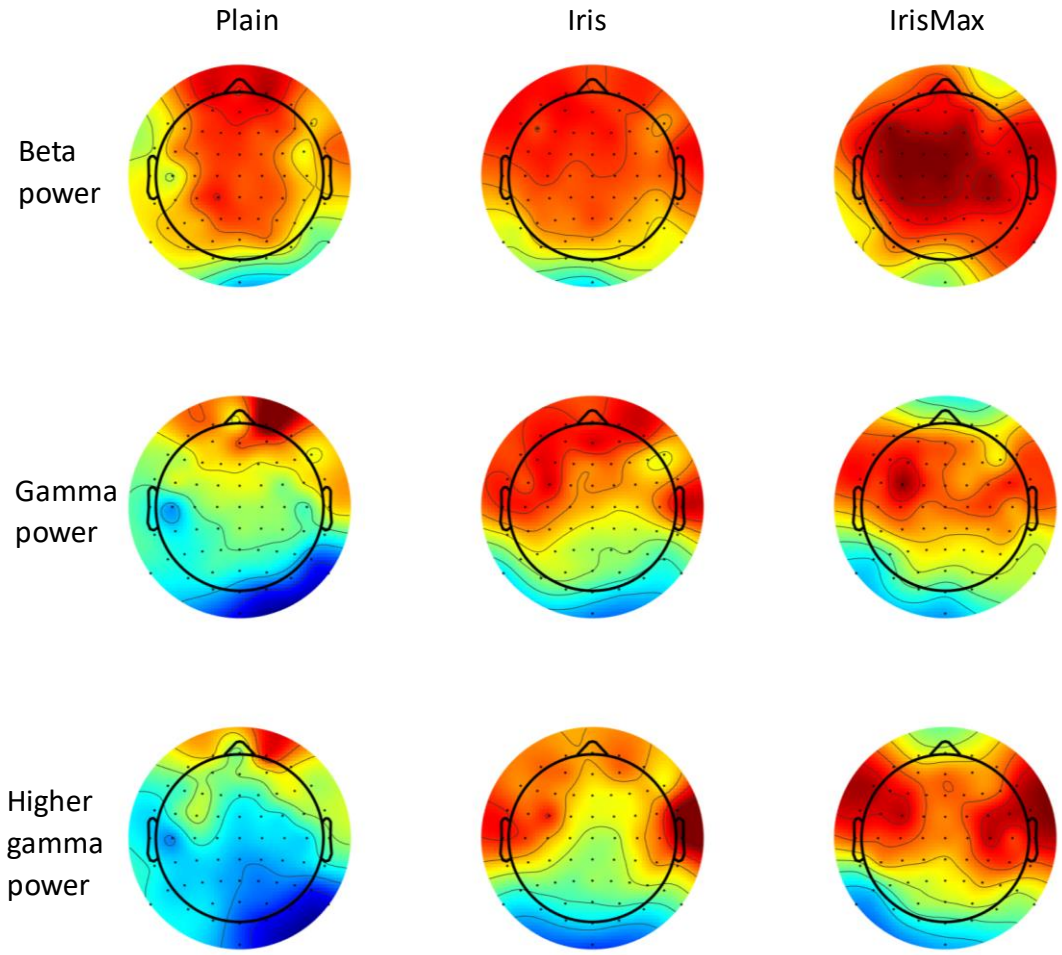

Figure 6. Scalp maps of higher frequency responses (beta, gamma and upper gamma) during listening to Wellness excerpts in pla in, Iris and IrisMax. Note the large increase of high frequency power over frontal brain regions for Iris and IrisMax.

We showed the distribution of spectral power in the three high frequency bands for wellness genre in Fig 7. Highest increase in the high frequency power was observed over broad frontal regions and for both Iris and IrisMax conditions. Although we could observe effects bilaterally but some left hemispheric dominance could also be seen for IrisMax. Previously, increased beta oscillations have been associated with preference for movie trailers [16], gamma oscillations with population-wide consumer choices, despite the stated preferences did not [17]; further, preferred strategic adverts were associated with frontal beta and gamma oscillations [9]. Given the role of frontal high frequency activities in processing reward [18, 19], these enhanced high frequency responses might reflect an increased level of implicit engagement for Iris and IrisMax enabled presentation of wellness excerpts. Of note, left hemispheric dominance in the gamma frequency band was earlier found in participants watching adverts that they found enjoyable [20], aligned with our observations.

Approach/avoidance metric

Human behavior is often dichotomized into two motivational systems, approach (when behaviour is motivated by an approachable or a desirable outcome) and avoidance (when behaviour is motivated by an aversive outcome). The neural correlates of such dichotomy could be captured by the asymmetry in frontal activations (see *Methods*). The cortical frontal asymmetry values were shown in Fig. 7. Of note, a larger asymmetry value would suggest higher left frontal activation (as compared to its right counterpart), and a relatively larger left than right frontal activity characterizes approach-oriented behaviours/states.

Across all genres, the mean frontal asymmetry values for both Iris and IrisMax were higher than those for plain (Fig. 7, upper panel); interestingly, the asymmetry for Iris was even higher than the value for IrisMax. Further, this effect was most conspicuous for classical, pop and wellness genre. This clearly demonstrates a left frontal dominance for excerpts with Iris and IrisMax, thereby suggesting a more approach and positive emotional engagement of the Iris enabled musical excerpts; the asymmetry values associated with plain excerpt were consistently the lowest, suggesting potentially least level of implicit emotional engagement.

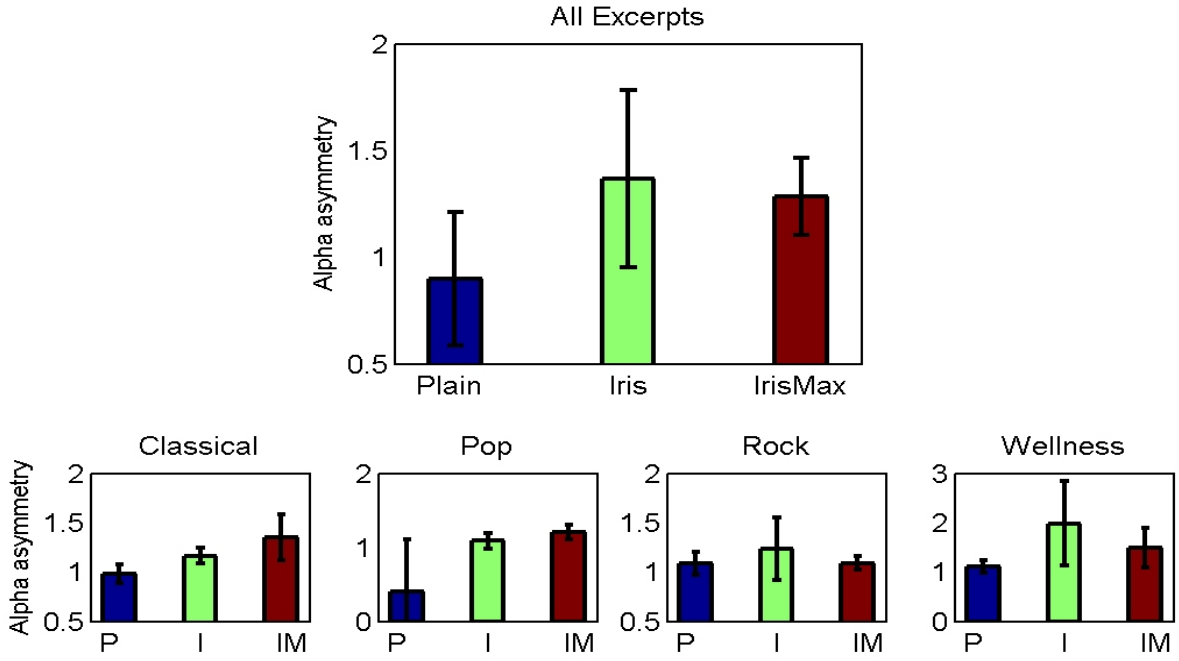

Figure 7. Upper Panel: Frontal alpha asymmetry values for three conditions: Plain, Iris and IrisMax; the values were averaged across all excerpts, genres, participants. Lower Panels: Frontal alpha asymmetry values for each genre separately (P: Plain, I: Iris, IM: IrisMax). Error bars represent s.e.m.

Summary of EEG findings

(i) In terms of activating the brain globally, Iris and IrisMax was most effective for wellness genre; high frequency brain responses were considerably enhanced, conspicuously over broad frontal regions for Iris and IrisMax.

(ii) Both Iris and IrisMax showed a consistent and robust signature of higher engagement and approach than plain as manifested by higher frontal alpha asymmetry.

ECG Results

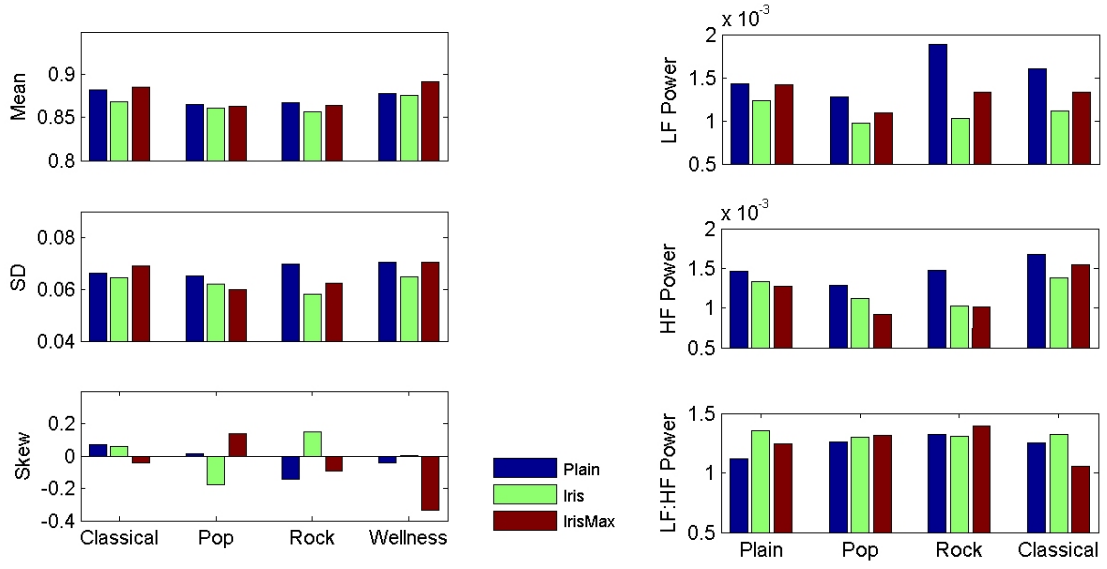

Figure 8. HRV indices – temporal domain ones (mean, SD and skew of R-R intervals) are shown on the left panel, while frequency domains (LF, HF and LF:HF ratio) on the right panel. Values were grouped according to four musical genre.

Fig.8 shows the mean values of three time domain measures, mean R-R, SD and skewness, and of three frequency doimain measures of R-R interval sequences for three conditions. In terms of mean R-R interval (i.e. inverse of heart rate), IrisMax was associated with lowering of heart rate and higher variability (i.e. larger values of SD) for classical and wellness genre. Of note, a very negative skew value was observed for IrisMax wellness excerpts. The patterns of frequency domain measures seem mixed, but nevertheless, we observed that IrisMax for wellness (and classical) was associated with increasing LF power, decreasing HF power, and a lower LF:HF ratio. The LF range is usually known as the baroreceptor band as it usually reflects baroreceptor activity at rest and associated with sympathetic nervous system, while the HF power is usually associated with respiratory sinus arrhythmia because it reflects the heart rate variations coupled with respiratory cycle and is related with parasympathetic nervous system activity; the LF:HF ratio ratio (usually reflecting a balance between PNS and SNS activities – a low value reflecting a parasympathetic dominance while a high ratio indicating sympathetic dominance [21], but see also [22]). This reported pattern for IrisMax therefore might reflect a reduced stress response.

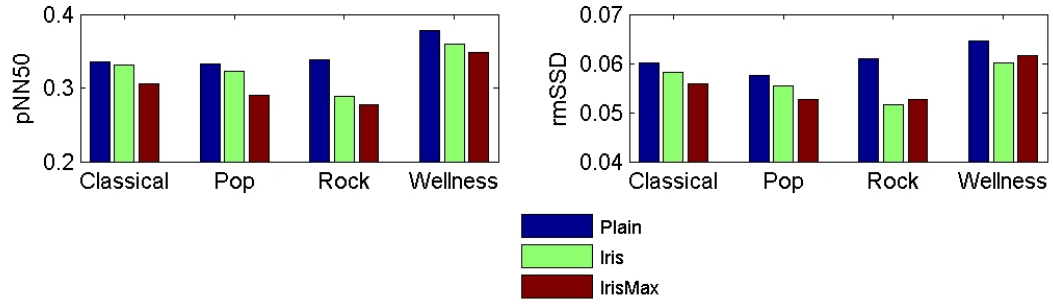

Figure 9. Mean values of pNNN50 and rmSSD for three conditions.

Of note, the other two time domain indices, pNN50 and rmSSD, showed similar patterns (Fig. 9) as both were higher for wellness genre as comparris and IrisMax. Since these indices are usually correlated with the activity of parasympathetic nervous system (PNS), we can conclude that wellness, out of four genre, were most effective genre for Iris and IrisMax to induce a relaxed cardiac state. However, it could be noted that the values for plain excerpts were even higher, therefore, the Iris and IrisMax states could be characterized as relaxed (lowering heart rate, enhanced PNS) but alert and engaged (enhanced high frequency frontal brain oscillations and enhanced cortical alpha asymmetry).

Summary of ECG findings

(i) The patterns are mixed but IrisMax showed a more consistent and pronounced effects than Iris.
(ii) Wellness (and classical) was found to be the most effective.
(iii) The overall state as achieved by IrisMax might be considered as relaxed but alert and engaged.

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