Biophysiological and acoustic correlates of self-reported driver emotional states to electric and diesel taxi cabs

Study conducted on 20 March 2018
Duncan Williams on behalf of London Electric Vehicle Company / Influence Associates

Abstract

This experiment aimed to evaluate the link between acoustic environment, driver mood, and biophysiological response, to the new electric taxi.

Four london taxi drivers participated in an experiment using discrete brain and body sensors to measure biophysiological cues as they drove an electric and a diesel taxi.
Acoustic cues extracted from a stereo recording suggested that the electric vehicle cab was not necessarily quieter, but had an increased dynamic range and lower spectral centroid, both correlates of fatigue in music listening exercises. Drivers described their own experience in the electric vehicle as happier and less stressful than the diesel vehicle, and heart rate and heart rate variability metrics corroborated these descriptions. Brain responses suggested a degree of emotional interaction, and an unexpected finding: correlates of higher concentration when driving the electric vehicle.

Background

Quentin Willson of Top Gear/Fifth Gear described the experience of electric vehicles as “silent speed.. A totally new concept for todays drivers”. There are a number of proposed acoustic correlates for mental states, and many people in Britain describe their experience of the environment as excessively noisy.
Previous driving metrics have suggested that heart rate and skin resistance are most correlated with driver stress (Healey and Picard 2005)
The ratio and duration of alpha and beta waves in brain activity has been shown to be correlated to stress (Puglisi-Allegra and Oliverio 2012) and used as an analog to stress in evaluation of driver mental state using virtual reality driving simulations (Schier 2000; Benoit et al. 2009). However, recent improvements in portability, combined sampling, and durability of A/D conversion allows for real-world testing (Rigas, Goletsis, and Fotiadis 2012; Ollander et al. 2016). This experiment combines acoustic measurement (stereo recording) with biophysiological and self-report metrics conducted on professional London taxi drivers in two conditions: electric and diesel vehicles, across a series of randomised case series trials.

Method

Experiment information sheets were explained and copies given to participants before undertaking the tests. Consent forms in accordance with the University ethics approval process were signed and collected from all participants.

4 professional taxi drivers undertook 12 trials around the Regents park area in the TX4 (diesel) and TX (electric) taxi cabs. Each trial took approximately 20 minutes.

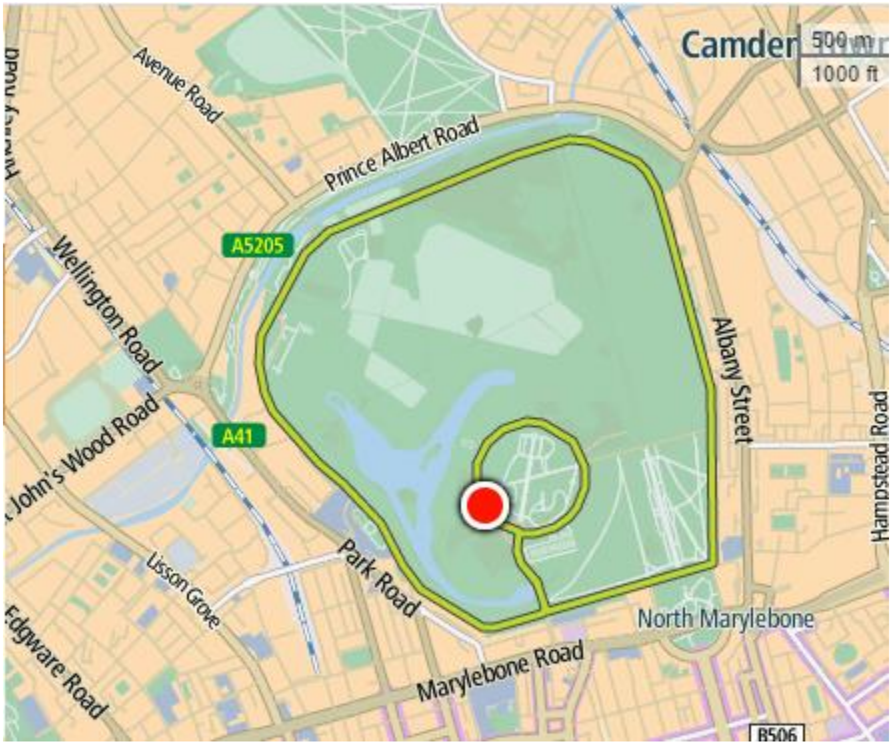

Figure 1. Map of route, Regent’s Park, London (approx 3.5 miles).

Data collected:

Stereo recording of audio files from the cab @44.1kHz, with synchronous 720p video recording.
Galvanic skin response (electrodermal activity) from ear lobe of driver (Although galvanic skin response has been previously shown to be useful in evaluating stress, it was difficult to place the sensors required in situ in the accepted position for this experiment. The sensors are traditionally placed over the finger and wrist, which would be impractical for drivers in the real-world data collection scenario. The GSR sensor was therefore placed behind the ear lobe.
Heart rate of each driver via optical wrist meter
Electroencephalogram (EEG): dry electrodes with 8 channels placed at Fp1, Fp2, C3, C5, P7, P8, O1, O2 in the 10/20 configuration, sampled @ 250Hz
Self-report after each trial across 5 descriptors drawn from psychological evaluation of driving conditions, using a 9-point Likert scale, with 1 being ‘least’ and 10 being ‘most’: Stress, anger, distraction, fear, happiness
3 channel **accelerometer** data @ 250Hz

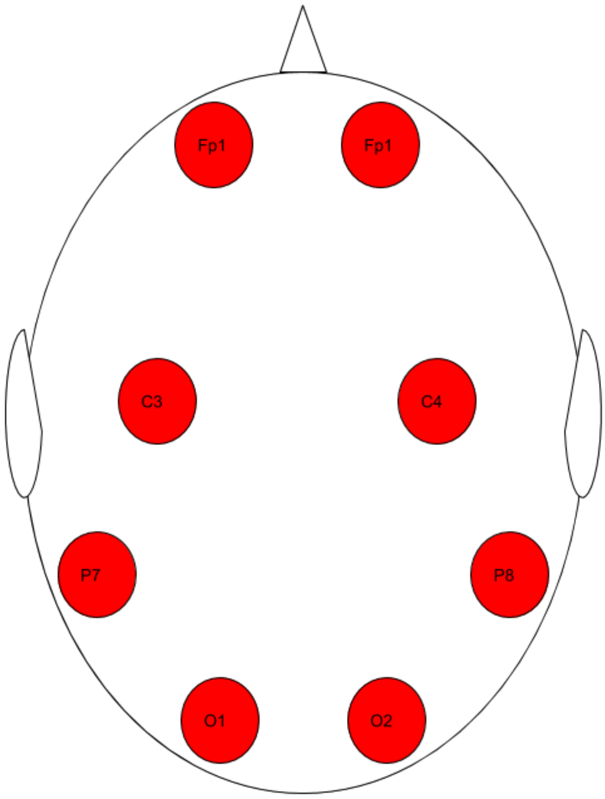

Figure 2. Approximate electrode placement following the 10-20 EEG placement protocol: Frontal (Fp1, Fp2), Central (C3, C4), Parietal (P7, P8), Occipital (O1, O2)

Analysis techniques

Readings for each vehicle type were summed and passed through:
an acoustic feature analysis using MATLAB across five features: Peaks, RMS, Dynamic range, auto correlation, crest factor, and spectral centroid.
EEG was low pass filtered at 50Hz and then butterworth filtered in the alpha and beta ranges. EEG was then inverse convolved with accelerometer data to smooth data with significant head movement
Heart rate variability per participant per trial
Across each self-report descriptor per vehicle (mean, standard deviation, variance)

Results

Self report measures shown in Table 1 indicate that participants described their experience of driving the electric vehicle as:
Less *stressful* than driving the diesel vehicle
Neither more or less *angry* than driving the diesel vehicle
Less *distracting* than driving the diesel vehicle
Neither more or less *afraid* than driving the diesel vehicle
Happier than driving the diesel vehicle

Diesel	Stress	Anger	Distraction	Fear	Happiness
Mean	3.50	1.33	3.83	1.17	6.83
St.Dev	0.89	0.52	1.97	0.00	1.41
Var	0.80	0.27	3.90	0.00	2.00
Electric	**Stress**	**Anger**	**Distraction**	**Fear**	**Happiness**
Mean	2.17	1.33	2.67	1.50	8.17
St.Dev	1.47	0.52	1.51	0.84	1.47
Var	2.17	0.27	2.27	0.70	2.17

Table 1. Self reported responses to the electric and diesel vehicle conditions made by drivers using a 9-point Likert scale (with 1 being 'least' and 10 being 'most') across five descriptors. Collected after each trial.

Heart rate: Drivers generally exhibited lower mean heart rate in the electric trials, as shown in Figures 3-4.

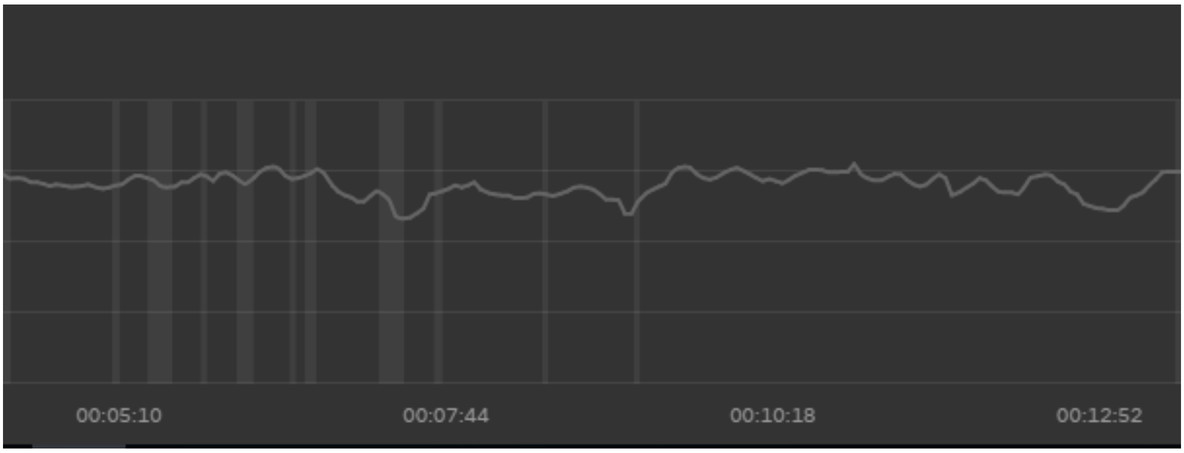

Figure 3. Heart rate across diesel trials for driver A.

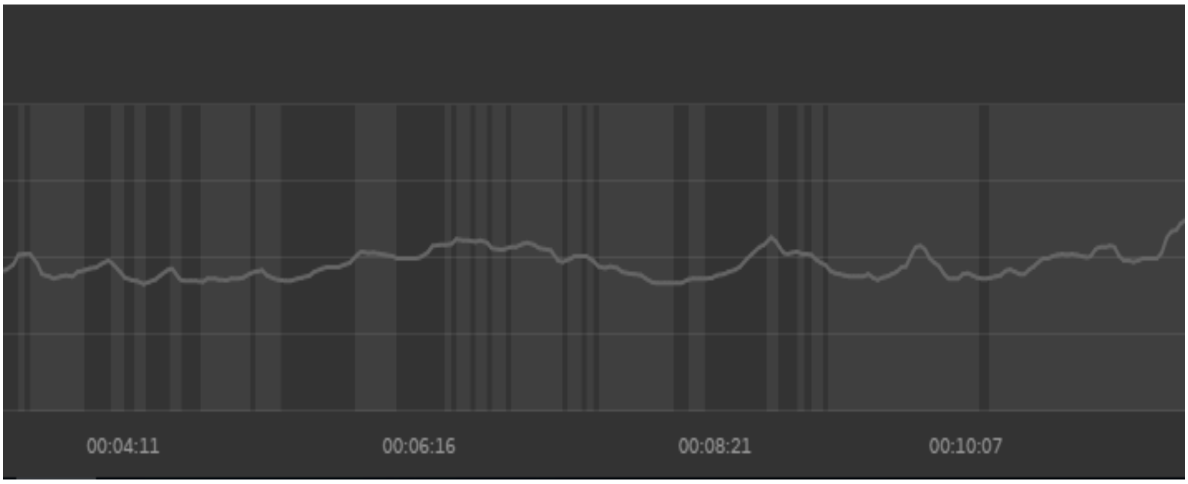

Figure 4. Heart rate across electric trials for driver A

Note the overall lower heart rate comparing the electric trial to the diesel trial for the same driver. This pattern can be seen in plots for ¾ of the driver participants (drivers A, B, and C). However, driver D showed a markedly similar mean heart rate when comparing diesel and electric trials, as shown in Figures 5-6.

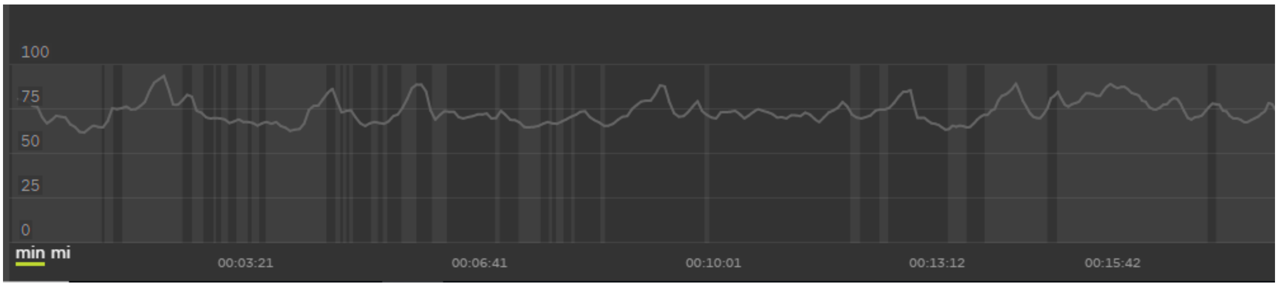

Figure 5. Heart rate across diesel trials for driver D. Note only slight reduction of range of heart rate (higher values in this figure ~3bpm) and increased variability in comparison to Figure 6 with large peaks and troughs occurring throughout the trial.

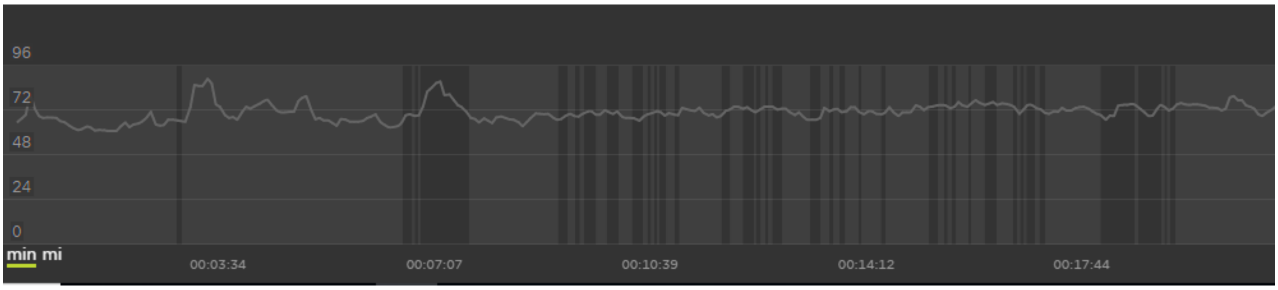

Figure 6. Heart rate across electric trials for driver D. Note only slight reduction of range of heart rate (lower overall values in this figure ~ 3bpm) and despite two large peaks early in the trial, an overall decrease in variability in comparison to Figure 5.

Whilst data regarding participant hearing was not collected, it was noted that the participant in question (driver D above) did wear a hearing aid. This suggests that whilst *the sound world may have influence on the mean heart rate*, there was nevertheless a degree of heart rate variability increase in the diesel trials in comparison to the electric vehicle trials in this case, as was also seen in the other participant trials. All drivers **exhibited lower heart rate variability** in the electric vehicle trials.

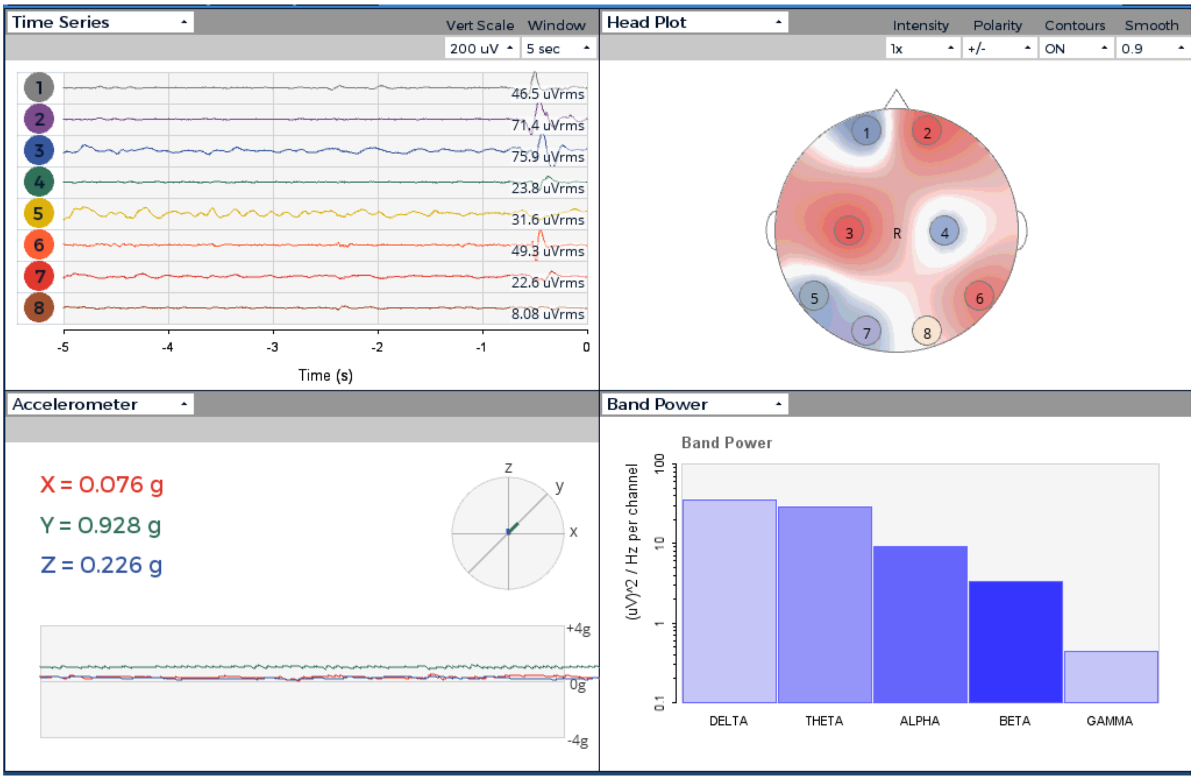

Figure 7. Time series, head plot, band power chart, and accelerometer data showing frame from playback recorded in a diesel vehicle trial. Note frontal, central, and parietal asymmetry with higher band power in alpha than beta range. Accelerometer showing no unusual head movement in X, Y, or Z planes (no movement >1g).

Figure 8. Time series, head plot, band power chart, and accelerometer data showing frame from electric trial showing marginally higher level of beta than alpha. No significant artefacts in accelerometer.

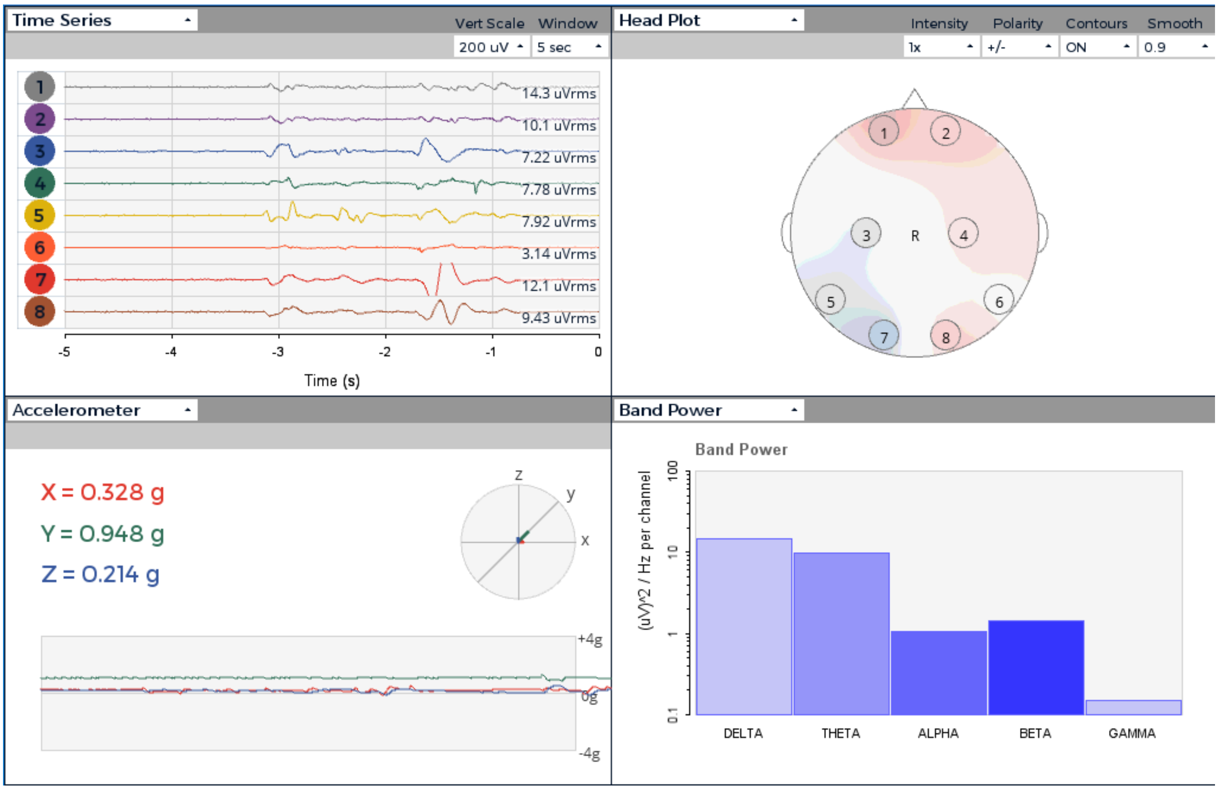

Figure 9. Time series, head plot, band power chart, and accelerometer data showing frame from electric vehicle trial with greater beta band power than alpha band power. Note occipital asymmetry.

Figure 9. F Time series, head plot, band power chart, and accelerometer data showing frame from diesel vehicle trial. Note central, parietal, and occipital asymmetry and greater band power in alpha

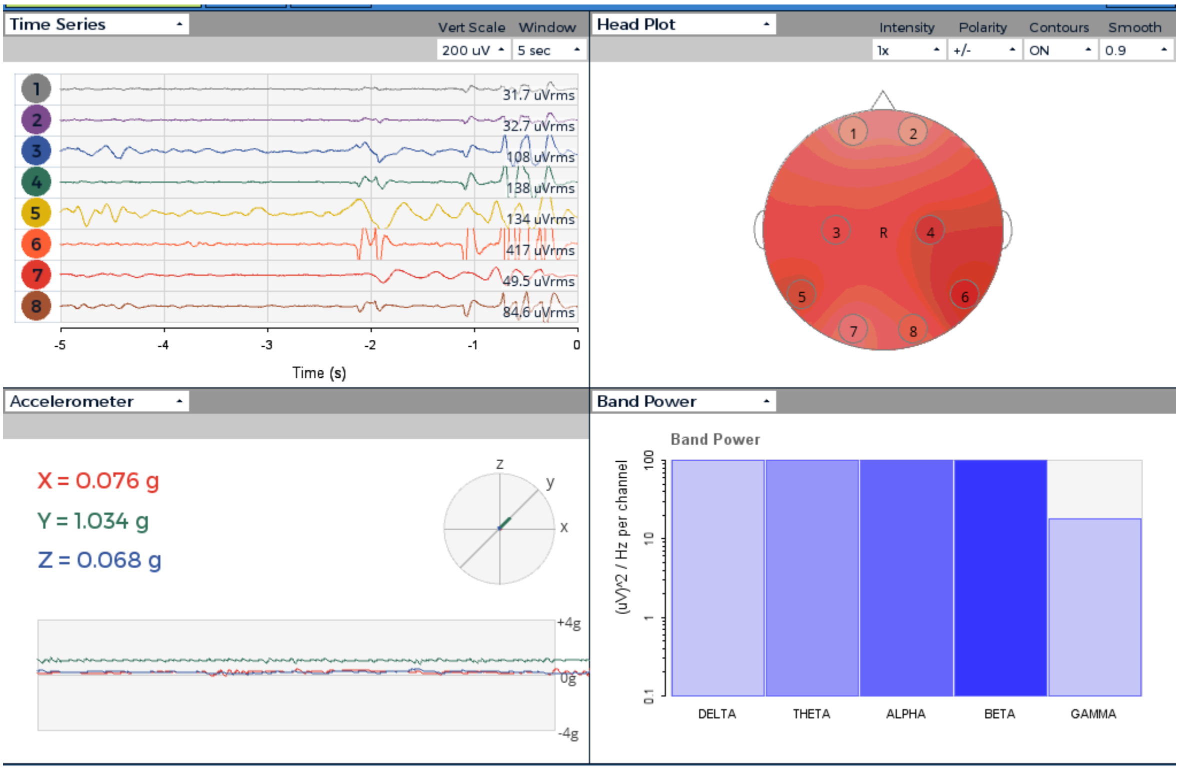

Figure 10. Time series, head plot, band power chart, and accelerometer data showing example of head related movement artefact: greater than 1g in accelerometer, time series clipped in multiple electrodes, band power clipped in most frequency bands.

The diesel trials frequently exhibited frontal asymmetry, which has been correlated with both negative and positive affect (Schaffer, Davidson, and Saron 1983). Asymmetry in itself is not necessarily a useful indicator of mood or mental state (Chu, Tranel, and Damasio 1994) and is to some extent a default, though frontal and parietal asymmetry has been shown more recently in EEG studies to be well correlated with positive and negative emotions (Palmiero and Piccardi 2017). Perhaps more unusually, the electric trials exhibit **less asymmetry** and **higher levels of beta** frequency band power in comparison to alpha frequency band power. Alpha frequencies tend to be correlated with restful or relaxed states of mind, and beta frequencies with concentration. This finding is thus quite unexpected for the electric trials -- drivers reported **more happiness, less stress**, in the electric vehicle -- so it may be that the **electric vehicle was less distracting** and in fact allowed drivers to concentrate more, resulting in **less overall fatigue** at the end of a driving session.

Galvanic skin response was not collected in the traditional way due to practical concerns (driving with sensors attached to fingers/hands). The GSR showed little difference between either vehicle type across the trials but these values were also below the statistical significance threshold. GSR distribution is shown in Figure 11.

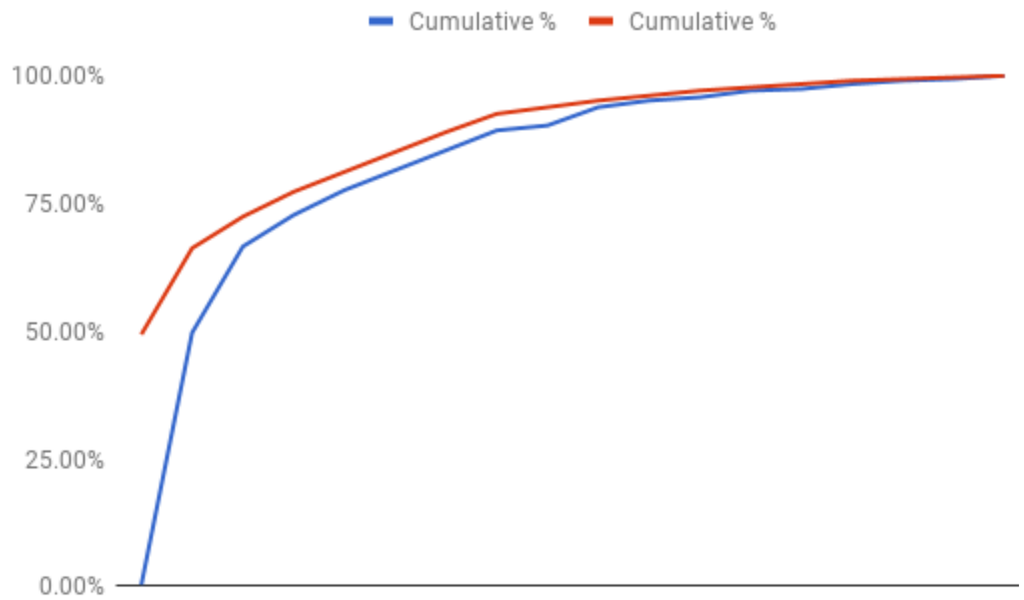

Figure 11. Distribution of galvanic skin response values across timestamp values for recordings (Electric vehicle in blue, Diesel vehicle in red). Note that *p*-value was below threshold for statistical significance.

Six acoustic features (peak values, root mean square amplitude, dynamic range, auto-correlation, crest factor, and spectral centroid) extracted using the signal processing toolbox in MATLAB are shown in Table 2.

PEAKS (maximum, minimum)	RMS	DYNAMIC RANGE (dBFS)	AUTO CORRELATION (s)	CREST FACTOR (dB)	SPECTRAL CENTROID
Max 0.94427 Min -0.94293	0.14031	89.8110	2.802	16.5601	4112.533
Max 0.72308 Min -0.70758	0.10795	87.4928	2.807	16.5197	3290.366
Max 0.85632 Min -0.87732	0.16385	88.9618	10.255	14.3637	6789.525
Max 0.91406 Min -0.92899	0.17248	89.5285	7.383	14.4847	6704.825
Max 0.99734 Min -1	0.17620	90.2859	4.192	15.0566	6772.741
Max 0.63519 Min -0.6145	0.11329	86.3671	15.710	14.9741	7980.007

Max 0.90921 Min -0.86606	0.16999	89.4823	15.710	14.5649	6750.248
Max 0.90918 Min -0.86609	0.16999	89.4820	15.710	14.5646	6750.241
Max 0.99997 Min -1	0.27585	90.3087	0.145	11.1863	11194.000
Max 0.91644 Min -0.89301	0.17731	89.5511	1.432	14.2676	5684.410
Max 0.85632 Min -0.87732	0.16385	88.9618	10.255	14.3637	6789.525
Max 0.91406 Min -0.92899	0.17248	89.5285	7.383	14.4847	6704.825

Table 2. A comparison of acoustic features extracted from stereo recordings made inside the diesel and electric vehicles during each trial. Although the order of trials was randomised during the collection, for ease of comparison here they are presented as follows: odd numbers are recordings from the diesel cab (shaded grey), even numbers from the electric cab (no shading)

The electric vehicle samples indicate lower peak values in comparison to the diesel vehicle recordings with higher spectral centroid in some samples in the diesel vehicle, and slightly lower mean amplitude (RMS) in the electric vehicle. Surprisingly, some **electric vehicle trials indicated a larger dynamic range**, though the variance across the dynamic range in all trials was minimal, consistently less than 5dB full scale. In laymans terms, these descriptors would typically correlate to a **slightly sharper (higher spectral centroid), louder (higher RMS and lower dynamic range) perceived sound in the diesel vehicle**. The lower dynamic range might be a directly correlated to the idle engine sound of the diesel vehicle as these analyses were extracted from complete trials.

Conclusions

Drivers self-reported little difference in *anger* or *fear* between either vehicle type, with no variation in response to *anger* and minimal variation in response to *fear* across the two vehicle conditions. Given these are professional drivers with many decades of experience on London roads, it is perhaps unsurprising that the drivers felt little sense of *anger* or *fear* undergoing these trials. The electric vehicle was reported to be less *stressful* and less *distracting*, as well as *happier* by the drivers than the diesel vehicle - with the largest improvement being in self-reported *happiness*, then reduction in *stress*, and finally reduction in *distraction*. The only diesel vehicle ratings with significant inter-participant variation where for the *distraction* descriptor. There was a greater degree of inter-participant variation amongst the electric vehicle ratings than the diesel ratings for *stress*, and to a lesser extent, *happiness*.

The EEG showed correlates in various regions, particularly asymmetry, suggesting different emotional responses in each trial, but more significantly a greater level of beta frequency band power in the electric vehicle trials than in the diesel vehicle trials. Alpha and beta frequencies have well documented and agreed upon correlates in relaxation (alpha), and active concentration (beta). An expected hypothesis, based on the self-report measures, would be that the electric vehicle, which drivers described as more fun and less stressful, would be accompanied by higher levels of alpha than beta - but the opposite appears to be the case. This might be because drivers were in fact able to concentrate more without the noise of the diesel engine, which becomes most noticeable at a standstill (e.g., waiting at lights etc).

For the majority of trials, there was a marked difference in mean heart rate, though this is not in itself a prominent correlate of mental state. Heart rate variability however is a well understood correlate for stressed mental states (Kim et al. 2018), and even in the case of the driver who exhibited little difference in mean heart rate between the two conditions, there was a marked increase in HRV in the diesel vehicle trials. The driver who exhibited no significant difference in mean rate between the two trials did wear a hearing aid device -- which suggests there might be a correlation between the sound world and the resulting influence on heart rate -- but this would be impossible to establish without a larger number of participants.

Whilst the biophysiological responses are not necessarily what would be expected given the self-report results, there seems to be a strong case to suggest that the drivers in the electric vehicle trials were less mentally and physically fatigued by the drive.

References

Benoit, Alexandre, Laurent Bonnaud, Alice Caplier, Phillipe Ngo, Lionel Lawson, Daniela G. Trevisan, Vjekoslav Levacic, Céline Mancas, and Guillaume Chanel. 2009. “Multimodal Focus Attention and Stress Detection and Feedback in an Augmented Driver Simulator.” *Personal and Ubiquitous Computing* 13 (1): 33–41.

Chu, C. C., D. Tranel, and H. Damasio. 1994. “How Reliable Are Occipital Asymmetry Measurements?” *Neuropsychologia* 32 (12): 1503–13.

Healey, J. A., and R. W. Picard. 2005. “Detecting Stress during Real-World Driving Tasks Using Physiological Sensors.” *IEEE Transactions on Intelligent Transportation Systems* 6 (2): 156–66.

Kim, Hye-Geum, Eun-Jin Cheon, Dai-Seg Bai, Young Hwan Lee, and Bon-Hoon Koo. 2018. “Stress and Heart Rate Variability: A Meta-Analysis and Review of the Literature.” *Psychiatry Investigation* 15 (3): 235–45.

Ollander, Simon, Christelle Godin, Sylvie Charbonnier, and Aurélie Campagne. 2016. “Feature and Sensor Selection for Detection of Driver Stress.” In *Proceedings of the 3rd International Conference on Physiological Computing Systems*, 115–22. SCITEPRESS - Science and Technology Publications.

Palmiero, Massimiliano, and Laura Piccardi. 2017. “Frontal EEG Asymmetry of Mood: A Mini-Review.” *Frontiers in Behavioral Neuroscience* 11 (November): 224.

Puglisi-Allegra, Stefano, and A. Oliverio. 2012. *Psychobiology of Stress*. Springer Science & Business Media.
Rigas, G., Y. Goletsis, and D. I. Fotiadis. 2012. “Real-Time Driver’s Stress Event Detection.” *IEEE Transactions on Intelligent Transportation Systems* 13 (1): 221–34.
Schaffer, C. E., R. J. Davidson, and C. Saron. 1983. “Frontal and Parietal Electroencephalogram Asymmetry in Depressed and Nondepressed Subjects.” *Biological Psychiatry* 18 (7): 753–62.
Schier, M. A. 2000. “Changes in EEG Alpha Power during Simulated Driving: A Demonstration.” *International Journal of Psychophysiology: Official Journal of the International Organization of Psychophysiology* 37 (2): 155–62.