Neurophysiophenomenology – predicting emotional arousal from brain arousal in a virtual reality roller coaster

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Introduction
Arousal is a core affect constituted of both bodily and subjective states that prepares an agent to respond to events of the natural environment [1]. While the peripheral physiological components of arousal have been examined also under naturalistic conditions [2], its neural correlates were suggested mainly on the basis of simplified experimental designs [3]. We used virtual reality (VR) to present a highly immersive and contextually rich scenario of roller coaster rides to evoke naturalistic states of emotional arousal. Simultaneously, we recorded EEG to validate the suggested neural correlates of arousal in alpha frequency oscillations (8-12Hz) over tempo-parietal cortical areas [3]. To find the complex link between these alpha components and the participants’ continuous subjective reports of arousal, we employed a set of complementary analytical methods coming from machine learning and deep learning.

Paradigm

Aim
Using the alpha components of the EEG data to predict for each single moment (second) the reported level of arousal.

Ground truth (Fig3):
- individual behavioural ratings
- tertile split of individual time series: high & low arousal

Two approaches:
- binary classifier (CSP, LSTM) of low & high arousal
- regression models (SPoC, LSTM)

Methods

Participants
38 (20 ♀) healthy, young (range: 18-35 years) adults

Stimulation
HTC Vive Head-mounted Display

Measurement
30 channel EEG (BrainProducts LiveAmp + actiCap)

Task (Fig1):
- passive viewing of two immersive virtual roller coaster rides [4] + intermediate 30s break (stable head-position)
- retrospectively: continuous rating of subjective emotional arousal during the prior VR episode based on a replay of the roller coaster episodes

EEG Analysis

Preprocessing
PRP pipeline [5], EOG activation removal

Dimensionality reduction
Spatio-spectral decomposition (SSD) [6] (Fig2 by [5])

Analysis approaches & Results

Common spatial patterns (CSP) [7]
- derives a set of spatial filters to project the EEG data onto components whose bandpower maximally relates to the prevalence of a specified class (e.g., high vs. low arousal).
- discriminates between two classes of mental states
- extracted feature: bandpower of 6 most discriminative components (1sec windows)

Results CSP – Binary Classification
- Avg. accuracy: 63.8% (SE=0.99%) sign. above chance level (p<.001, CI: 57-1)
- Avg. spatial activation patterns (Fig4)

Long Short-Term Memory (LSTM) recurrent neural nets [8]
- detect short & long-term dependencies in time series
- hyperparameters (e.g., layers, activation function) found via random search strategy [9] (Fig5)
- Model inputs: SSD alpha components (LSTMα) benchmarked with SPoC components (LSTMSPoC)

Results LSTMα – Binary Classification / Regression
- binary classifier: Avg. accuracy: 63.4% sign. above chance level (perm3000 p<.001, range .514–.816)
- regression: sign. above mean-accuracy-line (diff=.046, perm3000 p<.001, range .03–.173)
- in both tasks no sign. difference between LSTMα and LSTMSPoC (binary classification: perm3000 p=.554; regression: perm3000 p=.735)

Results LSTMSPoC – Regression
- Avg. correlation coefficients for single best components sign. lower than zero (mean r =.20, CI: –.28, .12 p<.001)
- 84% of them were negative (32/38)
- 39% of them (15/38) remained sign. (p<.05) after bootstrapping iterations (n=500)

Source Power Comodulation (SPoC) [10]
- extracts functionally relevant EEG components by maximising the correlation of their bandpower with the continuous ground truth (here: ratings, Fig3)

Results SPoC – Regression
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Summary & Discussion

- Power fluctuations in the alpha range (8-12 Hz), particularly in tempo-parietal areas, predict subjective ratings of emotional arousal
- Our results extend previous findings of simplified experimental designs [3] regarding emotional arousal to more ecologically valid settings
- These findings are consistent across the applied complementary set of methods in binary classification and continuous prediction
- Integrating different machine learning methods with VR immersive technologies provides a promising toolset towards a better understanding of human subjective experience in natural conditions

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References