Modality-specific Affective Responses and their Implications for Affective BCI

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Abstract

Reliable applications of multimodal affective brain-computer interfaces (aBCI) require a detailed understanding of the processes involved in emotions. To explore the modality-specific nature of affective responses, we studied neurophysiological responses of 24 subjects during visual, auditory, and audiovisual affect stimulation and obtained their subjective ratings. Coherent with literature, we found modality-specific responses in the EEG: parietal alpha power decreases during visual stimulation and increases during auditory stimulation, whereas more anterior alpha power decreases during auditory stimulation and increases during visual stimulation. We discuss the implications of these results for multimodal aBCI.

1 Introduction

Affective brain-computer interfaces (aBCI) aim to provide an intelligent and affective interface, using real-time processing and classification of (single trial) EEG signals. As such, aBCI belong to a new class of affective interfaces. This class relies on the assumption that the EEG reflects affective responses, which will be challenged in the current article.

aBCI studies found EEG signals, especially in the frequency domain, to be informative regarding the affective state [1, 2, 3]. Cognitive theories of affect (e.g., the component process theory [4]) suggest that the brain is involved in responses to affective stimulation through both a self-monitoring component and mechanisms of increased cognitive processing of relevant affective stimuli, comparable to the effects of attention [5]. Especially cognitive processes might depend on the modality through which emotional states are induced (e.g. by visual or auditory affective stimuli), because the respective modality-specific sensory processes are supposed to have their own neural substrates, with correlates of their activity in the alpha band [6, 7].

Here, we explore the stimulus-specific cognitive responses during visual, auditory, and audiovisual affective stimulation. According to theories of sensory processing [6], we expect parietal and fronto-central alpha activity to (negatively) correlate to visual and auditory processing, respectively. Specifically, visually induced affect should lead to a decrease of parietal alpha power, whereas auditorily induced affect should lead to a decrease of fronto-central alpha power. Audiovisual stimulation should lead to decreases in both regions.

2 Methods

Participants We collected subjective ratings, and measured EEG from 12 female and 12 male participants (mean age: 28 years, range: 19–39), all but one right-handed.

Table 1: Mean (std) ratings for the emotion conditions (norm [8, 9] and *participants'* ratings).

Condition	Visual Modality (IAPS)		Auditory Modality (IADS)		Audio-visual Modality	
	Valence	Arousal	Valence	Arousal	Valence	Arousal
(1) Unpleasant low arousal	2.58(0.60) *1.99(0.79)*	5.24(0.54) *4.98(1.60)*	3.05(0.51) *2.84(0.81)*	5.81(0.43) *4.55(1.73)*	- *2.28(0.78)*	- *5.08(1.56)*
(2) Unpleasant high arousal	2.26(0.34) *1.97(0.83)*	6.50(0.22) *5.73(1.84)*	2.70(0.51) *2.55(0.77)*	6.79(0.31) *5.32(1.64)*	- *2.02(0.90)*	- *5.82(1.61)*
(3) Pleasant low arousal	7.53(0.44) *6.88(0.70)*	5.26(0.52) *5.24(1.45)*	7.09(0.43) *6.17(0.71)*	5.59(0.39) *4.97(1.50)*	- *6.69(0.81)*	- *5.37(1.50)*
(4) Pleasant high arousal	7.37(0.31) *6.29(0.93)*	6.67(0.38) *5.50(1.60)*	7.19(0.44) *6.28(0.71)*	6.85(0.39) *5.67(1.62)*	- *6.40(0.69)*	- *5.92(1.65)*
(5) Neutral low arousal	4.92(0.54) *4.52(0.64)*	5.00(0.51) *4.41(1.24)*	4.82(0.44) *4.86(0.60)*	5.42(0.42) *4.10(1.29)*	- *4.54(0.60)*	- *4.38(1.38)*

Experimental Setup To manipulate the affective state, a binary division was made between both 40 IAPS [8] and 40 IADS [9] stimuli on both the valence (i.e., pleasant and unpleasant) and arousal (i.e., low and high) dimension. Additionally, a neutral class (i.e., low arousal, neutral valence) with 10 stimuli for each stimulus modality was constructed, see also Table 1[1]. The mean valence and arousal values of the conditions were matched as good as possible between the emotion conditions, and between modalities. For the audio-visual conditions, visual and auditory stimuli of the same emotion conditions were paired with special attention to match the content of picture and sound (e.g., pairing of "aimed gun" picture and "gun shot" sound).

The stimuli were presented in 3 separate blocks: visual, auditory, audio-visual, each preceded by a resting period of 60 seconds. Their order was balanced (Latin Square) across participants. Within each of these 3 modality blocks, the 5 emotion conditions were presented in pseudo-randomized order to ensure a balancing across participants. Each block was preceded by a 20 second resting period to minimize carry-over effects. Within each block, auditory and/or visual stimuli were presented in a randomized order, each for 6 seconds and separated by 2 seconds. A fixation cross was present in the center of the screen to minimize eye movements.

Before the experiment, participants gave their informed consent and their demographics. They were seated 90 cm away from a monitor and speakers. EEG was recorded with a Biosemi ActiveTwo Mk II system, with 512 Hz sampling frequency. 32 active silver-chloride electrodes were placed according to the 10-20 system. For later artifact rejection, the electrooculogram (EOG) was measured by 2 electrodes attached to the outer canti of the eyes and 2 attached below and above the left eye. Before the start, participants were instructed to avoid movements and to fixate at all times the fixation cross. After the experiment, all stimuli were presented once more to jog their memory while they rated the experienced valence, arousal, and dominance.

Data extraction and analysis The EEG data was resampled to 256 Hz, referenced to common average, and high-pass filtered with a 1 Hz FIR filter. EOG artifacts were removed by the AAR toolbox in EEGlab. For each emotion condition and modality, the mean alpha power (8–13 Hz) was extracted for stimulation and resting periods, using Welch's method with 256-point Hanning windows. Subsequently, the power was averaged over the *parietal* (P3,Pz,P4) and *fronto-central* (FC1,Fz,FC2) regions of interest, and a natural log transform was applied. The power during each condition was baselined by subtracting that of the preceding resting period.

For analysis, repeated measures ANOVAs were used. First, the affect manipulation was verified, using the valence and arousal ratings. Second, modality-specific effects on parietal and fronto-central alpha power were analyzed, using the data of the neutral versus the averaged emotion conditions for each region. Where appropriate, Greenhouse-Geisser correction has been applied. Partial eta-squared η_p^2 is reported as effect strength measure.

[1](1) IAPS: 2141,2205,2278,3216,3230,3261,3300,9120,9253,8230 IADS: 280,250,296,703,241,242,730,699,295,283 (2) IAPS: 2352.2,2730,3030,6360,3068,6250,8485,9050,9910,9921 IADS: 600,255,719,284,106,289,501,625,713,244 (3) IAPS: 1811,2070,2208,2340,2550,4623,4676,5910,8120,8496 IADS: 226,110,813,221,721,820,816,601,220,351 (4) IAPS: 4660,5629,8030,8470,8180,8185,8186,8200,8400,8501 IADS: 202,817,353,355,311,815,415,352,360,367 (5) IAPS: 2220,2635,7560,2780,2810,3210,7620,7640,8211,9913 IADS: 724,114,320,364,410,729,358,361,500,425

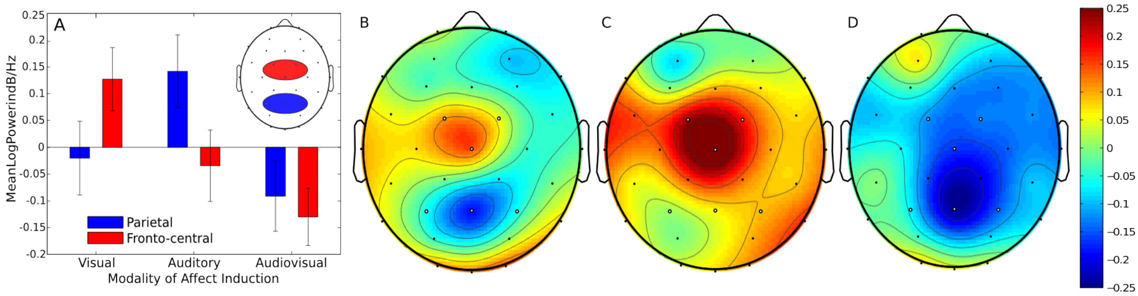

Figure 1: The parietal and fronto-central alpha power (whiskers: SEM) during visual, auditory, and audio-visual affect, averaged over all subjects that entered the respective analyses (A); and the 2nd level contrasts (emotion – neutral) of visual – auditory (B), visual – audio-visual (C), audio-visual – auditory affect (D), showing modality-specific responses averaged over all subjects.

3 Results

A 3(modality)×5(emotion) ANOVA on the valence ratings showed a main effect of both emotion (F(4,92) = 246.100,p $<$ 0.001,η_p^2 = 0.915) and modality (F(2,46) = 6.057,p = 0.005,η_p^2 = 0.208). A 3(modality)×3(valence) ANOVA indicated the successful manipulation of emotional valence (F(2,46) = 264.100,p $<$ 0.001,η_p^2 = 0.920), with an effect of modality (F(2,46) = 7.078,p = 0.002,η_p^2 = 0.235) due to more positive valence ratings for auditory stimuli. An interaction effect indicates less extreme ratings for auditory stimuli (F(4,92) = 14.813, p $<$ 0.001,η_p^2 = 0.392) and, hence, a weaker efficacy. A similar pattern was found in a 3(modality)×5(emotion) ANOVA on the arousal ratings, showing a main effect of emotion (F(4,92) = 12.588,p $<$ 0.001,η_p^2 = 0.354), and of modality (F(2,46) = 9.177,p $<$ 0.001,η_p^2 = 0.285). A 3(modality)×2(arousal) ANOVA showed higher ratings for arousing conditions (F(1,23) = 27.180,p $<$ 0.001,η_p^2 = 0.542), and an effect of modality (F(2,46) = 9.344,p $<$ 0.001,η_p^2 = 0.289), due to lower arousal for auditory stimuli (see Table 1).

For each EEG analysis we excluded all cases showing outliers ($>$ 1.5 × *interquartile range*), resulting in N = 20 for both regions of interest. The parietal alpha power showed an interaction of emotion and modality (F(2,38) = 3.373, p = 0.045, η_p^2 = 0.151). T-tests contrasting the emotion effects (i.e., emotion – neutral) of visual, auditory, and audio-visual conditions, revealed a significant difference between audio-visual and auditory affect (t = -2.651, p = 0.016), and a trend toward a difference between visual and auditory affect (t = -2.093, p = 0.052) . The fronto-central alpha power showed a significant interaction (F(2,38) = 4.891, p = 0.013, η_p^2 = 0.205). T-tests of the emotion effects showed a significant difference between audio-visual and visual affect (t = -3.155, p = 0.005), and a trend toward a difference between visual and auditory affect (t = 1.817, p = 0.085). So, on the one hand, parietal alpha decreases during visual and audio-visual and increases during auditory affective stimulation. On the other hand, fronto-central alpha decreases during auditory and audio-visual and increases during visual stimulation (see Figure 1).

4 Discussion

The responses to visual and auditory affective stimulation (see Figure 1) suggest the activation and deactivation of regions potentially associated with the appropriate and non-appropriate sensory modality, respectively[7]. The marked increases of alpha power over the regions associated with the processing of the non-appropriate sensory modality are in line with the putative role of alpha oscillations in the gating of sensory input[6]. Accordingly, the observed results might be interpreted as general cognitive responses to affective stimuli, rather than primary correlates of affect or feeling.

The current analysis does not allow a conclusion about the emotion-specificity of the observed responses. Especially for aBCI it would be of interest, if such modality-specific responses allow for a discrimination of valence and arousal. Given the opposing nature of visually and auditorily induced affective responses, a classifier trained on a certain modality will be limited in its capability to generalize its classification to affective states induced via other modalities. Assuming a general cognitive nature of the observed affective responses (e.g., the orienting response [5]), a classifier might be prone to confuse purely cognitive responses with affective responses. This poses a general problem for the community of aBCI: How can affective neurophysiological responses be adequately used for affective state discrimination, given their context-specific nature? Strategies like the restriction to specific contexts or the use of additional contextual information (e.g., the occurrence of external stimulation or peripheral physiological affective responses) might help to deal with the ambiguity of neurophysiological responses. However, context-specificity of correlates of affect demands a critical assessment of the generalizability and specificity of the classified EEG activity.

5 Conclusion

We showed that neurophysiological responses to visual and auditory affective stimulation are differing in terms of parietal and fronto-central activations in the alpha band. This has implications for the generalization and specificity of affect classifiers. Furthermore, these results open up exciting research questions for aBCI, such as: Is it possible to detect the modality of the trigger of an affective response, the object or event that induced a given affective state?

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