

Assessment of Aversive Stimuli Dependent Attentional Binding by the N170 VEP Component

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Abstract—For social species nonverbal communication by assessment of emotion expression is crucial for building up and maintaining social structures. In humans, body language not only includes gestures but also a variety of facial expressions. Negative associated facial expressions, e.g. disgust, fear, anger call for a higher attentional binding due their evolutionary background, denoting directly personal dangers for the receptive individual. In a number of psychiatric disorders such as schizophrenia or autism spectrum diseases, the assessment of emotions in faces is disturbed, leading to even more pronounced social cuts. In this article we present a new methodology for monitoring the attentional binding to emotion-tinged stimuli in a face recognition task. We were able to demonstrate a significant difference in habituation behavior to neutral and negative associated faces respectively. In future, this methodology might provide a fast and reliable scheme for the detection of psychiatric disorders comprising dysfunction of limbic structures.

I. INTRODUCTION

Communication is crucial for the development of social structures, but verbal communication only plays a less significant role compared to nonverbal means of information exchange. Nonverbal communication comprises postures, kinesics, haptics, eye gaze and facial expressions. In this article, our focus is on the assessment of facial expressions of emotion. Two main types of information needed to infer a face: first identification as unique individual and second facial expression analysis. The engagement of a highly specialized system was suggested considering the relative ease and speed with which facial identity and facial expression processing are accomplished. [1]

The detection of facial expressions associated with negative stimuli should be rapid and accurate, due to the immediate need of appropriate responses to possibly dangerous events. Attentional binding to the negatively tainted facial expressions (in absence of a threatening event) should be increased and habituation to a series of presented faces should be slowed. This behavioural relevant reaction has its analogue in a valence-dependency of brain area activation. Face-recognition tasks in general activate the fusiform gyrus as well as emotion-specific areas. According to previous fMRI studies, the presentations of emotional faces (fearful or happy) activate the fusiform gyrus more than neutral faces [2][3]. Posamentier et

al. had similar findings in fMRI and PET studies [1]. These results suggest that the processing of visual stimuli is boosted by emotional faces. This boosting might originate from the amygdala re-entrant projections [4]. Although amygdala response habituates to repeated presentations of human facial expression over time, the resulting attentional binding should last longer as compared to the attention to a presentation of neutral faces.

Adolphs et al. [5] investigated facial expression recognition in a large number of subjects with focal brain damage. The authors hypothesized that cortical systems primarily responsible for recognition of facial expressions would involve discrete regions of higher-order sensory cortices. Recognition of specific emotions would depend on the existence of partially distinct systems. This predicts that different patterns of expression recognition deficits should depend upon the lesion site. In general, none of the subjects showed impairment in processing happy facial expressions, but several subjects displayed difficulty in recognizing negative emotions (especially fear and sadness) [1].

In particular, amygdala lesions in adults result in significant deficits in fearful face recognition, despite the intact ability to identify other facial emotions [6][7]. Also some hypotheses emerged on the involvement of the amygdala in psychiatric disorders like schizophrenia or autism spectrum disorders [8]. In this article, we propose a new electrophysiological approach to the objective detection of psychiatric diseases comprising dysfunctions of brain structures responsible for emotional assessment. Based on a working model of attentional guidance and habituation, we evaluated event-related electroencephalographic-data of 9 subjects for an objective analysis of attentional binding and habituation processes towards negatively-tinged stimuli.

II. METHODS

A. Linking amygdala dysfunction to attention: A habituation model

Areas of higher cognitive processing in emotional face recognition tasks are valence dependent. The comparison of sad/angry vs. neutral facial expression by fMRI reveals valence-dependent activation of the amygdala, the anterior insula cortex and the cingulate cortex [9]. Supporting these results, pathological conditions comprising damage to the amygdala, like Klüver-Bucy-syndrome or Autism spectrum diseases, reveal difficulties in emotional empathy especially in the reaction to negative basic emotions [10][8].

The detection of possibly dangerous events and the fast

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elicitation of appropriate behaviour is crucial for survival. Limited attentional resources thus should be reassigned to threatening stimuli. A number of studies report a modulation of attention by aversive stimuli or difficulties in habituation towards presented stimuli due to their emotional valence in tinnitus aurium [11].

In our study, we use a habituation model based on the hippocampal comparator hypothesis by Vinogradova [12][13]. The hippocampus is acting as a comparing element of incoming sensory information and short lasting memory traces. Activity in the medial septum/diagonal band of Broca (MSDB) represents in this model the incoming sensory event, while activity of the fascia dentata (FD – dentate gyrus) forms the grade of familiarity to the stimulus, i.e., memory traces. The CA3 area is acting as the factual comparator in a regulatory circuit, governing the information flow through the CA1 unit via the mammillothalamic fascicle (MF – bundle of Vic D’Azyr) (informational circuit). Projections of the MF pass through dorsal thalamic nuclei, which on their part form a component of the thalamocortical feedback loops, governing attention, consider [13].

Habituation to the stimulus can only be archived if the burst trains of both, FD and MSDB, synchronize in a narrow time window. In modeling habituation, the FD is acting as weakly driven (by MSDB) oscillator. Please see [13] for a detailed description of the processing–algorithms underlying our model.

The amygdala has a high impact on the firing behavior of the FD [14][15], thus might prevent or inhibit habituation to stimuli carrying negative emotional valence. In the Klüver-Bucy-syndrome, the patients also suffer from hypermetamorphosis, characterized by an “irresistible impulse to notice and react to everything within sight” [16]. This could hint for increased switching of attended sensory streams due to fast and unimpeded habituation.

We claim: Negative–tinged stimuli in a face recognition task slow down habituation compared to neutral faces due to their valence–dependent activation of the amygdala.

Figure 1 depicts a systemic block diagram of the amygdaloid

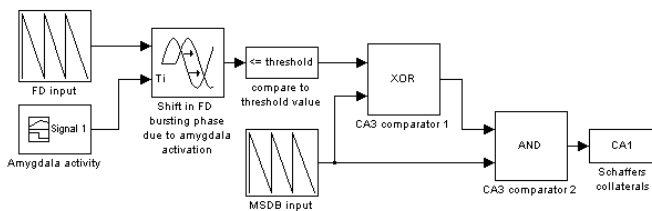


Fig. 1. Systemic model of amygdaloid influence on firing behavior and the resulting changes in CA1 informational flow due to phasic mismatch in the CA3 comparator

influence on the hippocampal comparator function. A co-activation of the amygdala by a concurrent stressor modifies the FD firing behavior, resulting in a bursting pattern different from the MSDB firing pattern. The imprinted threshold on

CA3 neurons is shifted, not longer matching the incoming MSDB signal. This results in an inactivation of tonic active CA3 neurons and in an increased information flow through CA1 and mammillothalamic fascicle.

B. Experimental Setup

Each subject was exposed to two experimental conditions in the following order:

- For the first condition, the subjects were told to relax and look at the screen for 10min. During this procedure, 20 different portrait-pictures of unknown people (taken from Ekman & Friesen [17]) with European appearance (10 males, 10 females), every with neutral face expression and in front-view were shown to the volunteers in a random order. Between each photograph, a fixation cross occurred. The stimulus was presented for 750ms. The interstimulus interval (ISI) was 750ms as well.
- After a short break, the subjects were again instructed to relax and pay attention to the screen above for the second condition: Now, again 20 different portrait-pictures of unknown people with European appearance (once more 10 males, 10 females) as of now with negative emotional face expressions (disgust, fear, & anger) were presented to the volunteers. The procedure was the same like in the first condition, i.e., ISI=750ms, remaining fixation cross between stimuli.

C. Subjects and Materials

A total of 11 healthy volunteers (mean age: 25) with normal eyesight participated in our study. The experiments were conducted in a sound proof chamber where the volunteers were located 60cm horizontal under a 17-inch monitor (EIZO FlexScan S2411W). The event-related potentials (ERPs) were acquired by a commercial available amplifier (g.tec USBamp, Guger Technologies Austria) for 600s at 512Hz. Single trials, i.e. the responses to the individual stimulus were recorded from 5 scalp sites according to the international 10-20 system (P3, PZ, P4, O1 & O2) using Au electrodes. All scalp electrodes were referenced to the vertex. A ground electrode was placed on the upper forehead. Impedances were balanced and maintained below 5kΩ. Artifacts over 50μV were removed by an artefact filter.

D. The Visual N170

The ERP peak named N170 is a member of the N2 family and ranges in latency between 156ms and 189ms. It is associated primarily with visual processing of human faces [18]. The topographic distribution of the N170 component for both familiar and unfamiliar faces is largest over the occipitotemporal regions. The N170 amplitude is significantly larger in response to faces than other natural or human-made objects [18]. In our application, the visual evoked potentials (VEPs) of the presented facial expression stimuli formed clear peaks in the N170 region. Reference VEPs of the presented fixation cross did not show an N170 response in contrast. Hence, we focused on the time window of the N170 as basis for the signal processing.

E. Extraction of Large-Scale Neural Correlates of Habituation

From the wavelet transform [19] of two signals α and β , the wavelet cross spectrum between α and β can be defined as

$$(\mathcal{P}^{\psi,\delta}\alpha,\beta)(a,b) = \int_{b-\delta/2}^{b+\delta/2} (\mathcal{W}_\psi\alpha)(a,\tau)\overline{(\mathcal{W}_\psi\beta)(a,\tau)}d\tau, \quad (1)$$

where $\alpha,\beta \in L^2(\mathbb{R})$, $\delta \in \mathbb{R}_{>0}$ and \mathcal{W}_ψ represents the wavelet operator to the wavelet ψ . Here δ gives the window for the calculation of the wavelet coherence. Finally the wavelet coherence $\Omega_\psi^\delta(\cdot,\cdot)$ of two signals α and β is defined as

$$(\Omega^{\psi,\delta}\alpha,\beta)(a,b) = \frac{|(\mathcal{P}^{\psi,\delta}\alpha,\beta)(a,b)|}{\sqrt{(\mathcal{P}^{\psi,\delta}\alpha,\alpha)(a,b)(\mathcal{P}^{\psi,\delta}\beta,\beta)(a,b)}}. \quad (2)$$

For a fixed wavelet ψ and smoothing parameter δ (see [20] for details) we define $(\Omega\alpha,\beta)(a,b) := (\Omega^{\psi,\delta}\alpha,\beta)(a,b)$ in order to simplify the notation in the following.

Let $\mathcal{X} = \{x_m \in L^2(\mathbb{R}) : m = 1, \dots, M_0\}$ be the sequence of M_0 sweeps. Using (2), we define the sweep-to-sweep time-scale coherence in \mathcal{X} by

$$d_m^\mathcal{X}(a,b) = (\Omega x_{m-1}, x_m)(a,b), \quad m = 2, \dots, M_0. \quad (3)$$

The coherence between sweep-to-sweep sequences is represented by a decreasing graph because of less coherence between two consecutive signals in the case of habituation. In order to visualize this sweep-to-sweep time-scale coherence (SSTC) decline, we make use of an analysis based on a moving average. Specifically, the moving average of the SSTC for a set \mathcal{X} is given by the sequence

$$\mathcal{D}_m^\mathcal{X}(a,b) = \frac{1}{m} \sum_{n=1}^m d_n^\mathcal{X}(a,b), \quad m = 2, \dots, M_0. \quad (4)$$

For our further discussion, we decompose the set \mathcal{X} in two subsets $\mathcal{X}_e = \{x_m : m = 1, \dots, M_e\}$ and $\mathcal{X}_r = \{x_m : m = M_r, \dots, M_0\}$ with $1 < M_e < M_r < M_0$. Here \mathcal{X}_r represents a reference set which corresponds to the number $|\mathcal{X}_r|$ of sweeps obtained during a electrophysiological examination assuming that we deal with steady state conditions in \mathcal{X}_r . Thus all the regular neurophysiological changes related to habituation are reflected in \mathcal{X}_e .

Using (4) and the sets defined before, we compute the direct difference of \mathcal{X}_e and \mathcal{X}_r by

$$\Delta^{\mathcal{X}_e,\mathcal{X}_r}(a,b) = \mathcal{D}_{M_e}^{\mathcal{X}_e}(a,b) - \mathcal{D}_{M_0}^{\mathcal{X}_r}(a,b). \quad (5)$$

Note that due to the definition of a sequence $\mathcal{D}_m^{\mathcal{X}_e/\mathcal{X}_r}(a,b)$ ($m = 2, \dots, M_e/0$) by (4) we have that $\mathcal{D}_{M_e/0}^{\mathcal{X}_e/\mathcal{X}_r}(a,b) = \frac{1}{M_e/0} \sum_{n=1}^{M_e/0} d_n^{\mathcal{X}_e/\mathcal{X}_r}(a,b)$. In order to capture the dynamics of changes reflected in \mathcal{X}_e , we define a modified version of (5) by the sequence

$$\tilde{\Delta}_m^{\mathcal{X}_e,\mathcal{X}_r}(a,b) = \mathcal{D}_m^{\mathcal{X}_e}(a,b) - \mathcal{D}_{M_0}^{\mathcal{X}_r}(a,b), \quad m = 2, \dots, M_e. \quad (6)$$

Note that $\tilde{\Delta}_m^{\mathcal{X}_e,\mathcal{X}_r}(\cdot,\cdot)$ exhibits large fluctuations for a large difference between the sweeps in \mathcal{X}_e and \mathcal{X}_r which we expect in the case of habituation. A more detailed description of this technique can be found in [20].

III. RESULTS AND DISCUSSION

The data from 9 of 11 subjects could be taken into account for the signal processing. The data sets of 2 subjects had to be removed due to artifacts. After applying the time-scale coherence with moving average, we averaged the data of all subjects over each of the five channels to see results in habituation for every condition (emotional & neutral task). Figure 2 exposes the N170 habituation in Channel P3 as an average over 9 subjects after smoothing on the upper left side. The black line marks the habituation (coherence over sweeps) to the negative associated facial expression stimuli, the gray line shows habituation to the presented neutral facial expression stimuli. It can be clearly perceived, that the subjects evinced an increased habituation to the non-emotional photographs than to the negative emotional photographs. The same results can be found for the electrodes PZ, P4 and O2 (Figure 2). Only Channel O1 showed no significant differences in habituation.

According to Narumoto et al. and Sato et al., regularly

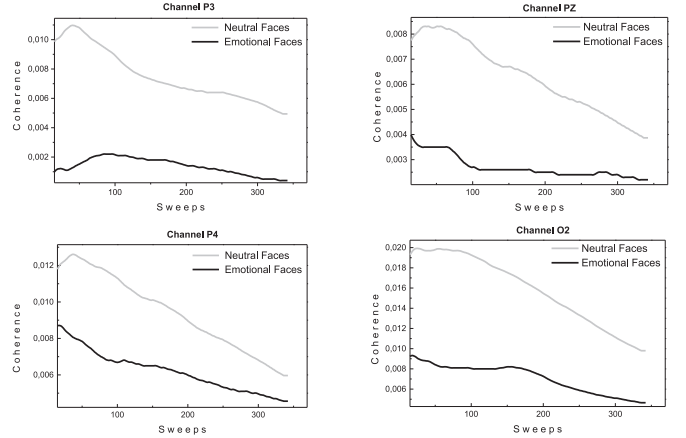


Fig. 2. Results in habituation in the emotional and neutral face recognition task as an average over 9 subjects for channel P3, PZ, P4 and O2 after smoothing.

the channels of the right hemisphere and the midline are leading to reproducible results for analyzing facial emotion precessing via EEG [21][4]. Considering this, the channels PZ, P4 and O2 expose exactly the expected results. This also confirms our results for attentional binding in the auditory system in [20] using the very same coherence measure.

Compendious, Figure 3 illustrates representative the differences in habituation for channel O2 over all considered subjects. The black bars evince the habituation to the presented emotional faces, the grey bars represent the habituation to the neutral faces. The hight of a bar signifies the time-scale coherence over all sweeps, i.e., the higher a bar, the faster habituation occurred and vice versa. So, 8 of

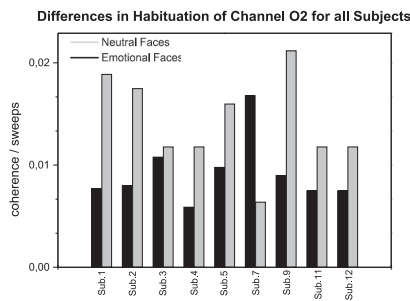


Fig. 3. Differences in habituation in the emotional and neutral face recognition task for channel O2 over all considered subjects. The height of a bar connotes the habituation increase.

9 subjects show an increased habituation to the neutral-faces task and a decreased habituation to the emotional-faces task in channel O2.

IV. CONCLUSION

These findings are supporting our expectations and fit very well to our habituation model.

Accordingly, we could prove in this study, that negative-tinged stimuli in a face recognition task slow down habituation compared to neutral faces due to their valence-dependent activation of the amygdala. This methodology might provide an objective approach to the detection of psychiatric disorders comprising dysfunction of limbic structures in future.

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