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Research report

Affective attitudes to face images associated with intracerebral EEG source location before face viewing

Diego Pizzagalli [a,b,*], Thomas Koenig [b], Marianne Regard [a], Dietrich Lehmann [a,b]

[a] EEG-EP Mapping Laboratory, Department of Neurology, University Hospital, CH-8091 Zurich, Switzerland
[b] The KEY Institute for Brain–Mind Research, University Hospital of Psychiatry, CH-8029 Zurich, Switzerland

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Abstract

We investigated whether different, personality-related affective attitudes are associated with different brain electric field (EEG) sources before any emotional challenge (stimulus exposure). A 27-channel EEG was recorded in 15 subjects during eyes-closed resting. After recording, subjects rated 32 images of human faces for affective appeal. The subjects in the first (i.e., most negative) and fourth (i.e., most positive) quartile of general affective attitude were further analyzed. The EEG data (mean $= 25 \pm 4.8$ s/subject) were subjected to frequency-domain model dipole source analysis (FFT-Dipole-Approximation), resulting in 3-dimensional intracerebral source locations and strengths for the delta–theta, alpha, and beta EEG frequency band, and for the full range (1.5–30 Hz) band. Subjects with negative attitude (compared to those with positive attitude) showed the following source locations: more inferior for all frequency bands, more anterior for the delta–theta band, more posterior and more right for the alpha, beta and 1.5–30 Hz bands. One year later, the subjects were asked to rate the face images again. The rating scores for the same face images were highly correlated for all subjects, and original and retest affective mean attitude was highly correlated across subjects. The present results show that subjects with different affective attitudes to face images had different active, cerebral, neural populations in a task-free condition prior to viewing the images. We conclude that the brain functional state which implements affective attitude towards face images as a personality feature exists without elicitors, as a continuously present, dynamic feature of brain functioning.

Keywords: FFT-Dipole-Approximation; EEG frequency analysis; Source localization; Personality; Laterality; Emotion

1. Introduction

Relationships between brain activity and personality are expected to describe the brain states and thereby, the mechanisms which implement personality features.

Developmental [6], psychological [40] and neuroscience research [7] consider affective reactivity or attitude as an intrinsic feature of personality. Quality, extent and susceptibility of affective responses to emotional elicitors differ between individuals: positive, approach-related and negative, withdrawal-related reactions constitute a primary dimension in emotion [16,58].

Higher brain functions such as personality and emotion are implemented by distributed brain systems [13,15,32,47]. The neuropsychology of emotion has stressed the left–right brain dimension as fundamental for emotional valence [16] with right hemispheric superiority when processing negative connotations of incoming information and left superiority for positive connotations [7,37,39,44,45]. Pathology showed agreeing lateralizations: depression is associated predominantly with left hemispheric lesions, inappropriate cheerfulness with right hemispheric lesions [46].

The non-invasive EEG (electroencephalogram) studies reported brain electric signatures for emotional dimensions of personality during emotional challenge (input) as well as during resting when the subjects had no reasons (no input challenge) for, and displayed no signs (no overt behavior) of specific emotions. During emotional challenge, EEG/personality relations included: less anxiety with frontal midline theta [36]; positive affectivity with general left-sided alpha reduction (interpreted as activation), and negative affectivity with right-sided alpha reduction [20]; and negative reactivity (disgust) with right less than left frontal alpha [8]. EEG recordings during resting also showed relations with personality: more alpha EEG power during open eyes in extraversion than introversion

* Corresponding author. The KEY Institute for Brain–Mind Research, University Hospital of Psychiatry, Lenggstr. 31, CH-8029 Zurich, Switzerland. Fax: +41-1-384-24-47; E-mail: dpizzag@key.unizh.ch

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[12], and often left-sided frontal activation (reduced left-sided alpha) with disposition to positive affect, right-sided activation for negative affect [48,53–55,60].

These studies on EEG, emotion and personality frequently focused on EEG alpha frequency, although some considered other frequency bands [2,42,56]; comprehensive analysis including all bands appears indicated. Further, interpretations concerning brain locations were based on the head surface distribution of the EEG parameters, assuming that maximal values on the scalp are indicative of underlying generators. However, this assumption is not generally valid, and accordingly, interpretations as to source locations are ambiguous [4,5,34].

For a comprehensive, non-ambiguous assessment of the brain mechanisms implementing personality, the present paper studies the spatial organization of brain electric activity of different frequency bands using 3-dimensional source modeling. This analysis is independent from the chosen reference electrode location, and does not require assumptions about an inactive site [34] and about the orientation of the generators [4,5] as assumed in interpretations based on the head surface distribution of the data.

Time series of multichannel brain electric field data can be modeled in the frequency domain by equivalent intracerebral sources via the FFT-Dipole-Approximation ([28]; also [31,57]). The approach was successful in studies of ongoing brain activity during various pathological conditions [9,33,51], drug effects [21,35], sensory studies [23], imagery and abstract mentations [27,52] and emotional states [22]. High correlations between the location of intracerebral EEG frequency domain sources and cerebral glucose metabolism were demonstrated [10]. Thus, source modeling proved to be appropriate to examine the 3-dimensional spatial organization of brain activity.

The present study was motivated by earlier results where event-related potential (ERP) topography was influenced by the individual preferences for the face images and also by the subject's general affective attitude [41]: subjects viewed face images during ERP recordings without task and, after the recordings, rated the images for affective appeal; accordingly, subjects were dichotomized into those with general positive and general negative affective attitude. Positively disposed subjects had a more left and anterior located center of gravity of ERP activity, although there was no request to attend to affective connotations of the faces. Since initial control EEG recordings were available from most subjects, we decided to examine whether brain electric signatures of affective attitude (general liking or disliking the face images) existed prior to viewing of the images; in this case, affective attitude would be a personality feature, a brain functional state without specific elicitors. Using 3-dimensional intracerebral frequency domain source modeling of the spontaneous EEG, we examined whether the interindividual differences in affective attitude towards face stimuli were related to different 3-dimensionally localized brain electric activity in the various frequency bands during initial resting (a no-task, no-input, no-response condition) prior to viewing the face images.

2. Materials and method

2.1. Subjects

Eighteen healthy volunteers participated after their informed written consent. History of psychiatric or neurological disorder or alcohol or drug abuse were exclusion criteria. Because of excessively frequent artifacts, spontaneous EEG data were available from only five female and 10 male subjects (mean age 29.6, range 22–37); all were right-handed [38].

2.2. Procedure

Twenty-seven electrodes were placed at positions [3] Fpz (recording reference), Fp1/2, Fz, F3/4, F7/8, FC1/2, Cz, C3/4, T7/8, CP1/2, Pz, P3/4, P7/8, PO3/4, Oz and O1/O2 and at the outer left canthus for eye movements.

Subjects were comfortably seated in a sound, light and electrically shielded chamber with intercom to the experimenter, and were told that the experiment consisted of EEG recordings during resting with open or closed eyes as requested by the experimenter, then during viewing of checkerboard reversals, and finally during viewing of face images on a computer display. Twenty-seven-channel data were recorded continuously (0.3–70 Hz, 256 samples/s/channel). Resting EEG consisted of (1) 20 s eyes open, (2) 40 s eyes closed, (3) 20 s eyes open, and (4) 40 s eyes closed. The face images were 32 faces from the Szondi-Test [50]. They were used because they generate a broad range of emotions and evoke emotional decisions (both approach- and withdrawal-related judgments [43,44]). Subjects were not informed about the specific aim of the study (relations between EEG and emotional attitudes to the images), and were not told in advance about the eventual rating procedure. The present report concerns the resting EEG that was recorded before the face image ERP recordings (for the latter, see Ref. [41]).

2.3. Image ratings

After recording, subjects rated the 32 face images as to personal affective appeal. Each black and white photograph (digitized and equalized for size, brightness and contrast) was printed on a 15×21 cm sheet. A vertical line (10 cm) on the right margin served as rating scale where subjects indicated with a tick mark how much they liked/disliked the face. In order to maintain attention, the (German) labeling of the end points: 'sympathisch' ('liked face') and 'unsympathisch' ('disliked face') was randomly inverted within each subject. The subject's affective attitude was assessed as mean rating score of all images. Mean affective score across subjects was 4.79 (S.D.: 0.6; range: 3.68–5.83).

2.4. Extreme subjects

The subjects in the first ($N = 4$) and forth quartile ($N = 4$) of the affective attitude scores were used for final analysis, following an approach common in EEG-personality studies (e.g., Refs. [20,53,55]). Subjects with most negative affective scores (mean 4.04 ± 0.29; 2 men, 2 women), i.e., general negative affective attitude, and subjects with most positive affective scores (mean 5.49 ± 0.29; 3 men, 1 woman), i.e., general positive affective attitude, did not differ in age (34.1 ± 3.3 vs. 29.2 ± 5.5), laterality index [38] (87.1 ± 16.1 vs. 82.6 ± 13.6), and educational level (17.5 ± 1.1 years vs. 17.4 ± 0.8).

2.5. Temporal stability of affective attitudes

The 15 subjects were asked by mail more than 1 year after the recording session to rate the same face images again; 13 replied.

2.6. EEG analysis

After careful off-line review for artifacts (EOG, movements, muscle), all artifact-free 2-s epochs of the first 30 s of the two eyes-closed conditions were analyzed. A total of 100 artifact-free epochs (25.0 ± 4.8 s/subject) were available, about equal for the two groups (27.0 ± 4.2 vs. 23.0 ± 5.0 s).

The EEG epochs were subjected to FFT-Dipole-Approximation analysis [28] which, (step 1) assuming a single, common phase angle for all generator processes, models multichannel brain electric field data in the frequency domain by a potential distribution map which is used for 3-dimensional source modeling. Single phase angle models explain on the average more than 93% of the variance of the original data [34]. For each epoch and FFT frequency point, the FFT-Dipole-Approximation (using a Hamming window) was stored as a map. For each subject, the mean map over epochs was computed by permutating the polarities of the member maps to obtain minimal variance [28]. For each mean map, (step 2) assuming a single source, the 3-dimensional equivalent dipole source was computed using a 3-shell model (program: R.D. Pascual-Marqui). The model source's location coordinates on the anterior–posterior, left–right, and inferior–superior axes and its strength (Global Field Power [29] in microvolts, i.e., square root of power) were determined. Location coordinates were expressed as mm distance from origin of the spherical head model (radius: 78 mm; origin = 10% above zero of the 10/20 system [3]). The coordinates of the source locations and their strengths were averaged for each subject within the three major frequency bands: delta–theta (1.5–8 Hz), alpha (8.5–12 Hz) and beta (12.5–30 Hz), and within the full band (1.5–30 Hz). To examine possible intra-band differences, the values were also averaged for each subject within the seven independent frequency sub-bands [25]: delta (1.5–6 Hz), theta (6.5–8 Hz), alpha1 (8.5–10 Hz), alpha2 (10.5–12 Hz), beta1 (12.5–18 Hz), beta2 (18.5–21 Hz) and beta3 (21.5–30 Hz).

For both subject groups, mean source locations for each frequency band were computed across subjects. We quantified how much a single subject's source location contributed to the difference between the groups' mean locations, and used these values for global statistics: The 3-dimensional difference vector between the mean locations of the two groups was computed. The single subjects' sources were projected onto this difference vector. The positions of these individual projections onto the difference vector were used for final analysis.

2.7. Statistics

Unpaired t-tests were used; two-tailed P-values are reported.

3. Results

The global tests using the 3-dimensional difference vectors (Table 1) showed that the EEG model source locations differed significantly between subject groups in the 3 major frequency bands (delta–theta: $P = 0.002$; alpha: $P = 0.025$; beta: $P = 0.023$).

Fig. 1 shows that the source locations of subjects with general negative as compared with positive affective attitudes were more inferior in all three major frequency bands, more right-located in the alpha and beta band, and more anterior in the delta–theta band but more posterior in the alpha and beta band. However, the strongest contribution to the differences (Table 1) were along the anterior–posterior axis for the delta–theta as well as for the alpha band, but on the left–right axis for the beta band.

For the full band (1.5–30 Hz), the EEG model source locations also differed significantly ($P = 0.025$) between groups (Table 1): subjects with general negative affective attitudes had more posterior, more right-located and more inferior full-band model source than those with positive attitudes. The strongest difference was along the left–right axis.

The global location analyses for the seven independent frequency bands showed significances between groups in the delta ($P = 0.015$), alpha1 ($P = 0.096$), alpha2 ($P = 0.009$) and beta3 ($P = 0.032$) sub-bands, but did not reveal substantially new aspects: the separate delta and theta bands showed similar results (negative affective attitudes: more anterior sources); likewise, the separate alpha1 and

Table 1
Mean locations across subjects (and S.D.) of the EEG model sources for the subjects with general negative and general positive affective attitude in the four main frequency bands (in millimeters from origin of coordinate system near head center, see Section 2)

		General affective attitude		Difference	Vector combining A–P, L–R and S–I
		Negative	Positive		
Delta–Theta (1.5–8 Hz)	A–P	21.03 (4.66)	5.62 (9.06)	15.41	
	L–R	−1.45 (9.01)	−1.57 (8.15)	0.12	17.68***
	S–I	−11.13 (7.33)	−2.46 (7.52)	−8.66	
Alpha (8.5–12 Hz)	A–P	−27.38 (7.97)	−10.50 (4.52)	−16.88	
	L–R	−13.03 (14.40)	−4.85 (9.31)	−8.18	20.96**
	S–I	−2.04 (14.44)	7.31 (8.17)	−9.35	
Beta (12.5–30 Hz)	A–P	−13.57 (19.09)	−0.97 (9.66)	−12.60	
	L–R	−9.04 (8.88)	9.76 (15.28)	−18.80	24.80**
	S–I	−12.54 (13.65)	−2.40 (10.99)	−10.14	
Full Range (1.5–30 Hz)	A–P	−7.12 (12.96)	−0.69 (5.66)	−6.43	
	L–R	−7.76 (8.31)	5.01 (9.36)	−12.77	17.26**
	S–I	−10.75 (10.98)	−1.08 (9.49)	−9.67	

A–P: anterior–posterior, L–R: left–right, S–I: superior–inferior axes; positive values towards anterior, left and superior from origin. Vector length (mm) measures the 3-dimensional differences between the model sources of the two subject groups. *** $P < 0.01$, ** $P < 0.05$.

alpha2 bands (negative attitude: more posterior and right located sources) and the separate beta1, beta2 and beta3 bands (negative attitude: more posterior and right located sources). The model source was more inferior for subjects with general negative than positive affective attitudes in all seven sub-bands.

The strengths of the equivalent dipole sources showed a trend in the beta band to lower band power for general negative vs. positive affective attitude (2.0 ± 0.5 vs. 3.3 ± 1.0 microvolt; $P = 0.06$), but no significant differences in the delta–theta (5.3 ± 1.0 vs. 5.1 ± 1.7), alpha (11.0 ± 5.4 vs. 11.0 ± 4.9) and full (1.5–30 Hz) band (4.1 ± 1.2 vs. 4.8 ± 1.1). These results were confirmed by the sub-band analyses where only beta1 (2.3 ± 0.9 vs. 3.8 ± 0.6; $P = 0.034$) and beta2 (2.6 ± 0.5 vs. 3.7 ± 0.3; $P = 0.012$) showed significant differences.

3.1. Temporal stability of affective attitudes

The 13 repeat scores 1 year after the original rating showed a highly significant correlation with the original scores (Spearman $\rho = 0.73$, $P < 0.02$). In the selected 8 extreme subjects, the repeat rating produced no change of subject assignments to the extreme groups (mean affective attitudes: 3.78 ± 0.6 vs. 5.26 ± 0.5, $P = 0.01$). Within these eight subjects, the scores of the same 32 images were correlated (range of Spearman ρ: 0.46–0.79; all eight

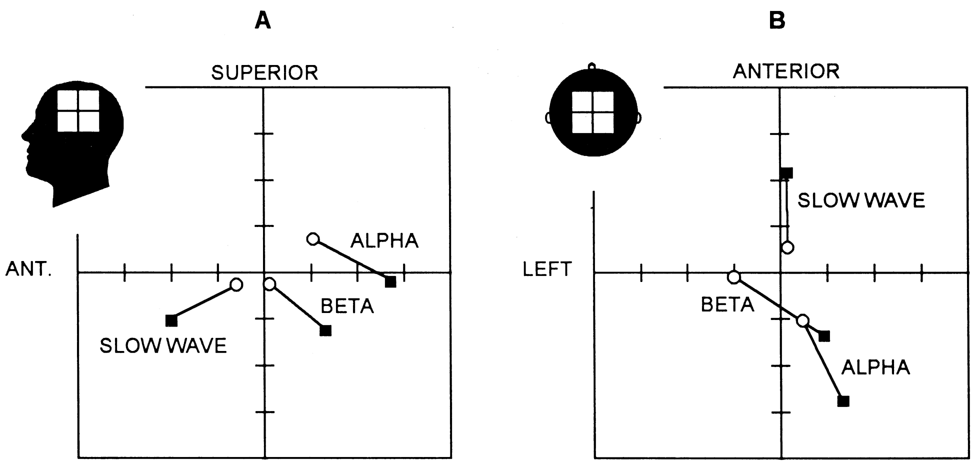

Fig. 1. Mean locations of the model sources for the subjects with general positive (open circles) and subjects with general negative (black squares) affective attitudes to face images, and for the three frequency bands, slow wave (delta–theta), alpha and beta. (A) Head seen from the left, showing the anterior (ANT.)–posterior and superior–inferior axes; (B) head seen from above, showing the left–right and anterior–posterior axes. Origin of coordinate system is near head center, see Section 2; tickmarks at 10 mm distances. $N = 4$ for both groups.

P-values < 0.01). The two groups did not differ in days between repeat rating and first rating (425.3 ± 88.5 vs. 422.8 ± 55.5).

4. Discussion

Affective reactivity or attitude was proposed as intrinsic feature of personality [6,7,40]. During resting, before viewing the face images, the intracerebral model sources of brain electric activity of the major EEG frequency bands were at significantly different locations depending on the (subsequently determined) subjects' general, positive or negative affective attitude towards face images; i.e., before emotional challenge, the subject groups with different affective attitudes evidently were in different brain functional states. These functional states apparently do not need to be re-installed when the need arises to handle an emotion-evoking information. Since the EEG was recorded during a no-task, no-input, no-response condition, possible confoundations were avoided such as caused by specific stimuli, execution of overt or covert tasks, motor responses, expectancy, or cognitive bias.

Our analysis modeled the EEG activity with a single dipole source for each frequency band. Locations of the model sources describe the 3-dimensional center of gravity of all neural elements that were active in the brain during the recording. If centers of gravity differ, the active neuronal populations must have different geometries, i.e., different locations and/or orientations [27,34]. Source modeling is a reference-independent analysis and produces non-ambiguous results without unvalidated assumptions (see Introduction). The center of gravity-approach for assessment of brain activity appears to be very appropriate since widely distributed brain systems are involved in emotions, as shown in cerebral blood flow studies [13,15,47].

Our observed main differences in EEG source location were: more right-located beta and full range (1.5–30 Hz) band sources, and more anterior delta–theta sources but more posterior alpha sources for subjects with general negative than with positive affective attitude.

The left–right differences relate to many papers on hemispheric functional differences. Right-handed individuals differing in lateralized, posterior hemispheric activation (inferred from paper-pencil tests) showed behavioral differences in the direction expected from the specialization of the posterior brain quadrants: subjects with right hemisphere arousal performed poorly on verbal tasks, subjects with left hemisphere arousal performed well [30]. Also, parietal and temporal resting EEG asymmetry was associated with verbal task performance [14]. Cerebral asymmetry in emotion and making emotional preference judgments was reported, the left hemisphere being relatively more involved in processing of emotionally positive stimuli, the right hemisphere in processing of negative stimuli [7,16,39]. Particularly, normals preferred faces presented to the right visual field/left hemisphere and disfavored faces presented to the left visual field/right hemisphere [37,44,45]. These observations are paralleled by behavioral indices of a more activated left hemisphere associated with more positive affect [59] and personal optimism/self-serving attributions [11]. However, we did not directly test the correlation between mood and affective attitude towards face images. Our data support the view that lateral preponderance of brain activity (relative asymmetry) is related to affective components of personality in terms of approach and withdrawal, as discussed in [7,16,39].

The brain's anterior–posterior axis in our results was also involved in personality, with delta–theta more anterior and alpha more posterior for negative compared to positive affective attitude. Such spatial patterns might be accounted for by more localized (anterior inhibitory, posterior resting) activity in negative, and more generalized activity in positive attitude ([23] showed comparable results during visual information processing). Anterior lobe-associated cognitive functions were decreased in unpleasant affect [18], but compared to frequent left–right differences, anterior–posterior differences appeared in fewer reports on valence. Relevant lesion studies [46] associated stronger depression with left-sided more anterior lesions and right-sided more posterior lesions.

Our results are in line with earlier reports on relations between emotion and/or personality and brain electric activity during emotional challenge or resting, although the earlier analysis methods often do not allow unambiguous localization (Refs. [4,5] and Section 1). During emotional challenge, positive (negative) affectivity was associated with a left (right) hemispheric alpha reduction ('activation'), respectively [20], while emotionally negative (disgusting) films elicited relative right frontal alpha reduction [8]. Frontal midline theta was linked to lower state and trait anxiety [36]. In resting EEG, relative right anterior activation (alpha reduction) was related to enhanced disposition for withdrawal [54,55,60]; repressive coping style showed relative left frontal activation [53]; degree of hemispheric arousal was considered as a trait-like marker of individual differences in the threshold of positive or negative affect. Our results also identify the left–right brain axis as fundamental dimension in emotions and personality, but also stress that (1) other EEG frequency bands (slow wave and beta) are associated with affective dimensions, and (2) personality features are likely implemented by distributed brain systems, since the single-model source location differences between subject groups were not restricted to anterior regions.

We found largest group differences in the delta, alpha2 and beta3 EEG sub-bands. The importance of slow and fast activity was reported in other EEG/emotion studies [2,42,56]. More right-located EEG model sources for beta2 were elicited by negative emotions in two other studies by our group, during verbal suggestions in hypnosis [22] and while reading and playing music with different affective valence (Koenig et al., unpublished). Other groups stressed the importance of alpha2 in emotion processing [1,19].

Our subjects with general positive affective attitude had more beta power than those with negative attitude, with significant differences in the beta1 and beta2 sub-bands. Increased power for positive than negative emotions was observed for left hemisphere total power [2] and for temporal beta power [49]. Also, more beta power in extraverts than introverts [12] and increased beta power during anxiolytic and antidepressive medication [17] was reported.

Whether our present brain electric characteristics of affective attitude are trait or state signatures is difficult to decide, since stability of the EEG parameters themselves was not tested. However, individual affective attitude—which was strongly related to EEG model source location—showed high stability when tested more than 1 year later. Affective attitude towards emotional materials thus is a strong candidate for an intrinsic, stable personality feature. Of interest here are our earlier ERP results [41] where different affective attitude (determined after the ERPs) influenced systematically the location of the electric gravity center. The present EEG results of the 1.5–30 Hz band enable a direct comparison with the earlier ERP results which used the same band. The location differences between subjects with general negative and positive affective attitude were similar in both analyses (general negative affective attitude had more posterior and right-located brain activity than positive attitude), although differrent analysis approaches were employed (dipole modeling vs. center computations). We therefore suggest that the differences in brain electric activity indicated individual differences in personality. The observations that the right hemisphere is relatively more involved in processing of information with negative affective tone [37,39,44,45] and that the state of the brain determines the fate of the incoming information [24,26] would explain why subjects with general negative affective attitude rated the face images more negatively.

Finally, we point to the limitation of our data: the small number of subjects with extremely high or low affective attitude suggests caution for generalizing. More work using unambiguous and unbiased EEG assessment in larger cohorts is needed. But, our results were similar to previous data on the general geometry of the EEG sources (deep and most anterior for slow waves, alpha most posterior and superior, beta more anterior and inferior than alpha) in larger cohorts [27,34,35].

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