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Subjective mood estimation co-varies with spectral power EEG characteristics

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Co-variation between subjectively estimated mood/activation and EEG characteristics, based on spectral power parameters, was investigated. Subjective estimation of mood was made by using Thayer's Activation-Deactivation Adjective Checklist, which yielded two dimensions: Energy-Tiredness (with Energy pole having positive valence connotation) and Tension-Calmness (negative connotation for Tension). A within-subject design with two sessions of EEG recording immediately followed by mood assessment was applied. These were separated by a cognitive task, introduced in order to modify the subjects' mood. The correlations between changes in mood estimation and changes in EEG spectral power parameters were calculated. Both ADACL dimensions co-varied with EEG in a specific way according to frequency and localization. Subjective estimation of Energy correlated negatively with alpha1 and, surprisingly, positively with delta, theta1 as well as theta2 relative power. Estimation of Tension correlated positively with theta1 and beta1, and negatively with alpha2 relative power. Presented results suggest that the adjective description of mood has objectively-measurable brain correlates in the EEG.

Key words: EEG power spectrum, delta, theta, alpha, beta, mood, activation, emotions, subjectivity, first-person data

INTRODUCTION

Mood can be defined as a transient affective state of low or moderate arousal (Reber 1985). The affective aspect of mood is available only indirectly, by a verbal self-report or by behavioral expression, while arousal and activation level can be measured by using physiological variables (Vaez Mousavi et al. 2007). The challenge for understanding phenomena such as feelings or mood requires an integration of the first person experiential methods with those of psychophysiology (Lorig and Schwartz 1989, Varela 1996, Lane et al. 1998, Lutz et al. 2002, Price et al. 2002, Coghill et al. 2003, Cacioppo 2004, Kaiser and Wyczesany 2005, 2006).

Here, we focus on a special kind of verbal self-description called "controlled self-report". It is based

on a limited list of adjectives describing various aspects of the subjective state. In this case, a possible range of answers is restricted to words or descriptors intended and chosen by the author(s) of the method. Subjects are required to indicate on a scale to what extent their current mood is described by each of the adjectives. We assume that factorial procedures of selecting the adjectives for constructing the assessment tools ensure that their denotative and connotative meanings remain relatively unambiguous. These kinds of methods are used with a sufficiently good reliability in studies of activation and mood (Thayer 1970). Another advantage of these tools is that they yield quantitative results, which can be used for statistical inferences.

Relations between brain activity and behavioral variables have been investigated extensively, however studies employing subjective reports as psychological variables are rarely found. Among them, the relations between brain activity and subjectively estimated level

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of arousal in terms of vigor, sleepiness, vigilance or activation mostly draw the researchers' attention.

In the study of Åkerstedt and Gillberg (1990) considering relations between subjective sleepiness and EEG, subjects were kept awake during the night in the laboratory. Every two hours EEG sessions were recorded and then followed by administering of two sleepiness scales: VAS (Visual Analog Scale) rating from "very sleepy" to "very alert" and KSS (Karolinska Sleepiness Scale). High sleepiness condition was related to increase in theta and alpha power. Horne and Baulk (2004) arranged two sessions on a driving simulator and tested the subjects in the afternoon, after shortened sleep the night before. Periodically, subjects estimated their state using KSS. There was only one EEG channel (C3–A1), which was continuously recorded. The subjective scores for each 200 s epoch were compared with averaged spectral power in these epochs. They found very high correlation between KSS scores and power of 4–11 Hz band (theta + alpha).

In another study (Leprout et al. 2003), authors checked long-time stability of the relation between subjective alertness, assessed by Visual Scale for Global Vigour (Monk 1989), and objective alertness measured by means of computerized vigilance task and psychophysiological data. These parameters were measured during 27 h period of wakefulness, every two hours, during the sessions with eyes open and closed. Data analysis revealed a positive correlation between decrease in Global Vigour scale and faster alpha power, and this result was stable over a 6-week time. An increased level of alpha together with reports of sleepiness was observed. In the study of Strijkstra and coworkers (2003), EEG spectral power and subjective level of sleepiness assessed by KSS were considered. Subjects were deprived of sleep during a 40 h period. Every two hours they estimated their state between "very alert", "very sleepy" and "fighting sleep", which was followed by 3-min EEG recording. On the first day theta power was negatively correlated with sleepiness (positively with the awake, active state) and this pattern became reversed during the first night of sleep deprivation. Alpha power was correlated negatively at all scalp locations with sleepiness during the whole recording.

A different approach to subjective data was applied in a number of studies which explored EEG spectral correlates of different types of mental activity, as characterized by subjects. Lehmann and colleagues (1995) considered freely described ongoing mental activity

together with the state of activity and bodily experience. These non-structured subjective reports were scored by blind raters on 20 scales describing cognition styles. The 16-seconds periods preceding the estimation were taken as associated EEG records. By means of canonical correlations analysis, the EEG profiles related to specific type of mental activity were established. Cognitions described as "apparently the awake type" were associated with an increase of beta and gamma band power.

There are few studies which focused on the subjective estimation of emotional states and their postulated associations with EEG patterns. A state of anxiety and negative affect assessed by State-Trait Anxiety Inventory (STAI) and Beck Depression Inventory (BDI) were not found to predict frontal asymmetry in the study of Tomarken and Davidson (1994). The relationships between UWIST Mood Adjective Checklist dimensions (Tense Arousal, Energetic Arousal and Hedonic Tone) and EEG activity source were analyzed using the LORETA method (Isotani et al. 2002). The activity source was moved to the right during negative emotions, compared to the positive conditions. In another study, beta2 (18.5–21 Hz) activity source was found to move right during anxiety conditions, compared to relax (Isotani et al. 2001).

Another approach to the problem of integration between EEG patterns and first-person data was presented in a pharmacological studies, where the mood was modified by drug administration. In the study of Ansseau and coworkers (1984), self-reports were made by means of the Hamilton Anxiety Scale. A significant relationship between reported anxiety and beta2 power over midline electrodes (Fz, Cz, Pz) was described. The results of these studies show that, to some extent, the first-person data are related to internal states and co-vary with EEG parameters.

The aim of the present study was to investigate putative associations between the first-person verbal data related to the quality as well as to the intensity of mood, and the spectral parameters of the EEG. By integrating these two measures, we expect to reveal relationships between cortical activity and subjective estimation of mood. We assume that subjective feelings can be considered as emergent properties of molar processes in the brain (Sperry 1969). Thus, changes of the EEG characteristics should co-vary with subjective experience, measured with the first-person data collection methods. Observation of stable correlations would

allow us to revise arguments denying the empirical status of the subjective experience and validate verbal self-report as a proper tool in mood and emotion research. In other words, the physical brain state in terms of EEG parameters would be to some extent predictable on the basis of validated first-person methods and *vice-versa*. In the following study, we used the spectral power of the EEG as a parameter describing brain activity.

As can be seen, the results described in literature are only fragmented and do not fully address our questions. As a consequence, it is hard to formulate precise experimental hypothesis. Some important suggestions concerning the method can be found in the literature cited above, concerning manipulation of mood (Anseau et al. 1984, Lehmann et al. 1995, Horne and Baulk 2004). Within possible factors affecting mood, cognitive task seems to be an effective one. Certain frequency bands of the EEG are associated with emotional processes, and we can, therefore, expect specific differentiation of spectral power in relation to the reported qualities of mood. According to the presented results, together with EEG band power analysis of Kubicki and others (1979), the lower frequency EEG rhythms (up to alpha) are more sensitive to changes in vigilance than the higher frequency rhythms (beta, gamma). We also expect to observe an association of emotional arousal mainly with alpha and beta band power. Alpha rhythm is positively correlated with awake relaxed state, which has emotionally positive valence and is contrary to tense arousal. Beta rhythm is observed in conditions of mental effort and also during emotional arousal, which in some conditions can have negative valence (Niedermayer and Lopes da Silva 1999).

In the present study we examine associations between subjective estimation of mood, assessed by Thayer's Activation-Deactivation Adjective Checklist (ADACL), and patterns of brain activity in terms of EEG spectral power. We decided to use a cognitive task to vary mood, and thus preceded and followed the task by separate measures of both mood and EEG. The main advantage of this approach is elimination of between-subject variance in EEG power. This computational procedure is only possible when both measurements for the same subject are taken in different conditions. Therefore, introducing a cognitive task between the measurements, together with the time as an additional factor, provides facilitation of the changes in mood state between pre- and post-task conditions.

During the analysis, we focus on correspondence between within-subject changes of subjective state and the changes in EEG spectral parameters, not on the raw mood and EEG data.

Data related to activation/mood and EEG frequencies let us formulate experimental hypotheses. In this paper we examine whether: (1) changes in adjective mood estimation are accompanied by changes in cortical activity measured with spectral power methods; (2) the Energy-Tiredness dimension is associated mainly with low-frequency rhythms; theta and alpha power are supposed to be negatively correlated with estimation of Energy. (3) The Tension-Calmness, as a dimension related to emotional arousal, will show negative correlation with alpha and positive with faster rhythms (beta and gamma).

METHOD

Subjects

Thirty seven subjects (21 women and 16 men), aged 19–32 (mean 22.1 years) participated in this study. None of them were diagnosed with any neurological diseases. They were all volunteers, found through advertisements. All of them gave written informed consent to participate in the study and received a sum of 20 PLN (approximately 6 EUR).

Apparatus

EEG data were recorded with a 32-channel Biosemi ActiveOne device, equipped with active electrodes and 16-bit A/D converters. An EEG cap with extended 10–20 electrode system was used. Two additional electrodes were used for reference on both mastoids and four over the eye muscles for EOG recordings, which were later used for ocular artifact correction. All electrode impedances were kept in a recommended range below 5 k Ω .

For collecting subjective data, the Polish adaptation of Activation-Deactivation Adjective Checklist ADACL Short Version (Thayer 1970, Grzegołowska-Klarkowska 1982) was used. The scale consists of 20 adjectives, describing mainly activation and also emotional qualities of mood. The adjectives are scored by subjects according to what extent they fit as a description of their current mood, estimated *via* a 4-point Likert-style scale.

Procedure

The experiment took place in a sound-proof air-conditioned cabin, with dimmed light. The subjects were seated in front of a 17" CRT computer monitor with refresh rate set to 85 Hz. They were informed that the aim of the study was to record brain activity during various tasks, which would be displayed on the screen. They were advised to keep the eyes open, and to avoid body movements during the procedure. The initial period of 5 minutes was intended for adaptation to experimental conditions. During this time participants had no particular tasks and were waiting for further instructions which were to be displayed on the screen. During the sixth minute the background EEG was recorded. This recording was immediately followed by a computer version of the ADACL. This pair of measurements (EEG and subjective) was indicated as "pre-task". Then, the subjects were engaged in the task based on the Sternberg Memory Task (Sternberg 1966), in which sequences of numbers were presented, and the subjects were required to answer if a certain number, always shown at the end of the series, had been presented in a preceding sequence. The original task was modified in order to make it more difficult; the presentation time of the numbers was decreased from 500 to 100 ms and the series length was increased from 6 to 15 elements. Next, a 2-minute idle period followed, during which another EEG measurement was taken during the second minute, and then the Thayer checklist was again presented, referenced later as "post-task". The detailed time schema of the procedure is presented in Fig. 1.

Although the recordings of the EEG were done just before the ADACL measurements, we treated this

sequential measurement of the EEG and the checklist measurement as quasi-simultaneous. The time shift of the measurements is necessary to avoid EEG artifacts caused by motor activity. Since mood changes in time are relatively slow, this procedure appears reasonable. Similar procedures have been also applied by other researchers (Thayer 1989, Tomarken and Davidson 1994, Lehmann et al. 1995, Gamma et al. 2000, Papousek and Schuller 2002, Fairclough and Venables 2006). It is important to mention, that the ADACL checklist, unlike many psychological trait questionnaires, was designed to measure the state of the subject. The effect of learning provoked by multiple use within the same person is minimized. Hence it is assumed that different results reflect changes in the measured state (Thayer 1970).

Both EEG segments of 1-minute length were filtered with a digital band pass filter of 1–60 Hz and 24 dB/oct slope with an additional notch filter (50 Hz). Ocular artifact correction, according to Gratton-Coles-Donchin method, was applied using a signal from the ocular electrodes (Gratton et al. 1983). For spectral power calculation, EEG recordings were divided into overlapped 2-second epochs, which were visually screened and rejected in case of any artifacts. Fast Fourier Transform with 1 Hz resolution and 10% Hanning window was computed for each epoch. Both pre- and post-task power density ($\mu\text{V}^2/\text{Hz}$) was calculated by averaging spectral power for all 2-second artifact-free epochs contributing to this band. The obtained power spectra density values were aggregated into following bands: delta (1–3 Hz), theta1 (4–5 Hz), theta2 (6–7 Hz), alpha1 (8–10 Hz), alpha2 (10–12 Hz), beta1 (13–15 Hz), beta2 (16–24 Hz), beta3 (25–30 Hz), gamma1 (31–48 Hz), gamma2 (52–60 Hz). The resulting values

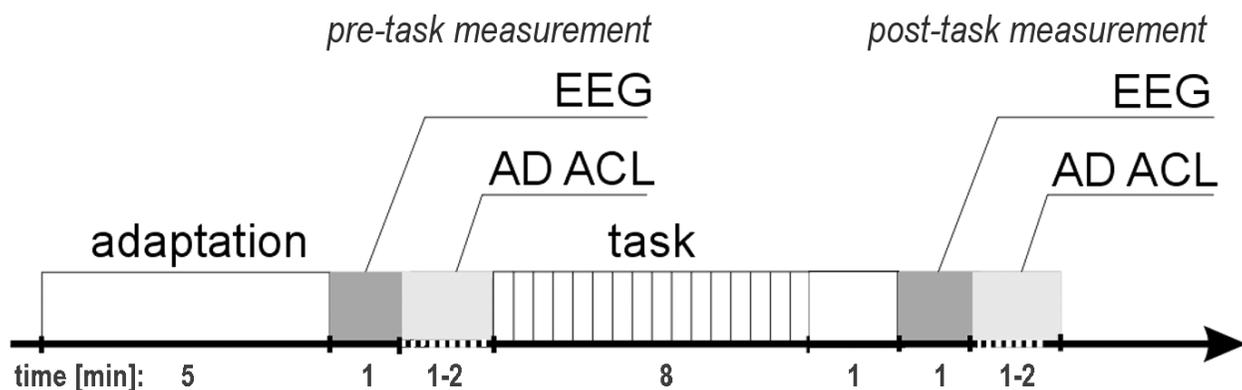


Fig. 1. Experimental procedure

were then normalized across subjects for all channels in a range 1–60 Hz to obtain relative power values. Finally, comparisons between the pre-task and post-task level of spectral power values were made.

According to ADAFL instructions, the scores for two main scales were calculated: Energy-Tiredness and Tension-Calmness (Thayer 1970, 1989). Comparisons between the pre- and post-task levels were carried out.

The differential data (post-task minus pre-task) for both subjective and EEG data were calculated for each subject. Correlations (Pearson’s *r*) between both subjective factors and each of the EEG frequency bands were analyzed for all the electrode positions. Although a large amount of statistical tests increase the possibility of type-I errors spuriously indicating significant correlations, no additional correction of *P*-level was applied since this might have caused a substantial loss of statistical test power (Papousek and Schulter 2002). To avoid such accidental effects we did not focus on single recording relationships, but rather on consistent patterns over the cortex. The localizations were considered only when they consisted of adjacent recordings with similar significant relationships according to the frequency and direction of the correlation.

RESULTS

EEG data: Comparison between pre- and post-task results

Relative EEG power in the pre- and post-task conditions differed significantly, as an effect of the procedure and the time. A significant increase in delta power was found after the task at midline frontal, central and left parietal electrodes. An increase in both theta ranges in the post-task condition was apparent at midline fron-

tal, central and parietal, as well as right temporal sites. Relative alpha bands power after the task was lower over the entire scalp. EEG power in the beta band increased significantly at the right temporal and parietal electrodes. High frequency gamma activity increased in the post task condition and this effect was observed at lateral frontal, midline central, both temporal and parietal sites.

Subjective mood data: Comparison between pre- and post-task results

The effect of the task on the subjective measures was checked using a *t*-test for dependent samples. There were no differences in either Energy-Tiredness or Tension-Calmness scores found for the group as a whole. However, detailed analysis of difference scores between pre- and post-task conditions revealed that, in fact, the task affected subjective estimations considered within subjects, although average changes across all subjects were close to zero. The task thus proved to affect the subjective state. Descriptive statistics of the differential subjective data are presented in Table I.

Integration of EEG and subjective mood data

Energy-Tiredness

An increase in Energy-Tiredness scores (more energetic and less drowsy state) was associated with an increase of relative delta power at midline fronto-central, central, centro-parietal, as well as right parietal sites (Fz, FC1, FC2, Cz, CP1, CP2, Pz, P4, PO4, P8, O2). The direction of correlations was the same for the theta bands, and the relationships were visible on midline frontal, central and parietal recordings (Fz, F3, FC1, FC2, Cz, C3, CP1, CP2, Pz). The alpha band (8–10 Hz) correlated negatively with Energy estimation at midline and some left frontal, central and parietal, as well as left temporal recordings (Fz, FC1, Cz, C3, Cp1, Pz, P3, T7). No significant relationships were found for alpha2, beta or gamma frequency bands (see Fig 3a).

Tension-Calmness

A correlation of EEG relative power and Tension-Calmness subjective estimation was found for the following bands: delta, theta1, alpha2 and beta1.

Table I

Changes in subjective estimation score between post- and pre-task for both subjective factors				
subjective estimation change (post- minus pre-task)	mean	min.	max.	SD
Energy-Tiredness	0.46	-7	11	3.04
Tension-Calmness	-0.05	-5	8	3.49

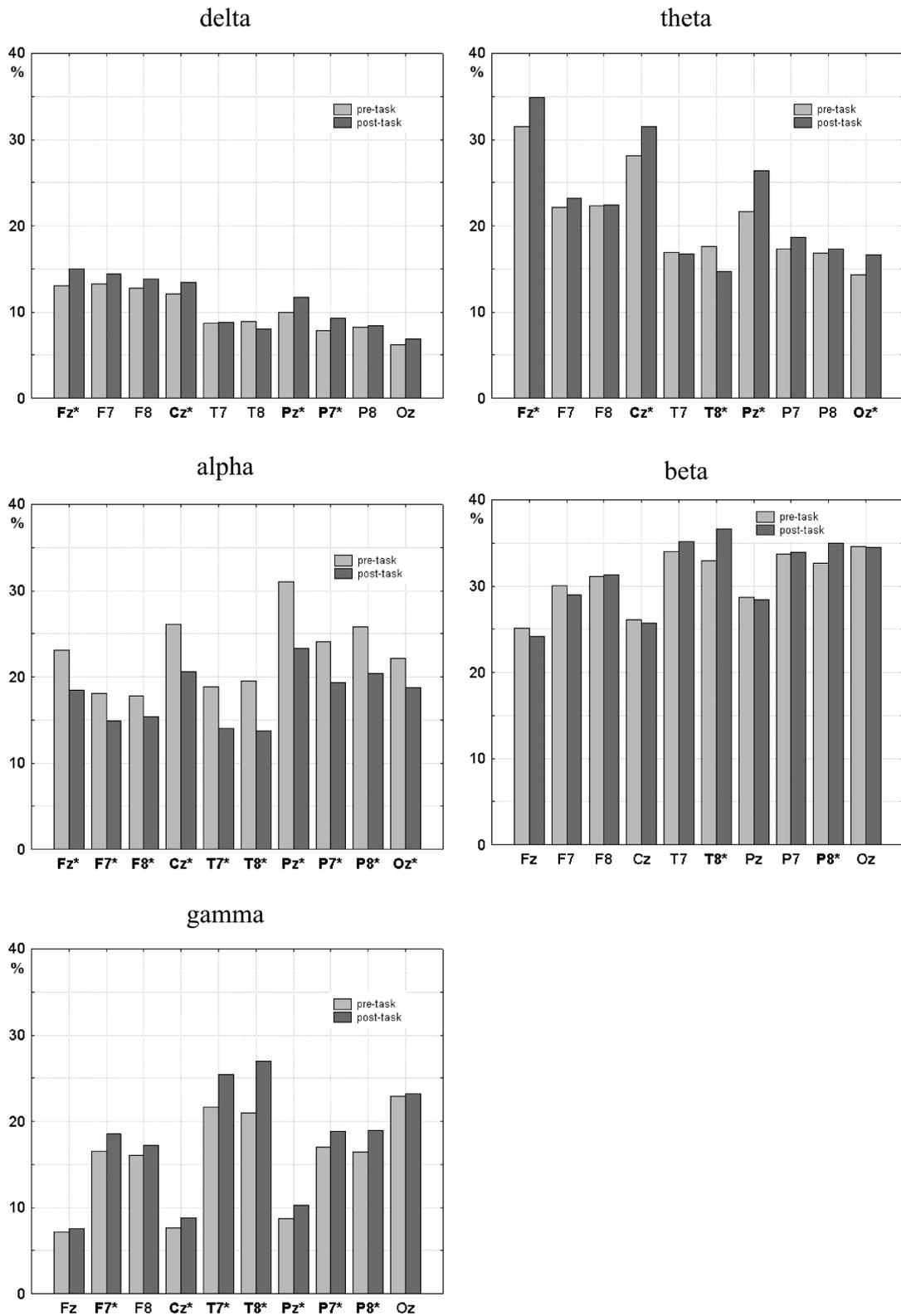


Fig. 2. Comparison of the EEG relative power (%) for aggregated bands in pre- and post-task conditions. Significant differences: * $P < 0.05$; ** $P < 0.01$.

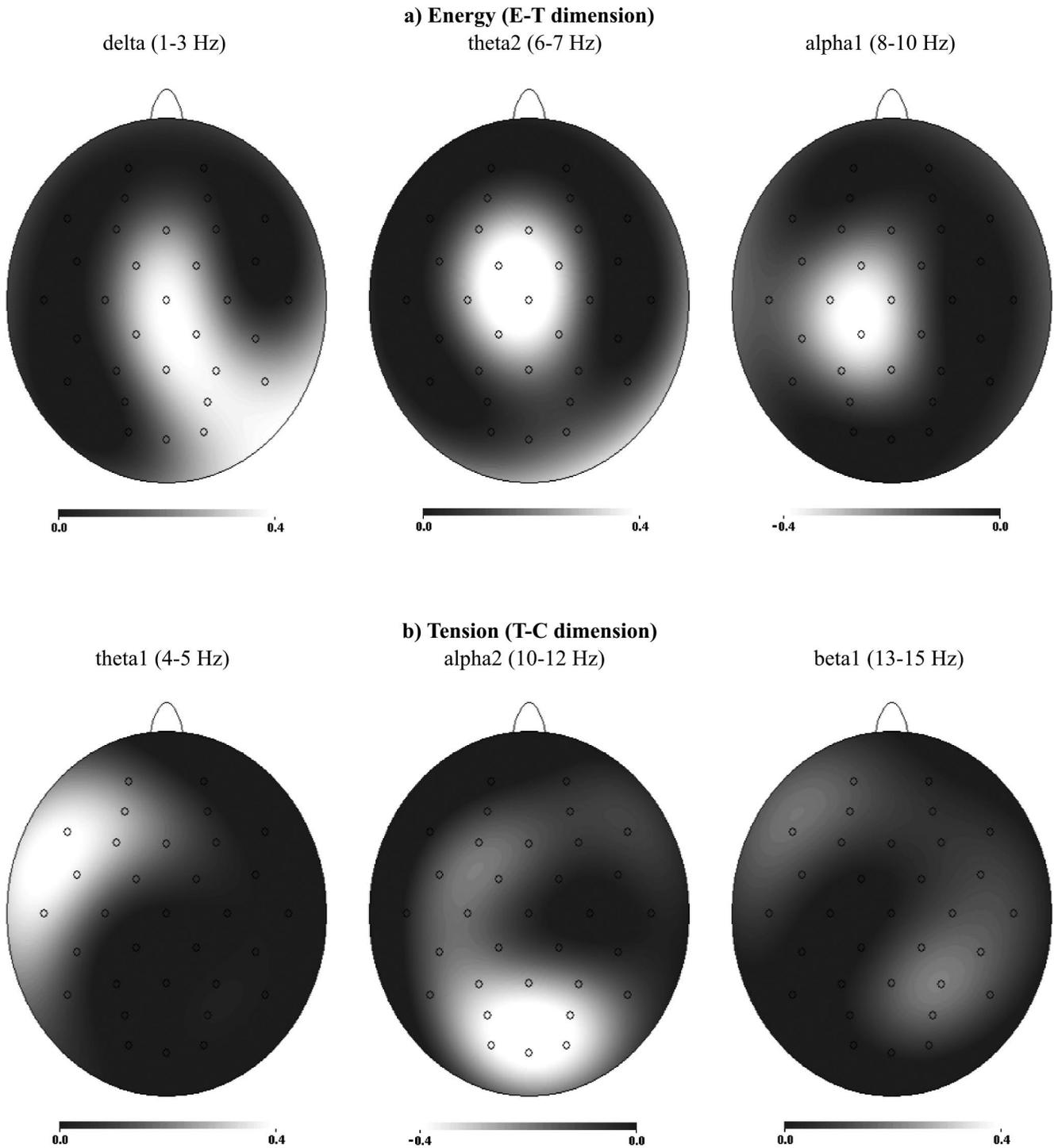


Fig. 3. Magnitude of correlations between subjective dimensions and changes in the EEG relative power. The scale below the maps represents correlation coefficient r : the brighter the area, the strongest association observed. Please note, that correlation scale for alpha band is reversed, which means negative relationship.

Delta power was positively correlated with Tension scores mainly at left frontal and temporal electrodes (Fz, Cz, AF4, FC1, F3, F7, FC5, T7). The observed associations for theta1 power were similar to delta (Fp2, AF3, F7, FC5, F3, Fz, T7). Alpha2 showed a decrease with Tension increase, and this effect was observed at central and left frontal sites (Fp1, F3, FC5, Fz, FC1), as well as symmetrically at posterior sites (Pz, P3, P4, PO3, PO4, O1, Oz, O2). Beta1 power was positively correlated with a feeling of tension at some frontal (AF3, AF4, F7, F4), right temporal (T8) and right parietal (P4, PO4, CP2) sites. For frequencies within alpha1, beta2 range and higher, no significant relationships were observed (see Fig. 3b).

DISCUSSION

Differences between pre- and post-task EEG

The relative power in the individual frequency bands after the task was different, compared to the pre-task measurement. Alpha relative power was characterized by a salient decrease over the entire cortex in the post-task conditions. Since high alpha power is related to the state of relaxed wakefulness (Andreassi 2000, Barry et al. 2004), its observed decrease may be related to the subjects' increase of mental arousal due to the task requirements, which remains observable some time after.

The increase in beta relative power after the task was found only over the right temporal and parietal recordings. Failure in observing more pronounced post-task beta increase can be explained by the fact, that the measurement was taken some time after the task was completed. However, for gamma we see an increase in relative power almost over the entire cortex. Although gamma is mainly considered as a synchronization recorded during cognitive tasks (Kahana 2006), our results suggest that a cognitive task can also have longer lasting effects in the highest frequency range (Lutz et al. 2004).

In the delta frequency, a slight (not exceeding 2%) but significant increase in relative power over frontal and central recordings was observed. The interpretation of this finding in terms of intentional increase of attention due to procedure demands is discussed below in more detail.

Correlation between subjective mood estimation and EEG

Changes of EEG parameters and subjective estimation due to procedural factors allow us to correlate the within-subject differences of the subjective and objective data. The results confirmed the general hypothesis of correlations between adjective mood estimation and patterns of cortical activity. Both ADACL dimensions are specifically associated with different patterns of EEG characteristics (Table II).

Energy-Tiredness

The Energy-Tiredness dimension describes subjective feeling of energy expenditure underlying both the physical and cognitive levels of activity. The increase of Energy has an emotionally positive value (Thayer 1989). The direction of the correlation with subjective scores is positive for delta as well as theta2 and negative for the alpha1 band. In other words, a higher energetic state is reported by subjects, thus more delta and theta2 power, together with suppression of alpha1 activity, can be observed.

Theta activity as a rhythm linked with a variety of psychological phenomena was studied extensively and related to drowsiness and degraded vigilance (Strijkstra et al. 2003, Eoh et al. 2005, Smit 2004) but also heightened alertness (Mizuki et al. 1980, Pennekamp et al. 1994, Başar et al. 2001) and cognitive activity (Miller 1989, Laukka et al. 1995), as well as to emotional processing (Heath 1972, Schacter 1977). According to the traditional view of theta activity, it is related to the states of decreased activity and drowsiness. On the other side, theta activity can be regarded as a manifestation of increased cortical activation in conditions of cognitive demands (Matsuoka 1990, Pennekamp et al. 1994, Orekhova et al. 1999, Aftanas and Golocheikine 2001, Jensen and Tesche 2002, Aftanas et al. 2004).

This apparent discrepancy suggests that in a range of low frequency, at least two functionally different theta rhythms should be distinguished. Some results suggest that the positive relation of theta power and sleepiness can be observed in conditions of excessive drowsiness, while in the normal awake state, theta activity is a marker of voluntary increment in alertness and attention. This is in line with the already cited study of Strijkstra and colleagues (2003), who observed both patterns of theta activity. This view is also supported

Table II

Values of correlations between subjective scores and relative power in selected bands

Energy-Sleep																
Delta	Fp1	AF3	F7	F3	FC1	FC5	T7	C3	CP1	CP5	P7	P3	Pz	PO3	O1	Oz
	0.11	0.16	0.12	0.28	0.32*	0.19	-0.16	0.28	0.39*	0.12	0.09	0.13	0.40*	0.00	-0.00	0.24
	O2	PO4	P4	P8	CP6	CP2	C4	T8	FC6	FC2	F4	F8	AF4	Fp2	Fz	Cz
	0.37*	0.44**	0.45**	0.42**	0.30	0.35*	0.30	0.17	0.23	0.38*	0.25	0.29	0.18	0.16	0.34*	0.30*
Theta1/2	Fp1	AF3	F7	F3	FC1	FC5	T7	C3	CP1	CP5	P7	P3	Pz	PO3	O1	Oz
	0.21	0.24	0.26	0.34*	0.39*	0.30	-0.20	0.34*	0.39*	0.19	0.10	0.20	0.33*	0.00	-0.02	0.28
	O2	PO4	P4	P8	CP6	CP2	C4	T8	FC6	FC2	F4	F8	AF4	Fp2	Fz	Cz
	0.38*	0.26	0.25	0.30	0.20	0.34*	0.27	0.01	0.16	0.41**	0.30	0.17	0.18	0.17	0.46**	0.39*
Alpha1	Fp1	AF3	F7	F3	FC1	FC5	T7	C3	CP1	CP5	P7	P3	Pz	PO3	O1	Oz
	-0.23	-0.26	-0.17	-0.28	-0.31*	-0.19	-0.41**	-0.47**	-0.43**	-0.28	-0.30	-0.36*	-0.36*	-0.29	-0.33	-0.23
	O2	PO4	P4	P8	CP6	CP2	C4	T8	FC6	FC2	F4	F8	AF4	Fp2	Fz	Cz
	-0.14	-0.19	-0.19	-0.17	-0.13	-0.23	-0.15	-0.19	-0.19	-0.30	-0.29	-0.14	-0.21	-0.16	-0.32*	-0.32*
Tension-Calmness																
Theta1	Fp1	AF3	F7	F3	FC1	FC5	T7	C3	CP1	CP5	P7	P3	Pz	PO3	O1	Oz
	-0.03	0.34*	0.39*	0.33*	0.27	0.42**	0.48**	0.21	0.08	0.24	0.10	0.05	0.08	-0.10	-0.12	0.11
	O2	PO4	P4	P8	CP6	CP2	C4	T8	FC6	FC2	F4	F8	AF4	Fp2	Fz	Cz
	0.20	0.22	0.12	0.16	0.16	0.08	0.03	0.22	0.14	0.17	0.24	0.15	0.29	0.14	0.33*	0.11
Alpha2	Fp1	AF3	F7	F3	FC1	FC5	T7	C3	CP1	CP5	P7	P3	Pz	PO3	O1	Oz
	-0.27	-0.23	-0.21	-0.32	-0.38*	-0.34*	-0.25	-0.20	-0.27	-0.30*	-0.23	-0.34*	-0.33*	-0.38*	-0.39*	-0.45**
	O2	PO4	P4	P8	CP6	CP2	C4	T8	FC6	FC2	F4	F8	AF4	Fp2	Fz	Cz
	-0.45**	-0.42**	-0.30*	-0.21	-0.05	-0.18	0.09	-0.14	-0.02	-0.12	-0.11	-0.30*	-0.17	-0.24	-0.34*	-0.24
Beta1	Fp1	AF3	F7	F3	FC1	FC5	T7	C3	CP1	CP5	P7	P3	Pz	PO3	O1	Oz
	0.22	0.33*	0.32*	0.25	0.23	0.24	0.16	0.11	0.22	0.17	0.27	0.24	0.25	0.24	0.14	0.14
	O2	PO4	P4	P8	CP6	CP2	C4	T8	FC6	FC2	F4	F8	AF4	Fp2	Fz	Cz
	0.20	0.30*	0.33*	0.24	0.27	0.29*	0.27	0.35*	0.24	0.25	0.33*	0.15	0.27	0.23	0.23	0.25

Significant differences: * $P < 0.05$, ** $P < 0.01$

by a factorial analysis of EEG bands (Kubicki et al. 1979), which showed negative correlations between low alpha (8.5–10.5 Hz) and low frequency rhythms (delta and theta, 1.5–6 Hz), recorded in a condition of normal awake state in subjects with open eyes. Since conditions of our experiment placed the subject in a moderate level of activity, we could not record changes in theta activity related to an extensive drows-

iness state. Thus, positive correlation between low frequency activity and subjective estimation of energy can be interpreted in relation to the task involvement and readiness to react.

During the awake state, alpha activity, which is mainly recorded at the central and posterior locations, is a marker of decreased cortical activation, observed during the states of relaxed wakefulness and low men-

tal activity. It is known to be suppressed during stimulus intake or cognitive activity (Niedermayer and Lopes da Silva 1999, Andreassi 2000) and increased in the conditions when cortex areas are deactivated for a correct performance of the task (Gómez et al. 2004).

As expected, the feeling of higher energy was associated with a decrease in relative alpha1 power. It is important to note that association with subjective reports was visible only for the lower alpha range (8–10 Hz). This observation suggests functional heterogeneity of alpha rhythms and dissociation between low and high alpha activity. The lower alpha band is often related to attentive and aware states, while higher alpha is associated with mental workload (Crawford et al. 1996, Klimesch 1999). Our result supports this distinction.

Surprisingly, delta waves also showed positive correlation with Energy-Tiredness scores. Low-frequency delta waves were, in the field of psychophysiology, usually investigated in relation to sleep. It is generally accepted that low-frequency activity predominates in conditions of sleepiness and sleep (Coenen 1998). However, our study found that relative delta power behaves similarly to both theta bands in relation to Energy-Tiredness estimation. As previously mentioned, the factor analysis of Kubicki and others (1979), yielded a band of 1.5 to 6 Hz as a single factor, which fits into our observations. This may suggest that, when considering associations with the level of energy, these two rhythms may behave in a similar way. In fact, a few studies show a functional similarity of theta and delta activity under certain conditions. It has been reported that besides theta, delta power also increases during conditions of cognitive activity (Dolce and Waldeier 1974, Harmony et al. 1996). It should also be noted that the observed changes in delta power accompanying estimation of energy, are very subtle compared to its huge increase during sleep conditions described in the literature (Andreassi 2000). The lack of sufficient support in the literature concerning delta activity during the awake state suggests that this outcome needs to be carefully interpreted.

Tension-Calmness

The second subjective factor, Tension-Calmness, is a dimension that describes the expenditure of energy related to negative emotional arousal and stress on the one side, and lack of tension with positive valence on

the other (Thayer 1989). It includes both valence and the activational aspect of mood.

EEG activity was found to be related to the estimated level of Tension for all affected bands (theta1, alpha2, beta1). The localization of the effect was different for these bands.

The relationships observed at the right posterior cortical sites, especially in the beta1 range, are in line with some reports relating this region to the experience of emotional arousal, irrespective of valence (Heller 1993). These associations could be then considered as state-dependent patterns related to the subjective intensity of emotion; the decrease of anterior alpha2 together with the increase of beta1 power may suggest activation of this area, expected in conditions of heightened tension. This result confirms again the functional dissociation between alpha1 and alpha2 rhythms. Decrease in alpha power during emotional tension is in line with the general view on the alpha band, postulating a positive correspondence between alpha and the relaxed state.

The associations with subjective reports observed in the anterior region can be related to the experience of emotional valence (Davidson 1992, Heller 1993, Papousek and Schulter 2002).

Beside alpha and beta frequencies, positive correlation with reported tension level was visible for theta1 relative power. Although the effect of increased power in the low frequency band, along with the increase of tension feeling, was not predicted in our hypotheses, it is in line with some known data from studies of emotional processing (Schacter 1977, Foster and Harrison 2002, Lal and Craig 2003, Umriukhin et al. 2005).

CONCLUSIONS

It can be concluded that the results presented in this paper support the hypothesis of a co-variation between subjective qualities of mood and brain activity patterns. Both subjective dimensions are specifically associated with EEG changes in a different way. EEG characteristics in terms of frequency and localizations related to the Energy-Tiredness dimension are different from those associated with the Tension-Calmness scale. Energy-Tiredness is related to delta, theta1, theta2 and alpha1 activity, mainly in central locations, while Tension-Calmness is related to theta1, alpha2 and beta1, mainly distributed in anterior and posterior regions. As predicted in the hypotheses, the Energy-Tiredness dimension is especially associated with

lower frequency rhythms. The Tension-Calmness scale is, however, sensitive to both low and high frequency rhythms, which can be explained by both valence and activational aspects of mood included in this scale.

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