International Journal of Psychophysiology xxx (2013) xxx–xxx

Contents lists available at SciVerse ScienceDirect

International Journal of Psychophysiology

journal homepage: www.elsevier.com/locate/ijpsycho

A neurophysiological signature of motivational incongruence: EEG changes related to insufficient goal satisfaction

Maria Stein [a,b,*], Yvonne Egenolf [a], Thomas Dierks [b], Franz Caspar [a], Thomas Koenig [b,c]

[a] Department of Clinical Psychology and Psychotherapy, University of Bern, Switzerland
[b] University Hospital of Psychiatry, Department of Psychiatric Neurophysiology, Bern, Switzerland
[c] Center for Cognition, Learning and Memory, University of Bern, Switzerland

ARTICLE INFO

Article history:
Received 23 November 2012
Received in revised form 27 March 2013
Accepted 22 April 2013
Available online xxxx

Keywords:
EEG
LORETA
Motivation
Alpha
Resting state
Synchronization
Mental health

ABSTRACT

Human behavior and psychological functioning is motivated and guided by individual goals. Motivational incongruence refers to states of insufficient goal satisfaction and is tightly related to psychological problems and even psychopathology. In the present study, individual levels of motivational incongruence were assessed with the incongruence-questionnaire (INC) in a healthy sample. In addition, multi-channel resting-state EEG was measured. Individual variations of EEG synchronization and spectral power were related to individual levels of motivational incongruence. For significant correlations, the relation to intracerebral sources of electrical brain activity was investigated with sLORETA. The results indicate that, even in a healthy sample with rather low degrees of motivational incongruence, this insufficient goal satisfaction is related to consistent changes in resting state brain activity. Upper Alpha band attenuation seems to be most indicative of increased levels of motivational incongruence. This is reflected not only in significantly reduced functional connectivity, but also in changes regarding the level of brain activation, as indicated by significant effects in the spectral power and LORETA analyses. Results are related to research investigating the upper Alpha band and are discussed in the framework of Grawe's consistency theory.

1. Introduction

With the arrival of connectionist approaches to psychological functioning, the assumption of parallel distributed information processing began to influence the formulation of psychological theories (Caspar et al., 1992; Rumelhart and Mcclelland, 1986). One of the important questions arising with a connectionist approach concerns the relationship between these parallel processes, their compatibility, and the impact that this compatibility has on psychological functioning. Grawe's consistency theory defines consistency as the compatibility of simultaneously activated psychological processes. Contrary to this, inconsistency denotes a state in which simultaneously activated processes interfere with each other, thus hindering smooth psychological functioning and effective interaction with the environment. From a systems perspective, consistency regulation is postulated to be a basic principle in psychological functioning (Grawe, 2004). Furthermore, as each psychological process has a neuronal analogue, consistency regulation is assumed to be an important principle in neuronal functioning as well (Grawe, 2007). Following this assumption, the question arises whether a neurophysiological correlate of the consistency-level can be found.

The concept of consistency characterizes the relation between different parallel psychological processes on the system-level, thus describing an organismic state. It does not include any assumption regarding the content and the direction of these processes, but only regards the question whether those processes are compatible and don't interfere with each other. Content-wise, human behavior and psychological functioning is motivated and guided by individual goals (Austin and Vancouver, 1996; Caspar, 1995; Grawe, 2004). These individual goals are supposedly formed to foster fulfillment or protection of basic human needs (e.g. Grawe, 2004; Horowitz et al., 2006). The individual goals represent desired states (Austin and Vancouver, 1996) and can either imply the presence of a desired experience - as in the case of approach goals - or the avoidance of an adverse experience - as in avoidance goals (Carver and Scheier, 1998; Elliot and Friedman, 2007; Grosse Holtforth, 2000).

Consistency regulation and goal-directed psychological activity are tightly linked to each other. In Grawe's theory, this linkage is incorporated in a particularly important subtype of inconsistency, which is motivational incongruence: the concept of motivational incongruence refers to the compatibility of active motivational goals and actual sensory experiences. It thus describes the extent of goal satisfaction: Motivational incongruence describes a state in which a person's experiences do not match his or her motivational goals. The stronger the mismatch between

* Corresponding author at: University Hospital of Psychiatry, Department of Psychiatric Neurophysiology, University of Bern, Bolligenstrasse 111, 3000 Bern, Switzerland. Tel.: +41 31 930 9348; fax: +41 31 930.
E-mail address: stein@puk.unibe.ch (M. Stein).

0167-8760/$ – see front matter © 2013 Elsevier B.V. All rights reserved.
http://dx.doi.org/10.1016/j.ijpsycho.2013.04.017

a person's actual experiences and his or her motivational goals, the higher the motivational incongruence. As the degree of goal satisfaction that one experiences may vary over time, motivational incongruence refers to a state rather than a trait variable. If the motivational goals imply the presence of desirable experiences, dissatisfaction leads to approach incongruence; if the avoidance goals are dissatisfied, avoidance incongruence occurs (Grawe, 2004; Holtforth and Grawe, 2003). In the long term, dissatisfaction of motivational goals (i.e. motivational incongruence) is assumed to foster psychological problems and even psychopathology (Grawe, 2004; Grosse Holtforth, 2008; Karoly and Anderson, 2000).

As humans did not develop a distinct sensorium allowing to consciously capture inconsistency on the system level, it is impossible to measure consistency levels directly with specific questionnaires or likewise. Motivational incongruence, as a subtype of inconsistency, also comprises non-conscious as well as consciously represented aspects. The incongruence questionnaire (INC, Grosse Holtforth, 2003) allows a reliable assessment of the level of consciously represented motivational incongruence. The high correlation of the INC-level with important clinical parameters such as subjective well-being, neuroticism, depressivity and severity of psychopathological symptoms underlines its relevance and validity (Holtforth and Grawe, 2003). Motivational incongruence is thus a very relevant and furthermore assessable subtype of the corresponding, higher-level construct of inconsistency.

As far as related constructs are concerned, a very prominent theory incorporating the approach-avoidance differentiation is Gray's Reinforcement Sensitivity Theory (RST). In its revised version (Gray & McNaugthon, 2000), it differentiates between the Behavioral Approach System (BAS), the Behavioral Inhibition System (BIS) and a Fight/Flight/Freeze System (FFFS). These systems are defined with respect to the stimuli they get activated by and with respect to the kind of behavior they initiate: In short, the BAS is activated by (un)conditioned stimuli signaling the absence of punishment or the availability of reward and it initiates approach behavior; the FFFS is activated by (un)conditioned stimuli signaling punishment or the absence of reward and initiates avoidance behavior; and the BIS is activated by conflicting situations and is responsible for goal conflict resolution (note, however, that the BIS had a very different role, i.e. mediating response to conditioned aversive stimuli and innate fear stimuli, in the earlier version of the RST (Gray, 1982) (see also Corr, 2008 for a more extensive discussion). This differentiation in the revised RST, while at first sight seeming similar to the distinction between approach and avoidance motivation discussed here, is distinct from the one used in consistency theory. In consistency theory, approach motivation refers to motivation generated by the availability of states one wishes to experience (i.e. by the availability of rewarding stimuli) while avoidance motivation is generated with respect to states one wishes to avoid (i.e. getting away from potentially punishing stimuli). Gray's revised RST however, subsumes both types of motivation under the BAS (i.e., in behavioral terms, joining positive and negative reinforcement). Motivational incongruence is defined in consistency theory as a state in which either a desired state cannot be achieved (i.e. the absence of a rewarding stimulus; approach incongruence) or an undesired state cannot be prevented (i.e. the presence of a punishing stimulus; avoidance incongruence). In Gray's revised RST, however, both states would activate the FFFS.

Therefore the understanding of approach and avoidance incongruence operationalized with the INC is closer to the conceptualization proposed for example by Carver and Scheier (1998) (see also Carver, 2004 for a more precise discussion of the theoretical differences). In this view, approach motivation is directed toward a desirable outcome and the failure to attain this outcome (as it is the case in approach incongruence) produces an “error signal” in monitoring feedback processes and can give rise to negative affective states. Avoidance motivation, on the other hand, is initiated by a negative event one wishes to prevent and the failure to prevent this event (as it is the case in avoidance motivation) is equally resulting in an error signal and negative affective states (Carver and Scheier, 1998).

As outlined above, consistency theory ultimately postulates consistency regulation as a basic principle of brain functioning. However, direct evidence – and even more evidence that is closely related to the theoretical framework of consistency theory – for this neurophysiological anchorage of consistency is still missing. The present study strives to provide this sort of evidence by investigating concepts from the framework of consistency theory directly with neuroscientific methods. The identification of a marked neurophysiological correlate of inconsistency would validate the postulation of consistency as a fundamental concept of psychological as well as brain functioning.

Inconsistency, the construct on the system level, was operationalized in this study by the concept of motivational incongruence. The level of overall motivational incongruence, as well as the level of approach and avoidance incongruence, can validly and reliably be assessed with the incongruence questionnaire (INC, Holtforth and Grawe, 2003). Even though the INC also includes more detailed scales that yield the incongruence level regarding a specific type of approach or avoidance goal, we concentrated in this exploratory study on the three summarizing scales of overall, approach and avoidance incongruence. If consistency regulation is fundamentally embedded in the brain's functioning and not restricted to a specific content, it should be traceable as a neurophysiological correlate of these three summarizing scales. The distinction between approach and avoidance congruence, however, was maintained, because this differentiation has proved to be important in psychological (e.g. Gable et al., 2003) as well as in neurophysiological (e.g. Davidson, 2003) research.

On the side of neurophysiological measures, we used multi-channel EEG to measure resting-state brain activity on a millisecond-to-millisecond-timescale. Modern EEG-methods offer highly sophisticated ways of data analysis that are well suited to explore a neurophysiological reflection of motivational incongruence: Global Field Synchronization (GFS) measures the overall degree of phase differences in EEG signal and is thus indicative of high synchronicity in the underlying brain activity (Koenig et al., 2001). As synchronicity is one of the main mechanisms of binding (and thus cooperation) between neuronal assemblies, GFS offers a very interesting approach to our research question: Following the assumption that incongruence reflects one subtype of incompatibility of activated psychological and neuronal processes, we expect the GFS to correlate negatively with the INC scales.

Another electrophysiological method, the topographical analysis of covariance (TANCOVA), allows to correlate an external variable (e.g. the INC score) with the amount of neuronal activity in the frequency range (EEG-resting state power spectra). The TANCOVA rationale builds on the fact that EEG fields are additive: If one or more brain regions exist, where activation changes proportionally to the incongruence-level, this leads to a single topography being added to our EEG data. The TANCOVA method enables us to retrieve such a topography and to test such an observed association between e.g. INC score and the EEG-data for significance. If in one of the EEG-frequency ranges, a significant correlation between the INC score and a certain EEG topography can be detected, this would indicate that there is a distinct neuronal generator network in which the amount of activation is related to the INC score. Once this significance is established, such a finding can then be more specified by estimating the intracerebral sources of the effect with modern source-analysis methods like sLORETA (standardized low resolution electromagnetic tomography, Pascual-Marqui, 2002). The methods outlined above are not only reliable and well established, but also suitably applicable to our research question. We therefore chose them to explore motivational incongruence, a central construct of Grawe's consistency theory, directly on the neurophysiological level.

Please cite this article as: Stein, M., et al., A neurophysiological signature of motivational incongruence: EEG changes related to insufficient goal satisfaction, International Journal of Psychophysiology (2013), http://dx.doi.org/10.1016/j.ijpsycho.2013.04.017

2. Method

2.1. Participants

Twenty-two healthy, German-speaking subjects participated in the study after informed consent. One subject had to be excluded because of poor quality EEG recording; another one was excluded because of missing data in the questionnaires, leaving a final sample of twenty healthy subjects (9 males, 11 females). Mean age was 25 (SD = 5.9, range: 21 to 49). As exclusion criteria included psychological disorders, participants were screened using a structured clinical interview (SKID, Wittchen et al., 1997).

2.2. Procedures

All procedures were approved by the cantonal ethics committee. After informed consent, participants filled in the INC-questionnaire, then the scalp electrodes for EEG measurement were applied and a resting-state EEG was recorded. This study was part of a larger one (Egenolf et al., in press), in which participants filled in two additional questionnaires before the resting-state EEG-measurement and completed an experiment after the resting-state EEG-measurement.

2.2.1. INC-questionnaire

The incongruence questionnaire (INC) is a reliable and valid measure of goal satisfaction (Holtforth and Grawe, 2003) and has become a valuable tool in clinical practice and research (i.e. Grosse Holtforth and Castonguay, 2007). The INC measures the satisfaction/dissatisfaction of 14 approach and 9 avoidance goals. It consists of 94 items that are grouped to inform 23 scales (14 scales for incongruence regarding the 14 different approach goals, 9 scales for the different types of avoidance incongruence). Additionally, the INC yields summarizing scores for overall incongruence (oINC), approach incongruence (apINC) and avoidance incongruence (avINC), each scale ranging from 0 (low incongruence) to 5 (high incongruence). As the degree of goal satisfaction may vary over time, the INC is measuring a variable that is usually closer to a state than a trait, even if the time scale on which this state is likely to change is highly variable (for example, approach incongruence related to the goal of recognition may decrease substantially during a short phone call in which you are informed that you have been selected for an interesting new job). On the other hand, a recently divorced person may experience approach incongruence related to the goal of intimacy for a longer time before establishing a new intimate relationship). The written instruction on the INK questionnaire asks subjects to indicate how much a certain goal was satisfied "recently" (German: "in letzter Zeit"). If subjects requested more detailed information on the time window, the experimenter specified it in terms of "within the last two weeks". Sample items of the INC are given in Fig. 1. For the summarizing scales of approach and avoidance incongruence, Cronbach's alpha in the samples used during construction and psychometric evaluation of the INC-questionnaire ranged from .83 to .91 in patient samples and from .84 to .92 in healthy samples (Grosse Holtforth et al., 2004; Grosse Holtforth, 2003). The scale of overall incongruence is defined as the mean between the two scales of approach and avoidance incongruence. In the samples used for psychometric evaluation, correlation between approach and avoidance incongruence ranged from .53 to .76 (Grosse Holtforth, 2003).

2.2.2. EEG recording and data reduction

Resting-state EEG was recorded with a Nihon-Kohden Neurofax 1100 system from 70 electrodes placed according to the extended 10/10-system. Two extra electrodes below the eyes were used to monitor eye-movement artifacts. All impedances were kept below 20 Ω, on-line filters were set at 0.3 Hz (high pass) and 120 Hz (low pass) and the data was digitalized with a sampling rate of 500 Hz. During recording, all electrodes were referenced against the mean of C3 and C4. Resting-state EEG was recorded for at least 5 min with eyes closed interrupted by at least two 30 second-epochs of eyes open.

Offline, Brain Vision Analyzer Version 1.05.0005 (BrainProducts, 2005) was used for EEG data preprocessing: During semiautomatic artifact rejection, epochs containing electronic or physiological noise (eye-movements, muscular artifacts) were marked and excluded from further analyses. All data was then recomputed against average reference and data from eyes-closed recording was segmented in 2-second-epochs. Only subjects from whom at least 20 artifact-free epochs (i.e. 40 s) of clean data could be obtained were included in the

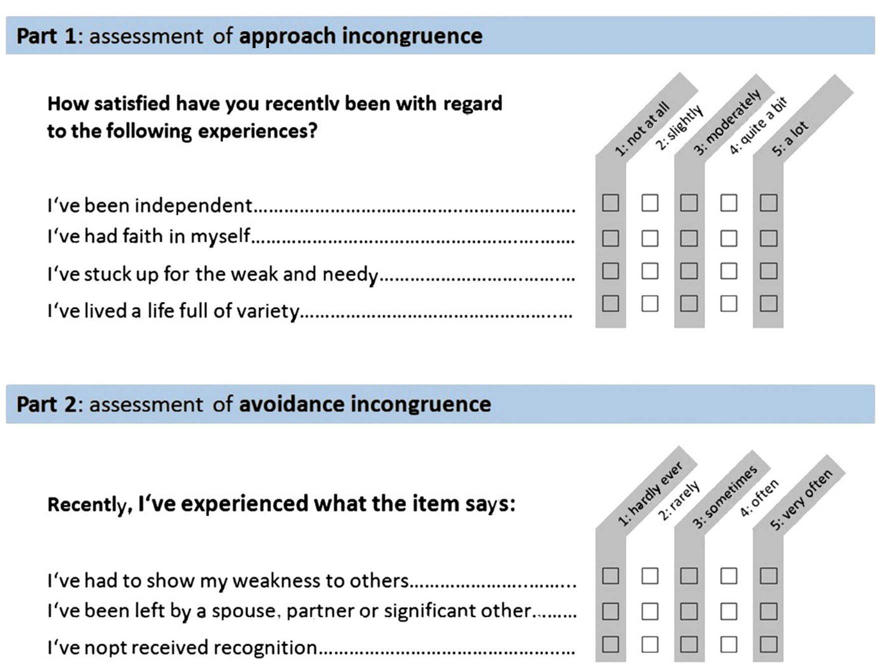

Fig. 1. Sample items of the INC-questionnaire (Grosse Holtforth and Grawe, 2003). Part 1: items for the assessment of approach incongruence; Part 2: items for the assessment of avoidance incongruence.

Please cite this article as: Stein, M., et al., A neurophysiological signature of motivational incongruence: EEG changes related to insufficient goal satisfaction, International Journal of Psychophysiology (2013), http://dx.doi.org/10.1016/j.ijpsycho.2013.04.017

analyses (Gasser et al., 1985). One participant had to be excluded, because this criterion was not met (see also Section 2.1). In the final sample of twenty subjects, a mean of 60 (range: 20 to 120) artifact-free, eyes-closed, 2-second-epochs per participant was extracted for further analyses. In a next step, two versions of a Fast Fourier Transformation (FFT) were performed on the EEG data: A complex FFT allowing for subsequent computation of Global Field Synchronization (see Section 2.2.3) and a standard FFT yielding power values for each frequency. For statistical analyses, FFT data was collapsed into 8 frequency bands (Delta: 1.5–6.4 Hz, Theta: 6.5–8.4 Hz, Alpha1: 8.5–10.4 Hz, Alpha2: 10.5–12.4 Hz, Beta1: 12.5–18.4 Hz, Beta2: 18.5–20.9 Hz, Beta3: 21–29.9 Hz, Gamma: 30–47.9 Hz).

2.2.3. Statistical EEG analyses

2.2.3.1. Global Field Synchronization (GFS). GFS measures the degree of phase-shift between all electrodes at a given frequency. For a given epoch and frequency point, GFS is computed by entering the FFT values of all electrodes into a single, two-dimensional scatterplot, where the x- and y-values correspond to the real and the imaginary parts of the FFT data. This two-dimensional cloud of points is then decomposed with a principal component analysis that yields two eigenvalues (e1 and e2). GFS is then defined as $|e1 - e2|/(e1 + e2)$. GFS-values range from 0 to 1 and increase with increasing phase-communality among the signals observed at the electrodes. As stated above, high GFS is thus indicative of high synchronicity in the underlying brain activity. GFS was measured at each frequency point and then averaged across all epochs and within each of the 8 frequency bands mentioned above. Then, for each frequency band nonparametrical (Spearman's rho) correlations between GFS and the three INC-scales (oINC, apINC, avINC) were calculated. A significant negative correlation between GFS-values in a given frequency band and one of the INC scales would indicate that subjects with higher incongruence levels display lower synchronization (and thus less binding and cooperation).

2.2.3.2. Topographical analysis of covariance (TANCOVA). FFT power was averaged across all epochs within the 8 frequency bands. Using the RAGU software (Koenig et al., 2011), these values were then correlated with the amount of motivational incongruence in a topographical analysis of covariance (TANCOVA, Koenig et al., 2008). The TANCOVA uses bootstrap randomization statistics to determine strength and significance of the correlation between brain activity (i.e. Alpha1-power) and an external variable (i.e. INCap-score): First the covariance of each electrode with the external variable is established and mapped on a covariance map. This covariance map corresponds to the brain generators that vary in activation proportionally to our external variable. The higher the association between the brain activity and our external variable, the higher the global strength (calculated as Global Field Power, GFP, Lehmann and Skrandies, 1980) of this covariance map will be. Therefore, the GFP of the covariance map will subsequently serve as a measure of effect size. In a next step, the assignment of the EEG data to the external variable is randomized 5000 times and the covariance maps are computed for each randomized dataset. Then, the GFP of these randomly-obtained covariance maps is computed. These 5000 randomizations thus yield the distribution of the measure of effect size against which the real effect is then tested for significance.

2.2.3.3. Standardized low resolution electromagnetic tomography (sLORETA, Pascual-Marqui, 2002). A significant finding in the TANCOVA indicates that activation in underlying brain structures varies in relation to the degree of motivational incongruence. Therefore, significant TANCOVA results were further explored with the sLORETA source analysis method as implemented by Pascual-Marqui (2002). This solution estimates the intracerebral distribution of current density in a realistic head model (Fuchs et al., 2002) under the assumption of similarity in orientation and neuronal strength of neighboring sources. The solution space is limited to gray matter and comprises 6239 voxels at 5 mm resolution. The individual mean voxelwise spectral power was computed based on averaged cross-spectral matrices obtained from the 2-second epochs and averaged within the frequency band of interest, assuming a signal to noise ratio of 1000. For each sLORETA voxel, the correlation with the external variable (i.e. one of the INC-scales) was assessed and regions with significant correlations ($p < 0.05$, corrected for multiple comparisons with nonparametric permutation tests, Nichols and Holmes, 2002) are reported.

3. Results

The mean INC scores of our sample was $m_{(oINC)} = 1.95$ for the overall incongruence (sd = 0.38, range: 1.33–2.49), $m_{(apINC)} = 2.12$ for approach incongruence (sd = 0.4, range: 1.33–2.65) and $m_{(avINC)} = 1.77$ for avoidance incongruence (sd = 0.43, range: 1.16–2.51). Given a possible range from 0 (low incongruence) to 5 (high incongruence), our sample displays rather low INC scores, which however is not an unexpected finding in a group of healthy volunteers. In the current sample, Cronbach's alpha was 0.83 for approach incongruence and 0.89 for avoidance incongruence.

In the Alpha2-band, Spearman-Rho correlations yielded a significant negative association of Global Field Synchronization (GFS) with overall incongruence (oINC, $r = -.40$, $p = .04$) as well as with avoidance incongruence (avINC; $r = -.42$, $p = .03$). The correlations were thus of moderate strength and – as expected – both negative, indicating reduced synchronization with increasing incongruence levels. Fig. 2 shows a scatterplot of Alpha2-GFS and the corresponding INC-scores. Note that in Fig. 2 one subject (the one with the lowest Alpha2-GFS) seems to depart from the average and might be considered an outlier when applying the Grubb's test for outliers with a significance level of

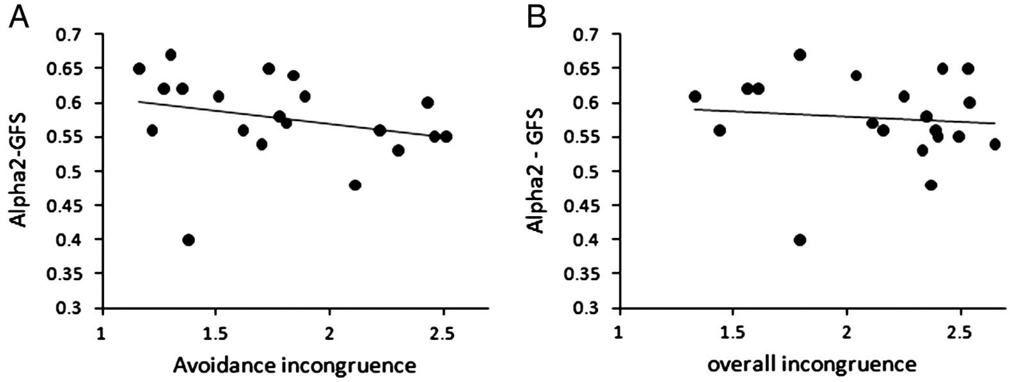

Fig. 2. Scatterplots between Alpha2-GFS and avoidance incongruence (A), respectively overall incongruence (B). Abbreviations: GFS = Global Field Synchronization.

Please cite this article as: Stein, M., et al., A neurophysiological signature of motivational incongruence: EEG changes related to insufficient goal satisfaction, International Journal of Psychophysiology (2013), http://dx.doi.org/10.1016/j.ijpsycho.2013.04.017

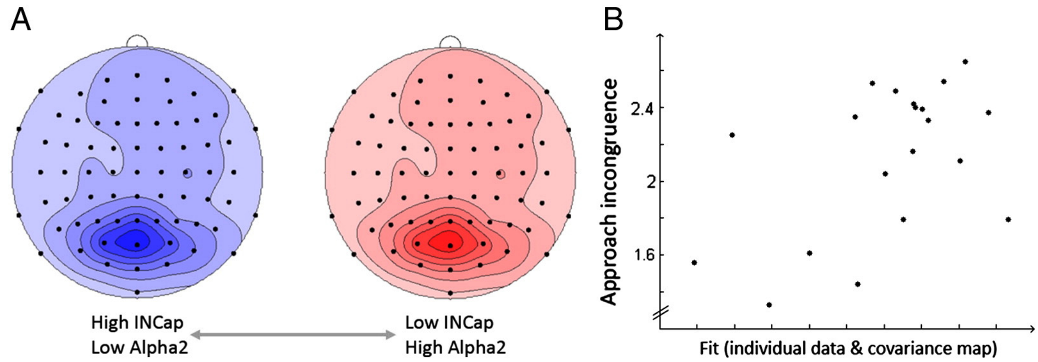

Fig. 3. A: Covariance map of the association between Alpha2 power and approach incongruence. Nose is up and electrode positions are indicated by black dots on the map. B: Fit (between individual EEG-data and covariance map, in arbitrary units) plotted against the individual level of approach incongruence. Abbreviations: INCap = approach incongruence.

0.05 (however, when applying Dixon's Q or the 3-standard deviation-criterion, this case was not classified as an outlier). Recalculation of the correlations depicted in Fig. 2 without this subject 20 resulted in even stronger correlations between Alpha2-GFS and overall incongruence (oINC, $r = -.51$, $p = .01$) as well as between Alpha2-GFS and avoidance incongruence (avINC; $r = -.53$, $p = .01$). There was however still no correlation between Alpha2-GFS and approach incongruence after the exclusion of this subject.

The TANCOVA yielded a significant correlation in the Alpha2-Band as well: Here Alpha2-power with a given topography (see Fig. 3A for a picture of the covariance map) correlated significantly with approach incongruence. Fig. 3B depicts how the fit between individual EEG-data in the Alpha2-band and the covariance map increased with higher approach incongruence. The association between this fit and approach incongruence corresponded to a Spearman's rho coefficient of $r = 0.46$ ($p = 0.04$) and an explained variance of 21%.

The p values computed by the TANCOVA suggested significant correlations between the INC scales and Gamma-power as well as a significant correlation between Beta3-power and approach incongruence. Inspection of the covariance maps however strongly suggested that remaining muscular artifacts at temporal electrodes accounted for these results. Therefore these results will not be further explored and subsequent analyses concentrated on the correlation between Alpha2-power and approach incongruence. As outlined above, a significant result in the TANCOVA indicates that there is at least one brain region in which activation changes proportionally to the level of approach incongruence that a person experiences. In order to find out which brain region displays such a proportional activation change, we computed a frequency domain sLORETA analysis in the Alpha2-band. The nonparametric permutation test yielded $r = -0.683$ as the threshold corresponding to a p-value of 0.05 (corrected for multiple comparisons) that was applied to the results. The results of this analysis are depicted in Fig. 4 and indicate that the strongest association of brain activation and approach incongruence is located in left inferior (Brodman Area (BA) 40) and superior parietal lobe (BA 7) and bilateral precuneus (BA 7 and 19): the higher the approach incongruence a person experiences, the lower the Alpha2-power in this cluster.

4. Discussion

In this study, motivational incongruence (a concept on the behavioral/experiential level) was used to operationalize inconsistency (a construct on system level) and the neurophysiological correlates of motivational incongruence were investigated. Motivational incongruence, as measured by the INC, describes to which extent a person's experiences meet his or her individual motivational goals. The reported association between neurophysiological measures and motivational incongruence can thus also be seen as an instance of neuronal activity related to states of insufficient goal satisfaction. Regarding the EEG-parameters under investigation, the results indicate that the upper Alpha frequency is most sensitive to increasing levels of motivational incongruence. This is not only reflected in reduced functional connectivity, as measured with GFS, but also in changes regarding the level of brain activation, as indicated by TANCOVA and LORETA analyses.

We could show that, even in a healthy sample with rather low degrees of motivational incongruence, this insufficient goal satisfaction is linked to traceable changes in resting state brain activity. This finding seems even more striking as we did not manipulate subjects to orient toward this incongruence: We were able to detect neurophysiological correlates of motivational incongruence in the subjects' resting state brain activity. The reflection of motivational incongruence in resting state brain activity indicates that states of insufficient goal attainment have a persisting impact on a subject's neuronal functioning. Like background lighting influences our impression of the objects in focus, this impact seems to be present even without allocation of attention to it. The neurophysiological reflection of the experience that one is unable

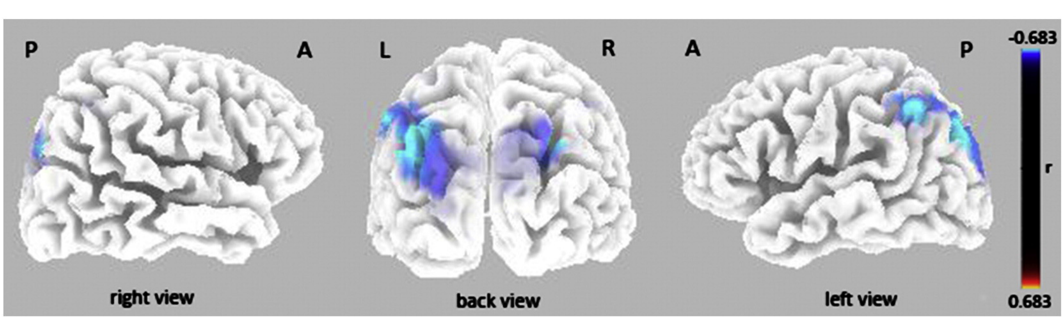

Fig. 4. sLORETA source localization of the association between Alpha2-power and approach incongruence. A threshold of $r = -0683$, corresponding to a p-value of 0.05 (corrected for multiple comparisons) was chosen. Abbreviations: P = posterior, A = anterior, L = left, R = right.

Please cite this article as: Stein, M., et al., A neurophysiological signature of motivational incongruence: EEG changes related to insufficient goal satisfaction, International Journal of Psychophysiology (2013), http://dx.doi.org/10.1016/j.ijpsycho.2013.04.017

to reach or protect certain goals thus extends beyond the very moment of experience and into the continuum of a subject's everyday life. As a first general conclusion, our results thus support the assumption that higher levels of motivational incongruence have long-range consequences (even though the exact path by which this might – on a neurophysiological level – eventually put people at risk for mental illness yet remains to be traced). Our results indicate that, with increasing levels of motivational incongruence, the power as well as the synchronization in the upper Alpha frequency decreases. Interestingly, motivational incongruence, which is assumed to be a risk factor for the development of psychological illness, thus has a neurophysiological correlate that coincides with the observation of neurophysiological deteriorations that have been observed across several psychological diseases: reduced Alpha power has been reported for bipolar disorder, schizophrenia and anxiety disorders (e.g. Galderisi et al., 2009; Hughes and John, 1999; Uhlhaas et al., 2008). Synchronization, being less investigated, has been reported to be reduced in unipolar depression (e.g. Hughes and John, 1999). It is intriguing that the present results, obtained in a healthy, highly functional sample, point in a similar direction. The findings from clinical psychological research as well as from neuroscientific investigations thus coincide in this point.

GFS measures synchronicity in the EEG signal and can thus be seen as an index of neuronal binding and of cooperation between neuronal assemblies independent of their location. This neurophysiological measure is thus very close to the construct of consistency, which implies the compatibility of simultaneously activated processes. As expected, all observed significant associations between GFS and motivational incongruence were negative. In the Alpha2-band, increased motivational incongruence was linked to lower GFS. This correlation was significant for overall incongruence, but was even stronger for avoidance incongruence, while approach incongruence showed no significant association with Alpha2-GFS in the present study. This suggests that the association between overall incongruence and Alpha2-GFS is mainly driven by avoidance incongruence (which, of course, is included in the calculation of the overall incongruence score). The Alpha2-band and recently also its BOLD-fMRI-correlates in the so-called default mode network (Brookes et al., 2011; Jann et al., 2009; Jann et al., 2010; Martinez-Montes et al., 2004) are thought to be involved in internal processing (Aftanas and Golocheikine, 2001; Cooper et al., 2003; Greicius et al., 2003; Mantini et al., 2007; Raichle et al., 2001; Shulman et al., 1997) and self-referential thinking (Knyazev et al., 2012; Knyazev et al., 2011). This body of literature is relevant to our study, because the present GFS effect in the Alpha2-band was observed in EEG data recorded during a resting state condition, when high DMN activity and prevalence of internal processing or self-referential thinking might be expected. While many previous studies analyzed slightly different EEG-parameters and/or pooled EEG data of both Alpha frequency bands together, one of the studies cited above specifically linked Alpha2-GFS to activity in the default mode network, thus indicating that long-range synchronization in the Alpha2-band is the mechanism by which this default mode network is organized and bound together (Jann et al., 2009). The observed link between increased avINC and reduced Alpha2-GFS might thus be indicative of a decoupling of this default mode network in states of higher avoidance incongruence. As the default mode network is assumed to facilitate the "maintenance of information for interpreting, responding to and even predicting environmental demands" (Raichle and Snyder, 2007, p.1087), such a decoupling might be associated with impaired preparation for and reaction to environmental demands, leading to suboptimal interaction with the environment.

The TANCOVA relating EEG spectral power to motivational incongruence also yielded an effect in the Alpha2-band, where the presence of a distinct topography (see Fig. 3A for the covariance map) in our subjects' data was significantly correlated to approach incongruence: With increasing approach incongruence, the power of this Alpha2-map with a posterior maximum was diminished. This association was of moderate strength and explained 21% of the overall inter-individual variance. The amount of tonic Alpha power has been inversely related to alertness in earlier studies (e.g. Jung et al., 1997; Makeig and Inlow, 1993). Therefore, one might argue that alertness should be considered as a mediating variable with explanatory potential for our results. In the absence of a task (or an additional, suited psychophysiological measurement) the influence of alertness can unfortunately not be quantified in this study. However, while it is possible that changes in approach incongruence and alertness are confounded, we favor a line of argumentation that includes additionally also other findings from EEG research on Alpha oscillations. Tonic Alpha power has also been positively associated with cognitive resources available to the individual (Klimesch, 1999) and has been found to predict optimal goal-directed behavior (e.g. Dockree et al., 2007). Furthermore, Alpha power typically decreases when task demands increase (e.g. Babiloni et al., 2004; Fairclough et al., 2005; Pfurtscheller et al., 1996). This suggests that with increasing levels of approach incongruence the neurophysiological signature at rest (a "no-task" situation) shifts in the direction of a typical "task" situation and the resources available for newly emerging tasks may be diminished. The TANCOVA effect indicates that there is at least one brain region, where activation changes proportionally to the level of approach incongruence. Subsequent analysis of underlying brain generators with sLORETA localized this association in posterior brain regions like the left inferior and superior parietal lobe as well as in bilateral precuneus. These localizations are consistent with results of research on posterior Alpha generators in wakeful, task-free brain states (e.g. Babiloni et al., 2006; Hari et al., 1997; Salenius et al., 1995) and extend these findings by associating the activation of these generators with the subjects' individual level of approach incongruence. Our TANCOVA and LORETA results may thus depict a very well conceivable, but rather unspecific effect. However, the sample recruited in the present study displayed low to moderate levels of motivational incongruence, and it remains to be seen whether more specific effects arise from research on samples with higher levels of motivational incongruence as they are observed in psychiatric patients.

As already mentioned in the Introduction, the summarizing INC scores have been shown to correlate positively with Neuroticism, a concept that is related to (or includes) trait anxiety (Ostendorf and Angleitner, 2004). Furthermore, anxiety measures have also been linked to the Alpha frequency in earlier studies. It is thus possible that anxiety is a confounding or mediating variable and that the fact that no anxiety measure was collected limits the interpretability of the present results. A number of earlier studies investigating resting state Alpha power in anxious subjects linked increased Alpha power to increased scores on measures of trait anxiety (Bell et al., 1998; Knyazev and Slobodskaya, 2003; Knyazev et al., 2003; Knyazev et al., 2002), even though there are also studies failing to report this association (Knyazev et al., 2008). Taking into account the previously reported positive correlation between the INC and Neuroticism (Grosse Holtforth, 2003) it thus has to be noted that these results cannot directly explain the findings of the present study, which indicated a negative correlation between high INC scores and Alpha2-power. There are however at least two possible explanations for this divergence. On the one hand, as has been discussed earlier (Knyazev et al., 2008; Knyazev et al., 2004), the effect of trait anxiety on Alpha oscillations might be mediated by state anxiety which is highly variable during resting state measures, like the one used in this study. On the other hand, it might be explained by the obvious difference in the questionnaire data (INC questionnaire vs trait anxiety measures) as well as in the methods used (TANCOVA vs classical or wavelet based power analyses). In any case, future studies should include anxiety measures in order to disentangle differential effects.

The dissociable effects of approach and avoidance incongruence may be viewed in the light of the differences between approach and avoidance motivation: Avoidance motivation has been increasingly investigated and empirical research has strongly suggested that being primarily motivated by avoidance goals poses a potential risk factor for the development and persistence of psychological problems (e.g. Coats et al., 1996; Grosse Holtforth, 2008). In contrast to approach goals that have a positive end point of experiencing some sort of satisfaction, avoidance goals focus on negative events that the subject strives to prevent from happening. As such, avoidance goals can never be reached "for good"; rather they are constantly (or at least frequently) under threat (Grosse Holtforth, 2005). Satisfaction of an avoidance goal thus is a permanent quest. Similarly, the dissatisfaction of avoidance goals (i.e. avoidance incongruence) was reflected in the more "global" effect of diminished functional connectivity during resting state activity. Higher levels of approach incongruence, on the other hand, were associated with a more circumscribed effect with a clearly defined topography. Whether the observed changes in brain activation are a correlate of the actual experience of states of higher incongruence or whether they rather represent a vulnerability factor that could allow the identification of subjects at risk of experiencing higher motivational incongruence cannot be inferred from this purely correlational study. Studies with an experimental manipulation of motivational incongruence and/or with a longitudinal design are needed to further elucidate the characteristics of this relationship.

As stated above, higher levels of approach as well as avoidance motivation were reflected in distinct effects in our subjects' tonic brain activity. However, the only significant correlation of brain activity with overall incongruence seemed to be driven mainly by the arithmetic linkage between overall and avoidance incongruence. In the absence of a clear neuronal correlate of overall incongruence, the dissociable effects of approach and avoidance incongruence therefore also pose another question concerning the theoretical conceptualization: Consistency theory postulates consistency regulation as a basic principle of brain functioning. Furthermore, motivational incongruence is seen as an important subtype of inconsistency, with approach and avoidance incongruence being subtypes of motivational incongruence. Following this conceptualization, we would have expected to find a strong effect of overall incongruence as well, which however, was not the case. If this finding is confirmed in future studies, it might possibly suggest that the distinction between approach and avoidance should be extended to higher-level constructs. However, the failure to observe a clear effect of overall incongruence might also be due to limited variance in levels of motivational incongruence or to the small sample size, which considerably reduced the statistical power in the present study.

As a general limitation, this analysis draws upon only 20 subjects, who in addition displayed only moderate levels of motivational incongruence. The findings thus clearly await replication and confirmation in a larger sample. Furthermore, it remains unclear, whether the observed associations between neurophysiological parameters and motivational incongruence extend to higher levels of incongruence. Future studies should therefore expand the analyses to psychiatric patients, who typically display higher levels of motivational incongruence. Furthermore, in the present study it was not possible to control for some potentially important constructs that might have an impact on the observed findings. Therefore, future studies should monitor the effect that constructs such as stress, alertness, anxiety or the level of other psychopathological symptoms have on the relation between motivational incongruence and neurophysiological measures. Finally, the authors clearly abstain from deducing a causal relationship from these correlative findings. Rather, this study presents a neurophysiological signature of the psychological construct of motivational incongruence.

Acknowledgement

We thank Caroline Stähli, Celine Wigger and Yvonne Fontana for their help during data acquisition and Rebekka Frei for her help during data analyses. Furthermore, we thank Martin Grosse Holtforth for inspiring discussions of the project and for valuable proof reading.

References

Aftanas, L.I., Golocheikine, S.A., 2001. Human anterior and frontal midline theta and lower alpha reflect emotionally positive state and internalized attention: high-resolution EEG investigation of meditation. Neuroscience Letters 310, 57–60.

Austin, J., Vancouver, J., 1996. Goal constructs in psychology. Structure, process and content. Psychological Bulletin 120, 338–375.

Babiloni, C., Babiloni, F., Carducci, F., Cappa, S.F., Cincotti, F., Del Percio, C., Miniussi, C., Moretti, D.V., Rossi, S., Sosta, K., Rossini, P.M., 2004. Human cortical responses during one-bit short-term memory. A high-resolution EEG study on delayed choice reaction time tasks. Clinical Neurophysiology 115, 161–170.

Babiloni, C., Binetti, G., Cassetta, E., Dal Forno, G., Del Percio, C., Ferreri, F., Ferri, R., Frisoni, G., Hirata, K., Lanuzza, B., Miniussi, C., Moretti, D.V., Nobili, F., Rodriguez, G., Romani, G.L., Salinari, S., Rossini, P.M., 2006. Sources of cortical rhythms change as a function of cognitive impairment in pathological aging: a multicenter study. Clinical Neurophysiology 117, 252–268.

Bell, I.R., Schwartz, G.E., Hardin, E.E., Baldwin, C.M., Kline, J.P., 1998. Differential resting quantitative electroencephalographic alpha patterns in women with environmental chemical intolerance, depressives, and normals. Biological Psychiatry 43, 376–388.

BrainProducts, 2005. Brain vision analyzer. Benutzerhandbuch (Version 1.05). München.

Brookes, M.J., Woolrich, M., Luckhoo, H., Price, D., Hale, J.R., Stephenson, M.C., Barnes, G.R., Smith, S.M., Morris, P.G., 2011. Investigating the electrophysiological basis of resting state networks using magnetoencephalography. Proceedings of the National Academy of Sciences of the United States of America 108, 16783–16788.

Carver, C.S., 2004. Negative affects deriving from the behavioral approach system. Emotion 4, 3–22.

Carver, C.S., Scheier, M.F., 1998. On the self-regulation of behavior. (1998) US, On the Self-regulation of Behavior. Cambridge University Press, New York, NY, p. 439.

Caspar, F., 1995. Plan analysis. Toward optimizing psychotherapy. Plananalyse. Seattle: Hogrefe & Huber (1995) 278 Seiten Price: DM 58 — Note: Englische Uebersetzung des Originals: 1989 Beziehungen und Probleme verstehen Eine Einfuehrung in die psychotherapeutische Plananalyse Bern: Huber.

Caspar, F., Rothenfluh, T., Segal, Z., 1992. The appeal of connectionism for clinical-psychology. Clinical Psychology Review 12, 719–762.

Coats, E.J., JanoffBulman, R., Alpert, N., 1996. Approach versus avoidance goals: differences in self-evaluation and well-being. Personality and Social Psychology B 22, 1057–1067.

Cooper, N.R., Croft, R.J., Dominey, S.J., Burgess, A.P., Gruzelier, J.H., 2003. Paradox lost? Exploring the role of alpha oscillations during externally vs. internally directed attention and the implications for idling and inhibition hypotheses. International Journal of Psychophysiology 47, 65–74.

Corr, P.J., 2008. The Reinforcement Sensitivity Theory of Personality. Cambridge University Press, Cambridge.

Davidson, R.J., 2003. Affective neuroscience and psychophysiology: toward a synthesis. Psychophysiology 40, 655–665.

Dockree, P.M., Kelly, S.P., Foxe, J.J., Reilly, R.B., Robertson, I.H., 2007. Optimal sustained attention is linked to the spectral content of background EEG activity: greater ongoing tonic alpha (approximately 10 Hz) power supports successful phasic goal activation. European Journal of Neuroscience 25, 900–907.

Egenolf, Y., Stein, M., Koenig, T., Holtforth, M.G., Dierks, T., Caspar, F., 2013. Tracking the implicit self using event-related potentials. Cognitive, Affective & Behavioral Neuroscience (in press). http://dx.doi.org/10.3758/s13415-013-0169-3.

Elliot, A.J., Friedman, R., 2007. Approach-avoidance: A Central Characteristic of Personal Goals, Personal Project Pursuit: Goals, Action, and Human Flourishing. Lawrence Erlbaum Associates Publishers, US, Mahwah, NJ, pp. 97–118.

Fairclough, S.H., Venables, L., Tattersall, A., 2005. The influence of task demand and learning on the psychophysiological response. International Journal of Psychophysiology 56, 171–184.

Fuchs, M., Kastner, J., Wagner, M., Hawes, S., Ebersole, J.S., 2002. A standardized boundary element method volume conductor model. Clinical Neurophysiology 113, 702–712.

Gable, S.L., Reis, H.T., Elliot, A.J., 2003. Evidence for bivariate systems: an empirical test of appetition and aversion across domains. Journal Research Perspectives 37, 349–372.

Galderisi, S., Mucci, A., Volpe, U., Boutros, N., 2009. Evidence-based medicine and electrophysiology in schizophrenia clinical EEG and neuroscience. Official Journal of the EEG and Clinical Neuroscience Society 40, 62–77.

Gasser, T., Bacher, P., Steinberg, H., 1985. Test–retest reliability of spectral parameters of the EEG. Electroencephalography and Clinical Neurophysiology 60, 312–319.

Grawe, K., 2004. Psychological therapy. Psychologische Therapie. Hogrefe, Seattle.

Grawe, K., 2007. Neuropsychotherapy: Towards a Neuroscientifically Informed Psychotherapy. Erlbaum, Mahwah, NJ.

Gray, J.A., 1982. The neuropsychology of anxiety — an inquiry into the functions of the septo-hippocampal system. The Behavioral and Brain Sciences 5, 469–484.

Gray, J.A., McNaughton, N., 2000. The Neuropsychology of Anxiety: An Enquiry into the Functions of the Septo-Hippocampal System, Second Edition. Oxford University Press, Oxford.

Greicius, M.D., Krasnow, B., Reiss, A.L., Menon, V., 2003. Functional connectivity in the resting brain: a network analysis of the default mode hypothesis. Proceedings of the National Academy of Sciences of the United States of America 100, 253–258.

Grosse Holtforth, M.G.K., 2000. Fragebogen zur Analyse Motivationaler Schemata (FAMOS). Fragebogen zur Analyse Motivationaler Schemata (FAMOS) (questionnaire for the analysis of motivational schemata). Zeitschrift fuer Klinische Psychologie und Psychotherapie 29, 170–179.

Grosse Holtforth, M.G.K., 2003. Der Inkongruenzfragebogen (INK). Ein Messinstrument zur Analyse motivationaler Inkongruenz. The Inkongruenzfragebogen (INK and K-INK). An instrument for the analysis of motivational incongruence. Zeitschrift fuer Klinische Psychologie und Psychotherapie 32, 315–323.

Grosse Holtforth, M.G.K.E.O.B.M., 2005. Reducing the dreaded: change of avoidance motivation in psychotherapy. Das Gefuerchtete reduzieren: Veraenderung der Vermeidungsmotivation in the Psychotherapie. Psychotherapy Research 15, 261–271.

Grosse Holtforth, M., 2008. Avoidance motivation in psychological problems and psychotherapy. Psychotherapy Research. 18.

Grosse Holtforth, M.P.A.L.G.K.M.B., Castonguay, L.G., 2007. When what you want is not what you get: motivational correlates of interpersonal problems in clinical and nonclinical samples Was du wuenschst ist nicht was du bekommst. Motivationale Korrelate interpersoneller Probleme in klinischen und nichtklinischen Stichproben. Journal of Social and Clinical Psychology 26, 1095–1119.

Grosse Holtforth, M., Grawe, K., Tamcan, Ö., 2004. INK. Inkongruenzfragebogen. Hogrefe, Bern.

Hari, R., Salmelin, R., Makela, J.P., Salenius, S., Helle, M., 1997. Magnetoencephalographic cortical rhythms. International Journal of Psychophysiology 26, 51–62.

Holtforth, M.G., Grawe, K., 2003. The incongruence questionnaire (INK). An instrument for the analysis of motivational incongruence. Zeitschrift fur Klinische Psychologie und Psychotherapie: Forschung und Praxis, p. 32.

Horowitz, L.M., Wilson, K.R., Turan, B., Zolotsev, P., Constantino, M.J., Henderson, L., 2006. How interpersonal motives clarify the meaning of interpersonal behavior: a revised circumplex model. Personality and Social Psychology Review. 10.

Hughes, J.R., John, E.R., 1999. Conventional and quantitative electroencephalography in psychiatry. The Journal of Neuropsychiatry and Clinical Neurosciences 11, 190–208.

Jann, K., Dierks, T., Boesch, C., Kottlow, M., Strik, W., Koenig, T., 2009. BOLD correlates of EEG alpha phase-locking and the fMRI default mode network. NeuroImage 45, 903–916.

Jann, K., Koenig, T., Dierks, T., Boesch, C., Federspiel, A., 2010. Association of individual resting state EEG alpha frequency and cerebral blood flow. NeuroImage 51, 365–372.

Jung, T.P., Makeig, S., Stensmo, M., Sejnowski, T.J., 1997. Estimating alertness from the EEG power spectrum. IEEE Transactions on Biomedical Engineering 44, 60–69.

Karoly, P., Anderson, C.W., 2000. The Long and Short of Psychological Change: Toward a Goal-centered Understanding of Treatment and Durability and Adaptive Success. 2000, Handbook of Psychological Change: Psychotherapy Processes & Practices for the 21st Century. John Wiley & Sons Inc, US, Hoboken, NJ, pp. 154–176.

Klimesch, W., 1999. EEG alpha and theta oscillations reflect cognitive and memory performance: a review and analysis. Brain Research. Brain Research Reviews 29, 169–195.

Knyazev, G.G., Slobodskaya, H.R., 2003. Personality trait of behavioral inhibition is associated with oscillatory systems reciprocal relationships. International Journal of Psychophysiology 48, 247–261.

Knyazev, G.G., Slobodskaya, H.R., Wilson, G.D., 2002. Psychophysiological correlates of behavioural inhibition and activation. Perspectives Individual Differences 33, 647–660.

Knyazev, G.G., Slobodskaya, H.R., Safronova, M.V., Sorokin, O.V., Goodman, R., Wilson, G.D., 2003. Personality, psychopathology and brain oscillations. Perspectives Individual Differences 35, 1331–1349.

Knyazev, G.G., Savostyanov, A.N., Levin, E.A., 2004. Alpha oscillations as a correlate of trait anxiety. International Journal of Psychophysiology 53, 147–160.

Knyazev, G.G., Bocharov, A.V., Levin, E.A., Savostyanov, A.N., Slobodskoj-Plusnin, J.Y., 2008. Anxiety and oscillatory responses to emotional facial expressions. Brain Research 1227, 174–188.

Knyazev, G.G., Slobodskoj-Plusnin, J.Y., Bocharov, A.V., Pylkova, L.V., 2011. The default mode network and EEG alpha oscillations: an independent component analysis. Brain Research 1402, 67–79.

Knyazev, G.G., Savostyanov, A.N., Volf, N.V., Liou, M., Bocharov, A.V., 2012. EEG correlates of spontaneous self-referential thoughts: a cross-cultural study. International Journal of Psychophysiology 86, 173–181.

Koenig, T., Lehmann, D., Saito, N., Kuginuki, T., Kinoshita, T., Koukkou, M., 2001. Decreased functional connectivity of EEG theta-frequency activity in first-episode, neuroleptic-naive patients with schizophrenia: preliminary results. Schizophrenia Research 50, 55–60.

Koenig, T., Melie-Garcia, L., Stein, M., Strik, W., Lehmann, C., 2008. Establishing correlations of scalp field maps with other experimental variables using covariance analysis and resampling methods. Clinical Neurophysiology 119, 1262–1270.

Koenig, T., Kottlow, M., Stein, M., Melie-Garcia, L., 2011. Ragu: a free tool for the analysis of EEG and MEG event-related scalp field data using global randomization statistics. Computational Intelligence and Neuroscience 2011, 938925.

Lehmann, D., Skrandies, W., 1980. Reference-free identification of components of checkerboard-evoked multichannel potential fields. Electroencephalography and Clinical Neurophysiology 48, 609–621.

Makeig, S., Inlow, M., 1993. Lapses in alertness: coherence of fluctuations in performance and EEG spectrum. Electroencephalography and Clinical Neurophysiology 86, 23–35.

Mantini, D., Perrucci, M.G., Del Gratta, C., Romani, G.L., Corbetta, M., 2007. Electrophysiological signatures of resting state networks in the human brain. Proceedings of the National Academy of Sciences of the United States of America 104, 13170–13175.

Martinez-Montes, E., Valdes-Sosa, P.A., Miwakeichi, F., Goldman, R.I., Cohen, M.S., 2004. Concurrent EEG/fMRI analysis by multiway partial least squares. NeuroImage 22, 1023–1034.

Nichols, T.E., Holmes, A.P., 2002. Nonparametric permutation tests for functional neuroimaging: a primer with examples. Human Brain Mapping 15, 1–25.

Ostendorf, F., Angleitner, A., 2004. NEO-PI-R - NEO Persönlichkeitsinventar nach Costa und McCrea - Revidierte Fassung. Hogrefe, Göttingen.

Pascual-Marqui, R.D., 2002. Standardized low-resolution brain electromagnetic tomography (sLORETA): technical details. Methods and Findings in Experimental and Clinical Pharmacology 24, 5–12 (Suppl. D).

Pfurtscheller, G., Stancak Jr., A., Neuper, C., 1996. Event-related synchronization (ERS) in the alpha band—an electrophysiological correlate of cortical idling: a review. International Journal of Psychophysiology 24, 39–46.

Raichle, M.E., Snyder, A.Z., 2007. A default mode of brain function: a brief history of an evolving idea. NeuroImage 37, 1083–1090 (discussion 1097–1089).

Raichle, M.E., MacLeod, A.M., Snyder, A.Z., Powers, W.J., Gusnard, D.A., Shulman, G.L., 2001. A default mode of brain function. Proceedings of the National Academy of Sciences of the United States of America 98, 676–682.

Rumelhart, D., Mcclelland, J., 1986. Parallel Distributed Processing: Explorations in the Microstructure of Cognition. MIT Press, Cambridge.

Salenius, S., Kajola, M., Thompson, W.L., Kosslyn, S., Hari, R., 1995. Reactivity of magnetic parieto-occipital alpha rhythm during visual imagery. Electroencephalography and Clinical Neurophysiology 95, 453–462.

Shulman, G.L., Corbetta, M., Fiez, J.A., Buckner, R.L., Miezin, F.M., Raichle, M.E., Petersen, S.E., 1997. Searching for activations that generalize over tasks. Human Brain Mapping 5, 317–322.

Uhlhaas, P.J., Haenschel, C., Nikolic, D., Singer, W., 2008. The role of oscillations and synchrony in cortical networks and their putative relevance for the pathophysiology of schizophrenia. Schizophrenia Bulletin 34, 927–943.

Wittchen, H.U., Wunderlich, U., Gruschwitz, S., Zaudig, M., 1997. Strukturiertes Klinisches Interview für DSM-IV. Hogrefe, Göttingen.

Please cite this article as: Stein, M., et al., A neurophysiological signature of motivational incongruence: EEG changes related to insufficient goal satisfaction, International Journal of Psychophysiology (2013), http://dx.doi.org/10.1016/j.ijpsycho.2013.04.017