ELSEVIER

Psychiatry Research: Neuroimaging Section 100 (2000) 139–154

PSYCHIATRY RESEARCH NEUROIMAGING

www.elsevier.com/locate/psychresns

Brain electric correlates of strong belief in paranormal phenomena: intracerebral EEG source and regional Omega complexity analyses

Diego Pizzagalli[a,*], Dietrich Lehmann[a], Lorena Gianotti[a], Thomas Koenig[a], Hideaki Tanaka[a], Jiri Wackermann[b], Peter Brugger[c]

[a] *The KEY Institute for Brain-Mind Research, University Hospital of Psychiatry, Zurich, Switzerland*
[b] *Institut für Grenzgebiete der Psychologie und Psychohygiene, Freiburg i. Br., Germany*
[c] *Department of Neurology, University Hospital, Zurich, Switzerland*

Received 30 March 2000; received in revised form 13 September 2000; accepted 15 September 2000

Abstract

The neurocognitive processes underlying the formation and maintenance of paranormal beliefs are important for understanding schizotypal ideation. Behavioral studies indicated that both schizotypal and paranormal ideation are based on an overreliance on the right hemisphere, whose coarse rather than focussed semantic processing may favor the emergence of 'loose' and 'uncommon' associations. To elucidate the electrophysiological basis of these behavioral observations, 35-channel resting EEG was recorded in pre-screened female strong believers and disbelievers during resting baseline. EEG data were subjected to FFT-Dipole-Approximation analysis, a reference-free frequency-domain dipole source modeling, and Regional (hemispheric) Omega Complexity analysis, a linear approach estimating the complexity of the trajectories of momentary EEG map series in state space. Compared to disbelievers, believers showed: more right-located sources of the β2 band (18.5–21 Hz, excitatory activity); reduced interhemispheric differences in Omega complexity values; higher scores on the Magical Ideation scale; more general negative affect; and more hypnagogic-like reveries after a 4-min eyes-closed resting period. Thus, subjects differing in

* Corresponding author. Laboratory for Affective Neuroscience, Department of Psychology, University of Wisconsin-Madison, 1202 W. Johnson Street, Madison, WI 53706, USA. Tel.: +1-608-263 5072; fax: +1-608-265 2875.
E-mail address: dpizzag@psyphw.psych.wisc.edu (D. Pizzagalli).

PII: S0925-4927(00)00070-6

their declared paranormal belief displayed different active, cerebral neural populations during resting, task-free conditions. As hypothesized, believers showed relatively higher right hemispheric activation and reduced hemispheric asymmetry of functional complexity. These markers may constitute the neurophysiological basis for paranormal and schizotypal ideation.

Keywords: Schizotypy; Paranormal belief; Interhemispheric differences; EEG frequency analysis; Source localization; Omega complexity; Brain functional states

1. Introduction

The psychometric high-risk paradigm has increasingly gained popularity in the investigation of the etiology and development of psychosis (Lenzenweger, 1991; Chapman et al., 1994; Kwapil et al., 1999; for review, see Lenzenweger, 1994). Its goal is to identify and characterize putatively psychosis-prone subjects through paper-and-pencil screenings. Individuals identified as psychosis-prone will not necessarily decompensate in clinical psychosis, but show higher vulnerability for this. Indeed, follow-up studies demonstrated that schizotypal subjects displayed, 10 years after the first assessment, a higher rate of personal/familial clinical psychosis, psychotic-like experiences, schizotypal dimensional scores, and poorer achievement/functioning (Chapman et al., 1994).

Several studies demonstrated that positive schizophrenic symptomatology (e.g. delusion- and hallucination-like phenomena) are present in non-psychotic subjects in the absence of manifest illness (Claridge and Broks, 1984; Thalbourne, 1994; Verdoux et al., 1998). Thus, psychotic symptoms seem to be distributed along a continuum ranging from normal experiences to severe psychotic symptoms, an observation that led Meehl (1962) to propose the term 'schizotype'.

The formation and maintenance of paranormal beliefs appear important for understanding schizotypal ideation. Previous research demonstrated a link between paranormal belief and schizotypy as well as other schizophrenia-relevant features [Tobacyk and Milford, 1983; Thalbourne, 1994; for reviews, see Irwin (1993) for the psychological perspective, and Brugger (in press) for the neurobehavioral view]. Paranormal belief, in general, and belief in extrasensory perception (ESP) and magical ideation ('belief in forms of causation that by conventional standards are invalid', Eckblad and Chapman, 1983, p. 215), in particular, are especially interesting because they share some similarities with delusional belief (Kwapil et al., 1999). Pathological peculiarities of ideation (odd beliefs or magical thinking, such as superstition, clairvoyance, '6th sense', belief in telepathy) and unusual perceptual experiences are diagnostic DSM-IV criteria for schizotypal personality disorder (American Psychiatric Association, 1994). Thus, people differing in their declared belief in paranormal phenomena, though being completely healthy, may nevertheless be characterized as being more or less close to schizotypy proper.

Striking similarities between psychometrically identified, hypothetically psychosis-prone subjects and patients with schizophrenic symptomatology have been demonstrated in several cognitive and psychophysiological domains. For instance, psychosis-prone subjects showed high occurrence of thought-disordered/idiosyncratic verbalizations (Coleman et al., 1996), uncommon word associations (Duchêne et al., 1998), deviant olfactory experiences (Kwapil et al., 1996), reduced allocation of attentional resources (Hazlett et al., 1997), impaired spatial working memory (Tallent and Gooding, 1999), increased frequency of mixed handedness (Chapman and Chapman, 1987a; Kelley and Coursey, 1992), and reduced P300 amplitudes (Fernandes et al., 1999). Overall, these studies suggest that psychosis-prone subjects and schizophrenic patients share some common peculiarities in brain functions.

In light of the observation that schizophrenic disorders may be associated with (structural and/or functional) hemispheric abnormalities

(Green et al., 1994; Bruder et al., 1999; Kwon et al., 1999), several behavioral studies investigated hemispheric functioning in psychosis-prone subjects and subjects differing in their paranormal belief, yielding, however, discrepant results. While some studies reported increased left (Overby, 1992) or decreased right (Jutai, 1989) hemispheric performance in subjects with schizotypal or paranormal ideation, the majority of them found increased right hemispheric performance in both verbal (Broks, 1984; Rawlings and Claridge, 1984; Brugger et al., 1993a; Poreh et al., 1993, 1994; Kravetz et al., 1998; Leonhard and Brugger, 1998), visual (Brugger et al., 1993b; Luh and Gooding, 1999) and spatial-exploratory tasks (Brugger and Graves, 1997a). Most telling, perhaps, is the direct association between the degree of disordered thought and paranormal ideation and indices of functional hemispheric asymmetry found both in patient populations (Bracha et al., 1993; Harvey et al., 1993) and in healthy individuals (Brugger and Graves, 1997a; Chapman and Chapman, 1987a; Mohr et al., in press).

To extend these behavioral findings, the present study was designated to investigate the relationships between patterns of brain activity during resting, task-free periods and belief in the paranormal, assumed to be an important manifestation of schizotypal ideation. In light of the literature reviewed above, the present study tested the hypothesis that subjects with strong belief in paranormal phenomena, compared to those with skeptical attitudes, would show higher right hemispheric activation and/or patterns of reduced functional asymmetry.

2. Methods

2.1. Subjects

Subjects were recruited among a sample of 352 undergraduate psychology students at the University of Zurich who filled in a six-item questionnaire assessing belief in and experience of paranormal phenomena (Mischo et al., 1993; Schienle et al., 1996; Pizzagalli et al., in press; see Appendix A) during introductory psychology courses. The items had to be scored on a 4-point scale. The total score can range from 0 to 18, denoting strong skepticism and strong belief in paranormal phenomena, respectively. Similar items are included in other schizotypy scales (e.g. Eckblad and Chapman, 1983; Claridge and Broks, 1984; Gruzelier et al., 1995; for review, see Kwapil et al., 1999).

The subjects were additionally asked about their willingness to participate in an experiment assessing ‘neuropsychological and electrophysiological correlates of belief in extrasensory perception’. The 117 students (91 women) willing to participate in the later experiment returned the questionnaire (mean paranormal belief score: 10.6, S.D. = 5.2). Because of the strong prevalence of women in our pre-screened sample and because gender is a confounding variable in laterality and schizotypy research (Beaton, 1985; Gruzelier and Doig, 1996), only female subjects were considered for this study.

From the original sample of 91 pre-screened women, those subjects scoring either in the upper 33% (believers, $n = 19$; range of paranormal belief score: 14–18) or in the lower 33% (disbelievers, $n = 18$; range: 0–8) were invited for the EEG experiment (Fig. 1). All subjects were right-handed (Chapman and Chapman, 1987b), were native German or Swiss-German speakers, and had no personal or familial history of neurological or psychiatric disorders. Six subjects (two believers, four disbelievers) were excluded prior to the final analysis because of insufficient numbers of artifact-free epochs (see below). Believers ($n = 17$; paranormal belief score > 69th percentile) and disbelievers ($n = 14$; paranormal belief score < 27th percentile) entering the EEG analysis did not significantly differ in regard to age, educational level and handedness score (Chapman and Chapman, 1987b), as listed in Table 1.

The study was approved by the Hospital’s Ethics Committee. Subjects gave informed, written consent and were paid CHF 40 (approx. $30) for their participation.

2.2. Procedure

After arrival at the laboratory, subjects com-

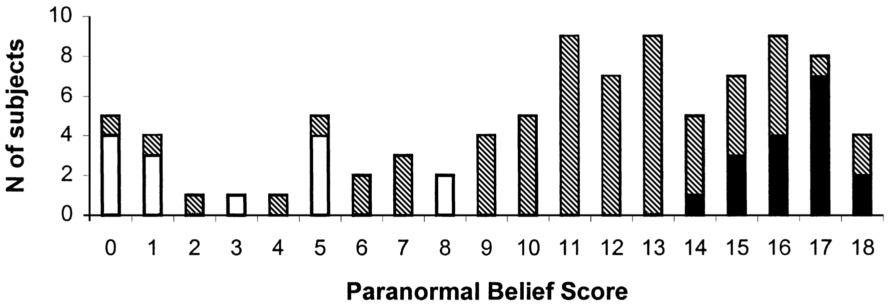

Fig. 1. Histogram of paranormal belief scores '(Mischo et al., 1993) in the entire female sample ($n = 91$). The scores of believers (dark bars; $n = 17$, paranormal belief score > 69th percentile) and disbelievers (open bars; $n = 14$, paranormal belief score < 27th percentile) in paranormal phenomena as well as the scores for all other subjects in the original sample not participating in the EEG experiment (gray bars; $n = 60$) are shown.

pleted the Magical Ideation (MI) Scale (Eckblad and Chapman, 1983) and the trait form of the Positive and Negative Affect Schedule (PANAS; Watson et al., 1988) during EEG electrode placement. The MI Scale is a 30-item scale asking about hallucination-like experiences and delusion-like beliefs. The scale has good reliability and validity in assessing 'schizotypy' or psychosis-proneness in the normal population (Lenzenweger, 1994). The PANAS scale contains 20 emotion descriptors, 10 assessing positive affect (PA; e.g. enthusiastic, inspired), and 10 assessing negative affect (NA; e.g. afraid, distressed). In the trait form, subjects indicate how they feel 'in general'. The PANAS scale was administered because it is known that affective dimensions of personality influence patterns of brain asymmetry (Tomarken et al., 1992; Pizzagalli et al., 1999, 2000), and thus may represent a confounding variable in laterality research.

Thirty-five electrodes covering the entire scalp homogeneously were placed according to the 10/10 international system (Fp1/2, Fpz, AF3/4, F7/8, F3/4, Fz, FC5/6, FC1/2, T7/8, C3/4, Cz, CP5/6, CP1/2, P7/8, P3/4, Pz, PO3/4, O1/2, Oz, O9/O10). Electrodes at the outer left and

Table 1
Demographic and self-report data (mean and S.D.) for believers ($n = 17$) and disbelievers ($n = 14$) in paranormal phenomena

	Believers	Disbelievers	*P*-value
Paranormal belief score [a]	16.4 (1.1)	3.0 (3.0)	$P < 0.0001$
Age (years)	25.8 (6.0)	27.8 (4.8)	ns
Educational level (years)	15.5 (3.2)	17.1 (1.8)	ns
Handedness score [b]	13.7 (1.4)	13.0 (0.7)	ns
MI score [c]	14.6 (3.8)	4.4 (3.0)	$P < 0.0001$
ASC score [d]	7.2 (2.5)	2.8 (2.8)	$P < 0.0001$
PANAS PA [e]	35.8 (3.2)	34.9 (5.8)	ns
PANAS NA [e]	19.4 (5.1)	15.6 (4.5)	$P < 0.05$

[a] Six-item questionnaire assessing belief in and experience of paranormal phenomena (Mischo et al., 1993; possible range: 0–18; see Appendix A).
[b] Chapman and Chapman (1987b).
[c] Magical Ideation score (Eckblad and Chapman, 1983).
[d] 19-item questionnaire assessing hypnagogic-type reveries (possible range: 0–19; see Appendix B).
[e] Positive and Negative Affect Schedule (PA: Positive Affect; NA: Negative Affect, trait form; Watson et al., 1988).

right canthus and an electrode at an infraorbital site were used to monitor horizontal and vertical eye movements. Cz was the recording reference. Subjects were seated in an electrical, sound- and light-shielded chamber, and instructed that the experiment involved EEG recording during resting with open or closed eyes (instructions about eye opening/closing via intercom). The following schedule was used for every subject: (1) 20 s eyes open; (2) 40 s eyes closed; (3) 20 s eyes open; (4) 40 s eyes closed; and (5) further 3:20 min eyes closed. The 35-channel EEG was recorded continuously (250 samples/s/channel; 0.05–60 Hz). Only data from the two 40-s eyes-closed conditions were analyzed. After the EEG recording, the experimenter entered the room and asked the subject to fill in a questionnaire about private experiences during the 'last, longer part of the recording where you had your eyes closed'. The questionnaire was developed in our laboratory (DP and DL) and contains 19 items asking for hypnagogic-type reveries, including visual, auditory, and somaesthetic hallucination-like experiences, brief dreams, intrusive thoughts such as suddenly appearing new, faster, clearer or deeper thoughts, loss of sense of present, reality distortions (see Appendix B). For each item, subjects answered if that particular experience occurred by choosing 'yes' or 'no'. The items were adapted from scales on altered states of consciousness (ASC; Dittrich et al., 1985) and hallucination proneness (Launay and Slade, 1981). For the present study, a global index (sum of acknowledged experiences: possible range: 0–19) was calculated.

2.3. EEG analyses

For each subject, EEG epochs from the two 40-s eyes-closed conditions were reviewed off-line for any kind of artifacts using a moving, non-overlapping 2048-ms-long window, and extracted for subsequent analyses. On the average, 16.7 ± 6.8 artifact-free epochs were available, with no significant differences between the two groups (believers: 18.7 ± 8.3; disbelievers: 14.4 ± 3.2). All available artifact-free epochs were downsampled to 128 samples/s/channel, and subjected to two different analyses, FFT-Dipole-Approximation (Lehmann and Michel, 1990) and Regional Omega Complexity (Wackermann, 1996).

(a) FFT-Dipole-Approximation (Lehmann and Michel, 1990; see also Lütkenhöner, 1992; Valdes et al., 1992) allows computing equivalent intracerebral source models of multichannel, FFT-transformed time series, and thus gives direct insight into the three-dimensional spatial organization of brain activity. Locations of the source model characterize the three-dimensional center of gravity of all neural elements active during the analysis period. The localization accuracy of the method was recently confirmed by the finding that the locations of intracerebral EEG frequency domain sources were closely related to (a) the locations of maximal cerebral glucose metabolism, as measured by positron emission tomography (Dierks et al., 1997) and to (b) the surgically determined seizure origins in patients with mesolimbic epilepsy (Lantz et al., 1999). Moreover, a study assessing the behavior of intracerebral EEG frequency domain sources during classical eyes-open and eyes-closed conditions (Kondakor et al., 1997) found that the eyes closed condition was associated with significantly stronger and more posterior sources for the α bands, as one might expect. The method, which was previously applied successfully in EEG studies of personality dimensions (Pizzagalli et al., 1999), mentation modes (Lehmann et al., 1993; Tesche et al., 1995) and pathological conditions (Dierks et al., 1993; Michel et al., 1993; Lantz et al., 1999), involves two basic steps: (1) modeling of multichannel brain electric field data in the frequency domain by a potential distribution map by assuming a single, common phase angle for the generating processes. This assumption proved to be plausible for baseline EEG recordings since single phase angle models accounted for more than 93% of the variance of the original data (Michel et al., 1992). (2) Computation of a conventional three-dimensional equivalent dipole source for the modeled potential distribution map by assuming a single source. In detail, in step 1, for each analysis epoch and each FFT frequency point, the values for all 35 channels were entered into a sine–cosine diagram. Using a Hamming window (Lehmann and Michel, 1990). Assuming single-phase generator processes, these entry points were projected onto the first principal component of the data cloud and their distances along the first principal component were read out in microvolt, forming a potential distribution map. With the use of a permutation procedure for the polarities of all available maps for each subject, a mean map with minimal variance was computed for each subject. This mean map was then subjected to three-dimensional equivalent dipole source modeling using a three-shell model (step 2). From this step, four variables were extracted: the model source's location coordinates along the anterior-posterior, left–right, and superior–inferior brain axes, and its strength (Global Field Power; Lehmann and Skrandies, 1980; in microvolts, i.e. square root of power). The model source locations represent distances in millimeters from the origin of the spherical head model (10% above zero of the 10/20 system; radius of the model: 78 mm). Because prior factor analysis research demonstrated the existence of independent EEG frequency bands (e.g. Kubicki et al., 1979), coordinates of the source locations and their strength were averaged over frequency points for: δ (1.5–6 Hz), δ (6.5–8 Hz), α1 (8.5–10 Hz), α2 (10.5–12 Hz), β1 (12.5–18 Hz), β2 (18.5–21 Hz), and β3 (21.5–30 Hz). On the functional level, δ activity is reportedly associated with inhibitory patterns, δ and α activity with normal resting and routine function patterns, and β activity with excitatory patterns.

(b) Regional Omega Complexity (Wackermann, 1996, 1999) is a global, voltage- and frequency-independent, single-value measure of the complexity of multichannel EEG data assessing the degree of synchronization between spatially distributed processes. Given K electrodes, the multichannel EEG data can be viewed as a series of momentary maps whose trajectories can be represented over time in a K-dimensional state space. Omega complexity assesses the shape of the trajectory ('data cloud') in the state space. The method decomposes the data into spatial principal components: the shape of the trajectory (its 'complexity') is assessed by means of its extension along the principal axes. The $K \times K$ covariance matrix between the signals recorded from the K electrodes is computed, and its eigenvectors and eigenvalues evaluated. The eigenvectors represent the directions of principal axes in the state-space (i.e. the topography), whereas the eigenvalues represent the proportional contribution of a respective component to the total variance. Omega is then computed using the formula (Wackermann, 1996):

$$\Omega = \exp\left\{ - \sum_{i=1}^{K} \lambda'_i \log \lambda'_i \right\}$$

where K = numbers of channels, and λ'_i = i-th eigenvalue of the matrix divided by the sum of all eigenvalues (normalized i-th eigenvalue). Thus, Omega attains values from 1 (maximal synchronization of the signals at different locations) to K (maximal de-synchronization, i.e. no correlation, of the signals at different locations). In other words, higher Omega complexity indicates less synchronization between spatially distributed processes or the presence of a higher number of simultaneously active processes. [Note that log Omega corresponds to the 'entropy' of the spectrum of eigenvalues of the covariance matrix (Szelenberger et al., 1996]. Changes in Omega complexity were studied across the sleep-wakefulness cycle, as a function of pharmacological and sensorimotor stimulation as well as in relation to brain maturation and during different emotional states (for review, see Wackermann, 1999).

Applied to our data, the analysis proceeded as follows: the 35-channel EEG was first zero-centered in time (temporal DC offset removal) and space (spatial DC offset removal). For all artifact-free epochs, Omega complexity was evaluated separately for electrode arrays over the left (Fp1, AF3, F7, F3, FC5, FC1, T7, C3, CP5, CP1, P7, P3, PO3, O1, O9) and right hemisphere (Fp2, AF4, F8, F4, FC6, FC2, T8, C4, CP6, CP2, P8, P4, PO4, O2, O10). The 15×15 covariance matrices for all possible electrode pairs over a given hemisphere were computed, and their eigenvectors and eigenvalues were obtained, using Jacobi's diagonalization method. For every subject, the mean

Omega complexity value for the left and right hemisphere was computed and used for further analysis.

2.4. Statistics

For the FFT-Dipole-Approximation analysis, a global vector analysis was used to test for differences between believers and disbelievers. The analysis consisted of four steps (Kondakor et al., 1997; Pizzagalli et al., 1999, 2000). First, the mean source location for every frequency band was computed for believers and disbelievers separately. Second, the three-dimensional difference vector separating these mean locations was computed. Third, the source for every single subject was projected to the difference vector. Finally, differences in projections between believers and disbelievers were tested by a two-sample t-test. In cases of significant results in the global analysis, post-hoc t-tests assessed on which brain axis the groups differed.

Additionally, possible group differences in the model source strengths were tested for every independent EEG band using two-sample t-tests.

For the regional Omega complexity analysis, a two-way analysis of variance (ANOVA) with Group (believers vs. disbelievers) as between-subject factor, and Side (left vs. right hemisphere) as repeated measure was performed.

Two-tailed P-values are reported, throughout. Standard deviations are reported as measures of dispersion.

3. Results

3.1. Self-report measurements

In addition to their differential beliefs in paranormal phenomena, the two pre-selected subject groups also differed in their MI scores ($t_{29} = 8.06$, $P < 10^{-8}$), ASC scores ($t_{29} = 4.58$, $P < 10^{-5}$), and NA scores, as assessed with the PANAS scale ($t_{29} = 2.21$, $P = 0.035$; Table 1). The point-biserial correlation between the group assignment (believers vs. disbelievers) and the MI scores ($r_{pb} = 0.83$, $t_{29} = 8.02$, $P < 0.0001$), ASC scores ($r_{pb} = 0.65$, $t_{29} = 4.57$, $P < 0.0001$), and PANAS NA scores ($r_{pb} = 0.38$, $t_{29} = 2.21$, $P < 0.035$) were significant. Thus, the group designation explained ~69, 42 and 14% of the variance of the later assessed MI, ASC and PANAS NA scores.

3.2. FFT-dipole-approximation analysis

From a descriptive perspective (Fig. 2), believers had more anteriorly located sources for θ, $\alpha 2$, $\beta 2$ and $\beta 3$; more posteriorly located sources for δ, $\alpha 1$ and $\beta 1$; more left located sources for all bands except $\beta 2$ and $\beta 3$; and more inferior sources for all bands. We note that the general geometry of the different band sources was remarkably similar to that reported in previous studies of eyes-closed EEG during various conditions (Michel et al., 1992; Lehmann et al., 1993; Pizzagalli et al., 1999). In all of these studies, δ and θ sources were the most anterior and inferior, α sources were the most posterior and superior, and β sources were intermediate for both the anterior–posterior and superior–inferior brain axes.

The global vector analysis (Table 2) revealed significant differences between believers and disbelievers only in $\beta 2$ ($t_{29} = 2.30$, $P = 0.029$) and $\beta 3$ ($t_{29} = 2.60$, $P = 0.015$). For $\beta 2$, post-hoc tests showed that the effect was due to different source locations along the left–right brain axis ($t_{29} = 2.05$, $P = 0.049$): for believers, the $\beta 2$ source was located slightly to the right of the midline, whereas for disbelievers, it was located to the left of the midline (Fig. 2B). For $\beta 3$, however, the post-hoc tests failed to reveal any significant results (believers showed only trends for more anterior and inferior $\beta 3$ sources).

Analyses of model source strength revealed only statistical trends for $\alpha 2$ and $\beta 3$. In both cases, disbelievers displayed higher GFP values (in microvolts: $\alpha 2$: 19.77 ± 11.51 vs. 13.31 ± 9.41;

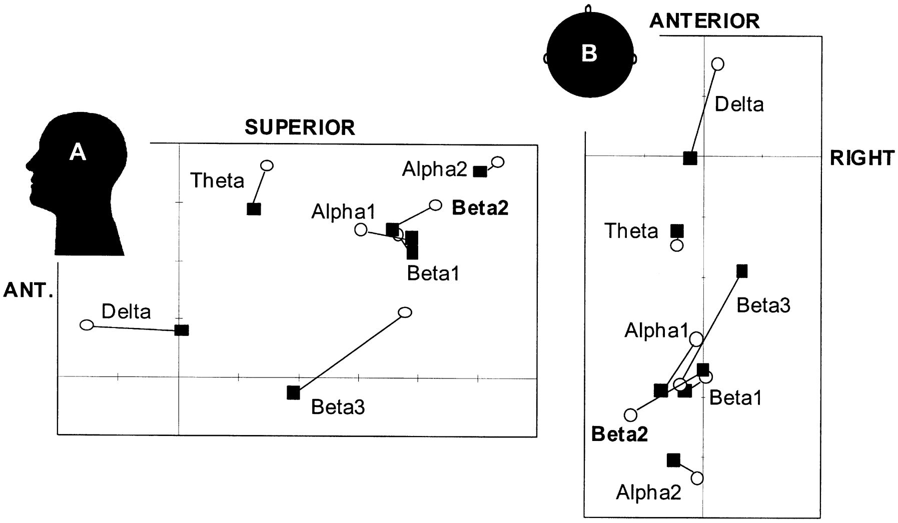

Fig. 2. Mean locations of the model sources for believers (black squares; $n = 17$) and disbelievers (open circles; $n = 14$) in paranormal phenomena for the seven independent frequency bands (δ: 1.5–6 Hz, θ: 6.5–8 Hz, α1: 8.5–10 Hz, α2: 10.5–12 Hz, β1: 12.5–18 Hz, β2: 18.5–21 Hz, and β3: 21.5–30 Hz). (A) Head seen from the left, showing the anterior (ANT.)-posterior and superior-inferior axes; (B) head seen from above, showing the left–right and anterior–posterior axes. Origin of coordinate system is near head center (tickmarks at 5-mm distances).

$t_{29} = 1.72$, $P = 0.096$; β3: 2.33 ± 0.67 vs. 1.95 ± 0.58; $t_{29} = 1.70$, $P = 0.10$).

3.3. Regional Omega complexity analysis

The ANOVA revealed a significant main effect of Side (left hemisphere: 4.14 ± 0.64 vs. right hemisphere: 3.98 ± 0.71; $F_{1,29} = 4.11$, $P = 0.05$) and a Group × Side interaction ($F_{1,29} = 3.02$, $P = 0.09$). Compared to disbelievers, believers had higher Omega complexity values over the right hemisphere (4.05 ± 0.70 vs. 3.91 ± 0.73; ns), but lower values over the left hemisphere (4.07 ± 0.55 vs. 4.21 ± 0.74; ns; Fig. 3). An alternative analysis tested for putative interhemispheric differences for the two subject groups separately. Omega asymmetry (left–right hemisphere) differed significantly from zero only for disbelievers (0.30 ± 0.45; left > right; $t_{13} = 2.45$, $P = 0.029$), whereas believers (0.02 ± 0.42; $t_{16} = 0.22$, $P > 0.8$) showed no significant interhemispheric differences. Analyses on the individual scores confirmed these patterns: eleven of 14 disbelievers [78.6%; binomial probability $P(11/14) = 0.022$], but only eight of 17 believers [47.05%; binomial probability $P(8/17) > 0.15$] had higher Omega complexity values for the left hemisphere ($\chi^2 = 3.21$, d.f. = 1, $P = 0.072$).

3.4. Additional analyses

As listed in Table 1, believers reported higher PANAS NA scores compared to disbelievers. Due to the fact that affective dimensions of personality influence asymmetrical patterns of brain electric activity (in general, increased right hemispheric activity is associated with more negative affect; Tomarken et al., 1992; Pizzagalli et al., 1999, 2000), the results reported here could have been confounded by differences in PANAS NA scores. To test this alternative hypothesis, Pearson correlations were computed between PANAS NA scores and the β2 source locations along the left-right brain axis, on one side, and the Omega complexity values for the left and right hemisphere, on the other side. For believers, disbelievers and for the entire sample, all correlations were clearly not significant (all $P > 0.30$).

Table 2
Mean locations across subjects (and S.D.) of the EEG model sources for believers ($n = 17$) and disbelievers ($n = 14$) in the seven independent frequency bands (in mm from origin of coordinate system near head center, see Section 2.3[a]

	(Hz)		Believers	Disbelievers	Difference	Vector
δ	(1.5–6)	A–P	−0.25 (13.47)	7.60 (20.88)	−7.85	
		L–R	1.08 (5.05)	−1.25 (5.90)	2.33	8.202
		S–I	3.95 (8.73)	4.39 (10.32)	−0.43	
θ	(6.5–8)	A–P	−6.25 (11.80)	−7.43 (12.27)	1.18	
		L–R	2.13 (7.08)	2.12 (7.12)	0.02	3.908
		S–I	14.37 (8.84)	18.09 (9.21)	−3.73	
α1	(8.5–10)	A–P	−19.52 (16.32)	−15.27 (10.64)	−4.24	
		L–R	3.43 (10.09)	0.54 (6.15)	2.89	5.180
		S–I	12.01 (11.22)	12.69 (10.87)	−0.67	
α2	(10.5–12)	A–P	−25.28 (12.77)	−26.69 (7.38)	1.41	
		L–R	2.42 (10.93)	0.40 (11.81)	2.02	2.617
		S–I	17.66 (10.90)	18.54 (8.82)	−0.88	
β1	(12.5–18)	A–P	−19.55 (8.94)	−18.39 (8.24)	−1.16	
		L–R	1.44 (6.49)	−0.27 (6.20)	1.70	2.585
		S–I	10.72 (10.67)	12.28 (6.92)	−1.56	
β2	(18.5–21)	A–P	−17.87 (8.79)	−21.50 (16.16)	3.63	
		L–R	−0.15 (7.55)	6.06 (9.44)	−6.21	7.509*
		S–I	12.68 (11.76)	14.85 (13.67)	−2.17	
β3	(21.5–30)	A–P	−9.60 (13.90)	−19.00 (22.78)	9.40	
		L–R	−3.38 (12.52)	1.82 (14.45)	−5.20	12.841*
		S–I	−1.42 (12.44)	5.62 (12.28)	−7.04	

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

Taken together, the results suggest that subjects differing in paranormal belief displayed different active, cerebral neural populations during resting conditions. Particularly, believers compared to disbelievers showed relatively higher right hemispheric activation and reduced hemispheric asymmetry of functional complexity.

4. Discussion

The present study was designed to investigate putative electrophysiological correlates of subjects' proclivity to generate and/or accept beliefs in paranormal phenomena. Adopting a three-dimensional EEG source modeling analysis procedure, we demonstrated that female participants reporting experiences with and belief in paranormal phenomena showed different intracerebral model sources compared to disbelievers during resting periods. Source modeling is reference-free and thus allows interpretations in terms of spatial distribution of brain activity. Intracerebral sources describe the three-dimensional center of gravity of all momentarily active neural assemblies. Because different center of gravity locations are indicative of different geometry of

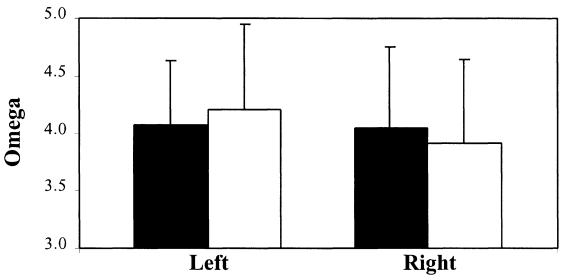

Fig. 3. Mean regional Omega complexity for believers (black bars; $n = 17$) and disbelievers (open bars; $n = 14$) in paranormal phenomena computed separately for the left and right hemisphere. Error bars denote standard deviations.

the active neural assemblies (Lehmann et al., 1993), we conclude that the two subject groups were in a different brain functional state during the baseline recording. Strong belief and skepticism in paranormal phenomena was associated with β2 sources located to the right and left, respectively, of the midline. In subjects with strong paranormal belief, a more right-located center of gravity for excitatory activity (β band) was indicative of a pattern of increased brain electric activity in the right hemisphere. The left-located β2 sources for disbelievers and the right-located sources for believers parallel those demonstrated in a prior study investigating schizophrenic and control subjects using FFT-dipole-approximation analysis (Michel et al., 1993). In this previous study, the model source for the β2 band (19.0–22.5 Hz) was to the right of the midline for patients and to the left for controls.

The source localization results were nicely complemented by those achieved with a linear complexity analysis of the map series' trajectories in state space (Wackermann, 1996, 1999). This analysis demonstrated that believers showed no significant interhemispheric differences of functional complexity, whereas disbelievers showed clearly higher complexity over the left brain hemisphere. The linear (covariance) measure of complexity assesses the number of independent processes within the brain: Increased regional complexity is indicative of more independent, parallel active processes. It is therefore concluded that believers showed a less pronounced hemispheric asymmetry of functional complexity than disbelievers.

The present electrophysiological results agree with and extend prior behavioral findings stressing a link between: (a) paranormal and schizotypal ideation; and (b) patterns of reduced functional asymmetries or right hemispheric processing bias (Broks, 1984; Rawlings and Claridge, 1984; Brugger and Graves, 1997a; Brugger et al., 1993a,b; Poreh et al., 1993, 1994; Gruzelier and Doig, 1996; Kravetz et al., 1998; Leonhard and Brugger, 1998; Luh and Gooding, 1999). We previously suggested that a relative overactivation of the right hemisphere may constitute the neuropsychological basis for schizotypal and paranormal ideation (Leonhard and Brugger, 1998; Pizzagalli et al., in press). This hypothesis was formulated after review of the neuropsychological literature indicating differential associative processing peculiarities of the two cerebral hemispheres, the left hemisphere being more activated during processing of close semantic relations, and the right hemisphere being more involved in processing of remote semantic relations (for extensive review, see Beeman and Chiarello, 1998). In schizotypal subjects, a relatively increased activation of the right hemisphere may lead to overreliance on its semantic processing characteristics, and thus to overestimation of the meaningfulness of naturally occurring coincidental events (Brugger and Graves, 1997b; Houran and Lange, 1998), which may in turn favor the formation of magical and paranormal belief. Noteworthy, in a sub-sample of the present subjects, we found that subjects with strong paranormal belief showed faster appreciation of distant semantic relations (i.e. stronger indirect priming effects), but only when the words were initially presented to the right hemisphere (Pizzagalli et al., in press). The emergence of 'loose' associations was explained by a relative overreliance on unfocused activation within right hemisphere semantic networks. The present EEG complexity results furnish strong support for this hypothesis due to the fact that increased EEG complexity is generally interpreted as an index of decreased (loosened) cooperation of different neural systems (or conversely, increased independence; Koukkou et al., 1993; Saito et al., 1998; Wackermann, 1999).

We previously argued that a relative overreliance on unfocused activation within right hemisphere semantic networks might also favor the emergence of a creative style of thinking (for review, see Leonhard and Brugger, 1998). Accordingly, it appears that two different peculiarities of paranormal and schizotypal ideation that have been traditionally discussed in the literature, one with negative connotation (psychosis proneness) and one with positive connotation (creative thinking), may share common biological mechanisms. From an evolutionary perspective, magical and paranormal beliefs (i.e. seeing connections between things that are in fact unrelated) would seem to be the price we have to pay for a highly developed, creative pattern-detection system. In terms of signal detection theory, creative detection of meaningful pattern against a background of (sensory or linguistic) noise must be conceived of as 'hits', whereas 'false alarms' would refer to the erroneous assumption of the presence of meaningful signals (visual or semantic, cf. Brugger and Graves, 1997b).

Structural (Kwon et al., 1999), electrophysiological (Bruder et al., 1999) and behavioral (Green et al., 1994) studies consistently demonstrated left-hemispheric dysfunction in schizophrenia, a finding recently extended to schizotypal personality disorder (Dickey et al., 1999). Such abnormalities were especially evident in patients with positive symptomatology (e.g. hallucinations; Barta et al., 1990) and in the left temporal regions, leading to a decreased or absent left hemispheric dominance in language processing (for review, see Crow, 1997). We do not expect such dramatic changes in our sample of well-functioning university students. However, within the framework of a diathesis-stress model of psychosis (Meehl, 1962; Chapman et al., 1994), we interpret a relatively increased right hemispheric activation in hypothetically psychosis-prone subjects as a necessary but by no means sufficient precondition for later psychotic development. Further research is needed to evaluate if the combination of a chronically overactivated right hemisphere and environmental stress may eventually impair left-hemisphere functionality.

The present female participants with paranormal experiences and beliefs also scored significantly higher on a questionnaire asking for other forms of magical ideation. This inventory, the 'Magical Ideation' scale (Eckblad and Chapman, 1983), was originally introduced as an 'indicator of schizotypy'. While believers' mean scores (14.6 $\pm$ 3.8) were in fact higher than those reported for a sample of healthy female college student (9.7 $\pm$ 5.9, Garety and Wesseley, 1994), the disbelievers' magical ideation scores were considerably lower (4.4 $\pm$ 3.0). Believers also reported more general negative affect and more hypnagogic-like reveries after a short resting period with eyes closed. While the former result may be interpreted as indexing anhedonic components in subjects with schizotypal/paranormal ideation (see Chapman et al., 1994; Kwapil et al., 1999), the latter is reminiscent of prior findings of a link between paranormal belief and proneness to dissociation (Irwin, 1994; Wolfradt, 1997). Specifically, the present results extend prior studies suggesting an association between proneness to dissociate and relative right hemispheric activation. Indeed, McCreery and Claridge (1996) reported that proneness to experience 'out-of-the-body' experience was linked to EEG indexes of relative activation of the right hemisphere and heightened inter-hemispheric coherence, while Persinger and coworkers found a relation between reports of vestibular-auditory experiences, space-time distortions, belief in spiritism, history of sensed presence and ego-alien intrusions, and EEG indices of right temporal lobe function (Lavallee and Persinger, 1992; Persinger, 1993). Anatomically, in the present data, the occurrence of hypnagogic-like reveries (especially perceptual distortion and body schema alterations) may well be associated with right parietal activation (cf. Saver and Rabin, 1997).

The present study presents two major limitations. First, only female participants were investigated. Since gender is a potential confounding factor in schizotypy (Gruzelier and Doig, 1996), future research is needed to extend the present findings to male subjects. Second, the study is correlational in its nature. Thus, the causal relationships between paranormal belief and EEG parameters cannot be assessed.

Summarizing, the present study demonstrated that subjects differing in their declared belief in and experience with paranormal phenomena as well as in their schizotypal ideation, as determined by a standardized instrument, displayed differential brain electric activity during resting periods. Believers in the paranormal were characterized by a relatively increased right hemispheric activation and by a reduced hemispheric asymmetry of functional complexity. These results furnish direct electrophysiological support for a neuropsychologically oriented model of schizotypal and paranormal ideation, where a link between overactivation of the right hemisphere and schizotypal/paranormal ideation is emphasized (Leonhard and Brugger, 1998; Pizzagalli et al., in press). Demonstration of specific patterns of hemispheric organization in putatively psychosis-prone subjects is important for psychiatric research because it may help identify subtle neurocognitive peculiarities prior to a potential exacerbation. More generally, the present results should be interpreted as an attempt to better understand the neurophysiological correlates of subtle differences in how people evaluate and conceptualize the 'functioning of the world'. Demonstrating neurophysiological substrates of belief in paranormal phenomena does not automatically demean the contents of these personal beliefs. Thus, the possibility of 'abnormal' phenomena is neither confirmed nor disconfirmed by demonstrations of brain correlates of belief in the paranormal (see Saver and Rabin, 1997 for a similar conceptualization).

Acknowledgements

This study was supported by the Institut für Grenzgebiete der Psychologie und Psychohygiene, Freiburg i. Br., Germany (Grants *n*67 13 10 to PB, DP and DL and *n*67 08 06 to DL). The authors wish to thank five anonymous reviewers for constructive comments.

Appendix A

Six-item questionnaire assessing belief in and experience of paranormal phenomena (translated from Mischo et al., 1993)

	Definitively true			Definitively false
I had at least one telepathic experience with another person	□	□	□	□
I never had any extrasensory perceptions[a]	□	□	□	□
I had at least once a presentiment that became true and that I thought it was not due to chance	□	□	□	□
I think telepathy exists	□	□	□	□
Some dreams refer to future incidences, which cannot be known before	□	□	□	□
I had at least one dream that referred to the future and that fulfilled so exactly that I think it was not due to chance	□	□	□	□

[a] Reversed scoring.

Appendix B

Nineteen-item questionnaire assessing personal experiences (hypnagogic-type reveries) during eyes-closed resting conditions (adapted from scales on altered states of consciousness: Dittrich et al., 1985, and hallucination proneness: Launay and Slade, 1981)

When I had my eyes closed, I saw	Points, flashes, or colors	☐ Yes	☐ No
	Patterns	☐ Yes	☐ No
	Images	☐ Yes	☐ No
	Moving scenes	☐ Yes	☐ No
I had the impression I heard	Words coming from myself	☐ Yes	☐ No
	Music coming from myself	☐ Yes	☐ No
I had sudden thoughts that were unrelated to previous ones		☐ Yes	☐ No
My body feeling was altered		☐ Yes	☐ No
I had the feeling I was levitating		☐ Yes	☐ No
My spatial orientation in the room was unsure		☐ Yes	☐ No
I felt	Happiness	☐ Yes	☐ No
	Sadness	☐ Yes	☐ No
	Tension	☐ Yes	☐ No
	Fear	☐ Yes	☐ No
I had deeper insights in the world		☐ Yes	☐ No
I had the feeling that everything around me was somewhat unreal		☐ Yes	☐ No
I had the feeling I could think quicker and clearer than usual		☐ Yes	☐ No
I experienced past, present and future as an entity		☐ Yes	☐ No
I had the feeling I was dreaming		☐ Yes	☐ No

References

American Psychiatric Association, 1994. Diagnostic and Statistical Manual of Mental Disorders, 4th ed. American Psychiatric Press, Washington DC.

Barta, P.E., Pearlson, G.D., Powers, R.E., Richards, S.S., Tune, L.E., 1990. Auditory hallucinations and smaller superior temporal gyral volume in schizophrenia. American Journal of Psychiatry 147, 1457–1462.

Beaton, A., 1985. Left Side, Right Side: A Review of Laterality Research. Batsford, London.

Beeman, M., Chiarello, C., 1998. Right Hemisphere Language Comprehension: Perspectives from Cognitive Neuroscience. Lawrence Erlbaum Associates, Mahwah, NJ.

Bracha, H.S., Livingston, R.L., Clothier, J., Linington, B.B., Karson, C.N., 1993. Correlation of severity of psychiatric patients' delusions with right hemispatial inattention (left-turning behavior). American Journal of Psychiatry 150, 330–332.

Broks, P., 1984. Schizotypy and hemisphere function—II. Performance asymmetry on verbal divided visual-field tasks. Personality and Individual Differences 5, 649–656.

Bruder, G., Kayser, J., Tenke, C., Amador, X., Friedman, M., Sharif, Z., Gorman, J., 1999. Left temporal lobe dysfunction in schizophrenia: event-related potential and behavioral evidence from phonetic and tonal dichotic listening tasks. Archives of General Psychiatry 56, 267–276.

Brugger, P., in press. From haunted brain to haunted science: a cognitive neuroscience view of paranormal and pseudoscientific thought. In: Houran, J., Lange, R., (Eds.), Spirited Exchanges: Multidisciplinary Perspectives on Hauntings and Poltergeists. McFarland, Jefferson, NC.

Brugger, P., Gamma, A., Muri, R., Schäfer, M., Taylor, K., 1993a. Functional hemispheric asymmetry and belief in ESP: towards a 'neuropsychology of belief'. Perceptual and Motor Skills 77, 1299–1308.

Brugger, P., Graves, R.E., 1997a. Right hemispatial inattention and magical ideation. European Archives of Psychiatry and Clinical Neuroscience 247, 55–57.

Brugger, P., Graves, R.E., 1997b. Testing vs. believing hypotheses: magical ideation in the judgements of contingencies. Cognitive Neuropsychiatry 2, 251–272.

Brugger, P., Regard, M., Landis, T., Cook, N., Krebs, D., Niederberger, J., 1993b. 'Meaningful' patterns in visual noise: effects of lateral stimulation and the observer's belief in ESP. Psychopathology 26, 261–265.

Chapman, J.P., Chapman, L.J., 1987a. Handedness of hypothetically psychosis-prone subjects. Journal of Abnormal Psychology 96, 89–93.

Chapman, L.J., Chapman, J.P., 1987b. The measurement of handedness. Brain and Cognition 6, 175–183.

Chapman, L.J., Chapman, J.P., Kwapil, T.R., Eckblad, M., Zinser, M.C., 1994. Putatively psychosis-prone subjects 10 years later. Journal of Abnormal Psychology 103, 171–183.

Claridge, G., Broks, P., 1984. Schizotypy and hemisphere function—I. Theoretical considerations and the measurement of schizotypy. Personality and Individual Differences 5, 633–648.

Coleman, M.J., Levy, D.L., Lenzenweger, M.F., Holzman, P.S., 1996. Thought disorder, perceptual aberrations, and schizotypy. Journal of Abnormal Psychology 105, 469–473.

Crow, T.J., 1997. Schizophrenia as failure of hemispheric dominance for language. Trends in Neuroscience 20, 339–343.

Dickey, C.C., McCarley, R.W., Voglmaier, M.M, Niznikiewicz, M.A., Seidman, L.J., Hirayasu, Y., Fischer, I., Teh, E.K., Van Rhoads, R., Jakab, M., Kikinis, R., Jolesz, F.A., Shenton, M.E., 1999. Schizotypal personality disorder and MRI abnormalities of temporal lobe gray matter. Biological Psychiatry 45, 1393–1402.

Dierks, T., Ihl, R., Frölich, L., Maurer, K, 1993. Dementia of the Alzheimer type: effects on the spontaneous EEG described by dipole sources. Psychiatry Research 50, 151–162.

Dierks, T., Jelic, V., Julin, P., Shigeta, M., Valind, S., Maurer, K., Winblad, B., Wahlund, L.O., Nordberg, A., 1997. Correlation between intracerebral equivalent EEG generators and cerebral glucose metabolism. Brain Topography 10, S57.

Dittrich, A., von Arx, S., Staub, S., 1985. International study on altered states of consciousness (ISASC): Summary of the results. German Journal of Psychology 9, 319–339.

Duchêne, A., Graves, R.E., Brugger, P., 1998. Schizotypal thinking and associative processing: a response commonality analysis of verbal fluency. Journal of Psychiatry and Neuroscience 23, 56–60.

Eckblad, M., Chapman, L.J., 1983. Magical ideation as an indicator of schizotypy. Journal of Consulting and Clinical Psychology 51, 215–225.

Fernandes, L.O.L., Keller, J., Giese-Davis, J.E., Hicks, B.D., Klein, D.N., Miller, G.A., 1999. Converging evidence for a cognitive anomaly in early psychopathology. Psychophysiology 36, 511–521.

Garety, P., Wesseley, S., 1994. The Assessment of Positive Symptoms. In: Barnes, T.R.E., Nelson, H.E. (Eds.), The Assessment of Psychoses. A Practical Handbook. Chapman and Hall, London, pp. 21–39.

Green, M.F., Hugdahl, K., Mitchell, S., 1994. Dichotic listening during auditory hallucinations in patients with schizophrenia. American Journal of Psychiatry 151, 357–362.

Gruzelier, J.H., Burgess, A., Stygall, J., Irving, G., Raine, A., 1995. Patterns of cognitive asymmetry and syndromes of schizotypal personality. Psychiatry Research 56, 71–79.

Gruzelier, J.H., Doig, A., 1996. The factorial structure of schizotypy: Part II. Cognitive asymmetry, arousal, handedness and sex.. Schizophrenia Bulletin 22, 621–634.

Harvey, S.A., Nelson, E., Haller, J.W., Early, T.S., 1993. Lateralized attentional abnormality in schizophrenia is correlated with severity of symptoms. Biological Psychiatry 33, 93–99.

Hazlett, E.A., Dawson, M.E., Filion, D.L., Schell, A.M., Nuechterlin, K.H., 1997. Autonomic orienting and the allocation of processing resources in schizophrenia patients and putatively at-risk individuals. Journal of Abnormal Psychology 106, 171–181.

Houran, J., Lange, R., 1998. Modeling precognitive dreams as meaningful coincidences. Psychological Reports 83, 1411–1414.

Irwin, H.J., 1993. Belief in the paranormal: a review of the empirical literature. Journal of the American Society for Psychical Research 87, 1–40.

Irwin, H.J., 1994. Paranormal belief and proneness to dissociation. Psychological Reports 75, 1344–1346.

Jutai, J.W., 1989. Spatial attention in hypothetically psychosis-prone college students. Psychiatry Research 27, 207–215.

Kelley, M.P., Coursey, R.D., 1992. Lateral preference and neuropsychological correlates of schizotypy. Psychiatry Research 41, 115–135.

Kondakor, I., Brandeis, D., Wackermann, J., Kochi, K., Koenig, T., Frei, E., Pascual-Marqui, R.D., Yagyu, T., Lehmann, D., 1997. Multichannel EEG fields during and without visual input: frequency domain model source locations and dimensional complexities. Neuroscience Letters 226, 49–52.

Koukkou, M., Lehmann, D., Wackermann, J., Dvorak, I., Henggeler, B., 1993. Dimensional complexity of EEG brain mechanisms in untreated schizophrenia. Biological Psychiatry 33, 397–407.

Kravetz, S., Faust, M., Edelman, A., 1998. Dimensions of schizotypy and lexical decision in the two hemispheres. Personality and Individual Differences 25, 857–871.

Kubicki, S., Hermann, W.M., Fichte, K., Freund, G., 1979. Reflections on the topics: EEG frequency bands and regulation of vigilance. Pharmacopsychiatry 12, 237–245.

Kwapil, T.R., Chapman, J.P., Chapman, L.J., Miller, M.B., 1996. Deviant olfactory experiences as indicators of risk for psychosis. Schizophrenia Bulletin 22, 371–382.

Kwapil, T.R., Chapman, L.J., Chapman, J.P., 1999. Validity and usefulness of the Wisconsin Manual for assessing psychotic-like experiences. Schizophrenia Bulletin 25, 363–375.

Kwon, J.S., McCarley, R.W., Hirayasu, Y., Anderson, J.E., Fischer, I.A., Kikinis, R., Jolesz, F.A., Shenton, M.E., 1999. Left planum temporale volume reduction in schizophrenia. Archives of General Psychiatry 56, 142–148.

Lantz, G., Michel, C.M., Seeck, M., Blanke, O., Landis, T., Rosen, I., 1999. Frequency domain EEG source localization of ictal epileptiform activity in patients with partial complex epilepsy of temporal lobe origin. Clinical Neurophysiology 110, 176–184.

Launay, G., Slade, P., 1981. The measurement of hallucinatory predisposition in male and female prisoners. Personality and Individual Differences 2, 221–234.

Lavallee, M.R., Persinger, M.A., 1992. Left ear (right temporal lobe) suppressions during dichotic listening, ego-alien intrusion experiences and spiritualistic beliefs in normal women. Perceptual & Motor Skills 75, 547–551.

Lehmann, D., Henggeler, B., Koukkou, M., Michel, C.M., 1993. Source localization of brain electric field frequency bands during conscious, spontaneous, visual imagery and abstract thought. Cognitive Brain Research 1, 203–210.

Lehmann, D., Michel, C.M., 1990. Intracerebral dipole source localization for FFT power maps. Electroencephalography & Clinical Neurophysiology 76, 271–276.

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

Lenzenweger, M.F., 1991. Confirming schizotypic personality configurations in hypothetically psychosis-prone university students. Psychiatry Research 37, 81–96.

Lenzenweger, M.F., 1994. The psychometric high-risk paradigm, perceptual aberrations, and schizotypy: an update. Schizophrenia Bulletin 20, 121–135.

Leonhard, D., Brugger, P., 1998. Creative, paranormal, and delusional thought: a consequence of right hemisphere semantic activation? Neuropsychiatry, Neuropsychology and Behavioral Neurology 11, 177–183.

Luh, K.E., Gooding, D.C., 1999. Perceptual biases in psychosis-prone individuals. Journal of Abnormal Psychology 108, 283–289.

Lütkenhöner, B., 1992. Frequency-domain localization of intracerebral dipolar sources. Electroencephalography & Clinical Neurophysiology 82, 112–118.

McCreery, C., Claridge, G., 1996. A study of hallucination in normal subjects. 2. Electrophysiological data. Personality and Individual Differences 21, 749–758.

Meehl, P.E., 1962. Schizotaxia, schizotypy, schizophrenia. American Psychologist 17, 827–838.

Michel, C.M., Koukkou, M., Lehmann, D., 1993. EEG reactivity in high and low symptomatic schizophrenics, using source modelling in the frequency domain. Brain Topography 5, 389–394.

Michel, C.M., Lehmann, D., Henggeler, B., Brandeis, D., 1992. Localization of the sources of EEG delta, theta, alpha and beta frequency bands using the FFT dipole approximation. Electroencephalography & Clinical Neurophysiology 82, 38–44.

Mischo, J., Boller, E., Braun, G., 1993. Fragebogenuntersuchung zur Erfassung von okkulten Glaubenshaltungen und Merkmalen schizotypischer Verarbeitung. Unpublished manuscript, Institut für Grenzgebiete der Psychologie und Psychohygiene, Freiburg.

Mohr, C., Röhrenbach, C.M., Laska, M., Brugger, P., in press. Unilateral olfactory perception and magical ideation. Schizophrenia Research.

Overby, L.A., 1992. Perceptual asymmetry in psychosis-prone college students: evidence for left-hemispheric overactivation. Journal of Abnormal Psychology 101, 96–103.

Persinger, M.A., 1993. Vectorial cerebral hemisphericity as differential sources for the sensed presence, mystical experiences and religious conversions. Perceptual & Motor Skills 76, 915–930.

Pizzagalli, D., Koenig, T., Regard, M., Lehmann, D., 1999. Affective attitudes to face images associated with intracerebral EEG source location before face viewing. Cognitive Brain Research 7, 371–377.

Pizzagalli, D., Lehmann, D., Koenig, T., Regard, M., Pascual-Marqui, R.D., 2000. Face-elicited ERPs and affective attitude: brain electric microstate and tomography analyses. Clinical Neurophysiology 111, 521–531.

Pizzagalli, D., Lehmann, D., Brugger, P., in press. Lateralized direct and indirect semantic priming effects in subjects with paranormal experiences and beliefs. Psychopathology.

Poreh, A.M., Whitman, D.R., Ross, T.P., 1993, 1994. Creative thinking abilities and hemispheric asymmetry in schizotypal college students. Current Psychology 12, 344–352.

Rawlings, D., Claridge, G., 1984. Schizotypy and hemisphere function—III. Performance asymmetries on tasks of letter recognition and local-global processing. Personality and Individual Differences 5, 657–663.

Saito, N., Kuginuki, T., Yagyu, T., Kinoshita, T., Koenig, T., Pascual-Marqui, R.D., Kochi, K., Wackermann, J., Lehmann, D., 1998. Global, regional, and local measures of complexity of multichannel electroencephalography in acute, neuroleptic-naive, first-break schizophrenics. Biological Psychiatry 43, 794–802.

Saver, J.L., Rabin, J., 1997. The neural substrates of religious experience. Journal of Neuropsychiatry and Clinical Neurosciences 9, 498–510.

Schienle, A., Vaitl, D., Stark, R., 1996. Covariation bias and paranormal belief. Psychological Reports 78, 291–305.

Szelenberger, W., Wackermann, J., Skalski, M., Niemcewicz, S., Drojewski, J., 1996. Analysis of complexity of EEG during sleep. Acta Neurobiologiae Experimentalis 56, 165–169.

Tallent, K.A., Gooding, D.C., 1999. Working memory and Wisconsin Card Sorting Test performance in schizotypic individuals: a replication and extension. Psychiatry Research 89, 161–170.

Tesche, C.D., Uusitalo, M.A., Ilmoniemi, R.J., Kajola, M.J., 1995. Characterizing the local oscillatory content of spontaneous cortical activity during mental imagery. Cognitive Brain Research 2, 243–249.

Thalbourne, M.A., 1994. Belief in the paranormal and its relationship to schizophrenia-relevant measures: a confirmatory study. British Journal of Clinical Psychology 33, 78–80.

Tobacyk, J., Milford, G., 1983. Belief in paranormal phenomena: assessment instrument development and implications for personality functioning. Journal of Personality and Social Psychology 44, 1029–1037.

Tomarken, A.J., Davidson, R.J., Wheeler, R.E., Doss, RC., 1992. Individual differences in anterior brain asymmetry and fundamental dimensions of emotion. Journal of Personality and Social Psychology 62, 676–687.

Valdes, P., Bosch, J., Grave, R., Hernandez, J., Riera, J., Pascual, R., Biscay, R., 1992. Frequency domain models of the EEG. Brain Topography 4, 309–319.

Verdoux, H., van Os, J., Maurice-Tison, S., Gay, B., Salamon, R., Bourgeois, M., 1998. Is early adulthood a critical developmental stage for psychosis proneness? A survey of delusional ideation in normal subjects. Schizophrenia Research 29, 247–254.

Wackermann, J., 1996. Beyond mapping: estimating complexity of multichannel EEG recordings. Acta Neurobiologiae Experimentalis 56, 197–208.

Wackermann, J., 1999. Towards a quantitative characterisation of functional states of the brain: from the non-linear methodology to the global linear description. International Journal of Psychophysiology 34, 65–80.

Watson, D., Clark, L.A., Tellegen, A., 1988. Development and validation of brief measures of positive and negative affect: the PANAS scales. Journal of Personality and Social Psychology 54, 1063–1070.

Wolfradt, U., 1997. Dissociative experiences, trait anxiety and paranormal beliefs. Personality and Individual Differences 23, 15–19.