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ORIGINAL PAPER

Memories of attachment hamper EEG cortical connectivity in dissociative patients

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Abstract In this study, we evaluated cortical connectivity modifications by electroencephalography (EEG) lagged coherence analysis, in subjects with dissociative disorders and in controls, after retrieval of attachment memories. We asked thirteen patients with dissociative disorders and thirteen age- and sex-matched healthy controls to retrieve personal attachment-related autobiographical memories through adult attachment interviews (AAI). EEG was recorded in the closed eyes resting state before and after the AAI. EEG lagged coherence before and after AAI was compared in all subjects. In the control group, memories of attachment promoted a widespread increase in EEG connectivity, in particular in the high-frequency EEG bands. Compared to controls, dissociative patients did not show an increase in EEG connectivity after the AAI. Conclusions: These results shed light on the neurophysiology of the disintegrative effect of retrieval of traumatic attachment memories in dissociative patients.

Keywords EEG connectivity · Adult attachment interview · Dissociative disorders · Unresolved/disorganized attachment · EEG coherence

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Introduction

The term dissociation in psychiatry is used to identify the outcomes of pathogenetic processes which cause the interruption or alteration of high-level integrative mental functions such as self-identity, memory, perception of the external world and control of bodily movements [1–3]. Many researchers and clinicians have extended the consequences of dissociation to alterations in other integrative functions such as affect regulation, control of behavior and impulses; body image, metacognitive monitoring and consistency in autobiographical narratives [4–8]. Contemporary scholars derived this “disintegrative” concept from Pierre Janet who first indicated it as the major pathogenetic mechanism of dissociation: the disconnection (*désagrégation*) of the normally overlapping and integrated different functional levels of the mind, when caused by violent emotions related to traumatic experiences [1, 3, 9–11]. Van der Hart et al. [12] remark that according to Janet, the violent emotions inherent in traumatic memories have a disintegrating effect manifesting in “the dissociation and emancipation of the systems of ideas and functions that constitute personality (Janet, 1907, p. 332).”

Liotti [13, 14] suggested that frightened, frightening or dissociative behavior exhibited by attachment figures, being frightening to infants [15], could be a risk factor for the loss of integration involved in dissociative symptoms and disorders. Research on infant attachment disorganization and its sequels supported this suggestion, providing evidence that disorganization of early attachment predicts dissociation in later years [16]. Theoretical, neuroscientific and clinical studies suggest that attachment disorganization is an early relational trauma that causes vulnerability to dissociative psychopathology by hampering the development of integrative mental functions [1, 7, 17–22]. A growing number of studies have reported that the unresolved/disorganized category appears to be overrepresented in clinical samples [23], especially in adults with disorders characterized by dissociative processes [8, 18, 21, 24, 25]. Besides the dissociative disorders, borderline personality disorder (BPD), conversion disorder (CD) and post-traumatic stress disorder (PTSD) qualify among those characterized by dissociative processes and symptoms, as it is suggested by recent studies of BPD [11] and CD [26, 27], and by the inclusion of a dissociative subtype of PTSD in the DSM-5 [28]. Although only preliminary data on adults with disorders characterized by dissociative symptoms are as yet available [29], several studies have found association between unresolved or cannot classify adult attachment interviews (AAIs) categories (linked to traumatic attachment) and dissociative symptoms in patient samples [30–32]. It has been argued, on clinical and theoretical grounds, that memories of early relational trauma exert their influence on dissociative processes in adult disorders in moments of daily life when the attachment motivational system is activated by stimuli such as pain, fatigue, fear or strong emotional memories of moments when one felt intense attachment needs [33].

To begin to test this hypothesis, we decided to use the AAI [34] as a stimulus capable of activating the attachment system both at the cognitive and emotional levels through an intensive series of inquiries into participants' relational histories with their childhood attachment figures [35, 36], and electroencephalography (EEG) connectivity as an index of integrative and disintegrative processes in the brain and in the mind.

Over the last decade, many researchers have demonstrated the role of widely distributed cortical networks in underpinning higher-order integrative mental functions [37, 38]. These networks are conceived as dynamic states of the cerebral cortex, characterized by a high degree of functional connectivity between widely distributed neurons. They can be measured with non-invasive methods such as EEG coherence [39]. In particular, dynamic cortical connectivity networks are considered to play a crucial role in high-level cognitive functions: working memory, top-down executive functions, attentive tasks and consciousness [37, 38, 40]. There is growing evidence that "the functional integration of information through neural synchrony shapes the level and content of consciousness and contributes to the emergence of coherent cognition and perception and, thereby, the phenomenal unity of consciousness" [38]. The efficiency of these neuronal networks has also been considered to be an important index of cortical development [39], and their impairment has been found in individuals with adverse early life experiences [41]. Impairments in cortical connectivity revealed by EEG have been found in neurologic and psychiatric disorders [42, 43]. Hopper et al. [43] found significantly lower EEG coherence in alter personality of dissociative identity disorder (DID) compared to the so-called host personality. Bob et al. [44] recently confirmed a relationship between dissociative symptoms and decreased synchronization of neural networks in schizophrenic patients in resting state.

Despite the fact that most modern neurobiological dissociation models involve the idea that dissociation relates to a disruption of functional cortical connectivity [10, 38, 45], to the best of our knowledge, to date, their have been no studies that have explored EEG connectivity after an attachment-related emotional stimulus in people with dissociative disorders.

We planned to measure EEG cortical connectivity after retrieval of attachment memories collected during AAI both in a control group and patients with dissociative disorders. We hypothesized that in dissociative patients, attachment memories lead to modifications of EEG cortical connectivity related to the impairment of high integrative mental functions.

Methods and materials

Participants

Thirteen consecutive patients with disorders characterized by severe dissociative symptoms from a psychiatric outpatients clinic were enrolled, six men and seven women, aged 24–60 years (mean age 40.92 ± 11.02). All patients received a complete psychiatric interview performed by a trained psychiatrist (BF) and were diagnosed according to the DSM-IV TR criteria [2]. A control group of healthy subjects (with no Axis I and II DSM-IV diagnosis) matched for age and gender was also included (six men and seven women, aged 28–65 years, mean age 37.01 ± 12.08). The demographic details and diagnosis of the subjects enrolled in the study are listed in Table 1.

The exclusion criteria for both patients and the control group were as follows: left handedness, history of medical or neurologic diseases, head trauma, consumption of central nervous system active drugs in the 3 weeks prior to the study and presence of EEG abnormalities at the baseline recording.

Patients and the control group all gave their written informed consent to participate in the study that was performed according to the Helsinki declaration standards and that was approved by the Catholic University in Rome's local Ethical Committee.

Procedure

At recruitment, all patients and controls were informed about the study's aims and procedures and received

Table 1 Diagnosis and AAI classifications

Patients					Controls				
	Age	Sex	Diagnosis	AAI		Age	Sex	Diagnosis	AAI
1	24	M	CD, dissociative amnesia	U/F2/F4	1	48	F	n.a.	U/E1/E2
2	30	F	DID	U/CC/E1/E2/Ds2	2	33	F	n.a.	F3/F4
3	44	M	PTSD, dissociative amnesia	U/CC/E2/Ds2	3	30	F	n.a.	Ds3
4	31	F	MD, depersonalization disorder	Ds1	4	25	F	n.a.	F4
5	47	M	APD, DDNOS	U/E1/E2	5	29	M	n.a.	F2
6	42	M	BPD, depersonalization disorder	U/E3/E1	6	28	F	n.a.	F5/F4/F2
7	52	M	DDNOS	U/CC/E2/Ds2	7	32	M	n.a.	F2/F4
8	42	F	Dissociative amnesia	U/CC/E2/E1/Ds3	8	29	F	n.a.	F4/F2
9	23	F	CD, dissociative amnesia	U/CC/E1/Ds3/F5	9	36	F	n.a.	F4/F2
10	50	F	SD, depersonalization disorder	U/E1/E2	10	28	M	n.a.	F4
11	43	M	DDNOS	U/CC/E2/E1/Ds2	11	53	M	n.a.	Ds3
12	44	F	PTSD, BPD, DDNOS	U/CC/E1/Ds3/E2	12	65	M	n.a.	F2/F4
13	60	F	PTSD, dissociative amnesia	U/CC/E1/E3/Ds2	13	45	M	n.a.	Ds3

CD conversion disorder, *DID* dissociative identity disorder, *PTSD* post-traumatic stress disorder, *MD* major depression, *APD* avoidant personality disorder, *DDNOS* dissociative disorder not otherwise specified, *BPD* borderline personality disorder, *SD* somatoform disorder, *F* secure/autonomous, *Ds* dismissing, *E* preoccupied, *U* unresolved with respect to loss or trauma, *CC* cannot classify

psychiatric, medical and psychometric evaluations. After recruitment, on a separate day from the initial evaluation, all participants underwent AAI as activating stimulus of the attachment behavioral system. Trained clinical psychologists (CT, CMV) administered the AAI in the morning in a quiet and comfortable room. EEG and psychophysiological indices (EKG, skin conductance) recordings were performed before, during and after the interviews (for more details see the "EEG recordings" paragraph). The interviews lasted on average 1.5 h.

Self-report scales

The 20-item Somatoform Dissociation Questionnaire is a self-administered instrument with good psychometric characteristics that evaluates the severity of somatoform dissociation [26, 46]. The SDQ-20 assesses positive symptoms as site-specific pain and negative symptoms as blindness, impairment of auditory perception, motor inhibitions, kinesthetic anesthesia and analgesia. Items are answered on a five-point scale, ranging from 1 = this applies to me not at all to 5 = this applies to me extremely. Items are summed to provide a total score (range 20–100). Subjects were asked to respond with reference to a time frame of the preceding 12 months. The best sensitivity–specificity relation in earlier studies was established at cutoff point of 35 [27, 47]. The Dissociative Experiences Scale [48] is a 28-item self-administered inventory to measure the frequency of dissociative experiences. To answer DES questions, subjects circle the percentage of time (given in 10 % increments ranging from 0 to 100) that they have the experience described. The higher total score (mean of the 28 items) indicates greater level of dissociation. The α reliability found in earlier studies was at average 0.93, and a cutoff point of 20 was established to best identify patients with pathological level of dissociation [49, 50].

Adult attachment interview

The AAI [34, 51] is a semi-structured interview, audiotaped and transcribed verbatim. Twenty central questions with structured probes are involved, and participants are asked alternately for general descriptions of relationships with the main attachment figures in childhood, specific supportive or contradicting memories, traumatic experiences occurring throughout their lifetime (e.g., loss or abuse) and descriptions of current relationships with the attachment figures [34]. Specific questions regarding critical attachment experiences, such as illnesses, separations and rejections, are also included. AAI interviews were administered by trained researchers blind to diagnoses. The interviews were transcribed verbatim and three coders (AMS, CT, CMV)[1] certified as reliable by Main and Hesse used Main et al. coding system [51] in order to classify adults into one of five categories for overall state of mind with respect to attachment: (1) secure/autonomous (F); (2) dismissing (Ds); (3) preoccupied (E); (4) unresolved/

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[1] AMS has been trained at the AAI Training Institute of Rome, 1990, by M. Main and E. Hesse; CT has been trained at the AAI Training Institute of Rome, 2008, and CMV at the AAI Training Institute of Rome, 2010, by D. Jacobvitz and N. Dazzi.

disorganized (U); (5) cannot classify (CC). Differently from F, Ds and E (organized classifications), individuals classified as U (when adults) show signs of disorientation and disorganization in the monitoring of reasoning or discourse during discussions of potentially traumatic events such as loss or abuse. CC individuals show instead a global disruption of attachment strategy, with oscillations between opposite and contradictory mental states (Ds, E) or low coherence pointing to a general inability to rally an organized stance. A best-fitting primary organized classification is secondarily assigned to U or CC classifications. U and CC categories are especially relevant in clinical samples characterized by dissociative processes in that they suggest a temporary or global alteration in consciousness or working memory.

EEG recordings

Electroencephalography recordings were performed before, during and after the administration of AAI. Each session included a baseline EEG recording, performed before the test; a continuous recording, performed during the interview, and a post-test EEG recording, performed immediately after the end of the AAI. Baseline and post-test EEG recordings were performed with the subject sitting, with their eyes closed, in a quiet, semi-darkened silent room. Each recording lasted 5 min. Montage included 19 standard scalp leads positioned according to the 10–20 system (recording sites: Fp1, Fp2, F7, F3, Fz, F4, F8, T3, C3, Cz, C4, T4, T5, P3, Pz, P4, T6, O1, O2). The reference electrodes were placed on the mastoids. Impedances were kept below 5 KΩ before starting the recording and checked again at the end of the recording. Sampling frequency was 256 Hz. A/D conversion was made at 16 bit. Preamplifier amplitude range was ±3,200 μV, and prefilters were set at 0.15 Hz. EEG was recorded by means of a system plus evolution digital polygraph (Micromed® SpA, Mogliano Veneto, TV, Italy).

Frequency analysis

EEG frequency analysis was done before the connectivity analysis. Fast Fourier transform was performed with a 1-s interval on the EEG signal, in all scalp locations. The following frequency bands were considered: δ (0.5–4 Hz), θ (4.5–7.5 Hz), α (8–12.5 Hz), β (13–30 Hz), γ (30.5–100 Hz). Frequency analysis and comparison between conditions were performed by means of a dedicated software (low-resolution electric tomography, LORETA) [52].

Connectivity analysis

The connectivity analysis was performed by the LORETA software [52]. EEG coherence analysis was performed in blocks of EEG tracings lasting 5 min. Artifacts rejection was performed visually. Coherence values were computed for each frequency band (δ, θ, α, β, γ), in the frequency range 0.5–100 Hz.

Connectivity analysis was performed by the computation of lagged coherence. This approach better allows the identification of the connections between generators of scalp potentials [53]. EEG potentials recorded at any electrode location are generated by two major sources: (1) the “excitable medium” and (2) the electrical fields of the brain. The excitable medium consists of an anatomical network made up of axons, synapses, dendritic membranes and ionic channels; the signals which propagate through this medium undergo a time delay due to neural conduction. The corresponding EEG potentials show a phase delay (phase lag). The electrical fields of the brain consist of dipoles distributed in space, which turn on and off and oscillate at different amplitudes and frequencies. These electrical fields operate at the speed of light activating the dipoles in the electrical field, which in turn generates EEG potentials and propagates by volume conduction, with a zero time delay [53]. EEG connectivity is defined by the magnitude of electric coupling between neurons, and it is an exclusive property of the “excitable medium.” Connectivity does not occur at the speed of light and is measured when there are time delays, due to axonal and synaptic conduction. For these reasons, the measurement of lagged coherence enables the evaluation of the potentials generated by local neural networks and to exclude potentials generated due to volume conduction [53]. Moreover, the measurements of lagged coherence allows one to obtain reliable esteems of phase synchronization that do not change in the presence of common sources like the presence of an active reference electrode in EEG [54].

The analysis of EEG connectivity was performed as prescribed in a recent study by Lehman et al. [54]. Intracortical lagged coherence was calculated between all possible pairs of the 19 regions of interest (ROIs) for each of the five EEG frequency bands, for each subject and for each condition. The definition for the complex valued coherence between time series x and y in the frequency band ω is:

$$r_{\mathrm{xy}\omega} = \frac{\operatorname{Re}\operatorname{Cov}(\mathrm{x},\mathrm{y}) + \mathrm{i}\operatorname{Im}\operatorname{Cov}(\mathrm{x},\mathrm{y})}{\sqrt{\operatorname{Var}(x) \times \operatorname{Var}(y)}}$$

which is based on the cross-spectrum given by the covariance and variances of the signals, and where i is the imaginary unit ($\sqrt{-1}$). The squared modulus of the coherence is:

$$r^2_{\mathrm{xy}\omega} = \frac{[\mathrm{Re}\,\mathrm{Cov}(\mathrm{x},\mathrm{y})]^2 + [\mathrm{Im}\,\mathrm{Cov}(\mathrm{x},\mathrm{y})]^2}{\mathrm{Var}(x) \times \mathrm{Var}(y)}$$

and the lagged coherence is:

$$\mathrm{Lag}\,R^2_{\mathrm{xy}\omega} = \frac{[\mathrm{Im}\,\mathrm{Cov}(\mathrm{x},\mathrm{y})]^2}{\mathrm{Var}(x) \times \mathrm{Var}(y) - [\mathrm{Re}\,\mathrm{Cov}(x,y)]^2}.$$

Definition of regions of interest (ROIs)

The estimation of electric neuronal activity that is used to analyze brain functional connectivity makes necessary to define ROIs. In order to assess functional connectivity between all major areas, we used the cortex areas located under the 19 head surface electrodes of the international 10/20 system. All EEG data epochs were re-calculated into a cortical current density time series at 6,239 cortical voxels.

Statistical analysis

The statistical analysis of the EEG connectivity was performed using paired t statistics on the coherence values after Fisher's z transformation available in the LORETA program package [55], as used in a recent study, with similar design, by Lehman et al. [54]. Statistical comparisons, for all measured parameters (171 electrodes pairs for each frequency band), were performed between and within groups (patients and controls) in the two conditions: before AAI (pre-AAI) and after AAI (post-AAI).

Scores obtained at the psychometric scales (patients vs controls) and HRV parameters (patients vs controls; pre-AAI vs post-AAI) were compared by means of the non-parametric Mann–Whitney *U* test; the level of significance was set to $p < 0.05$.

All statistics regarding psychometric scales were performed by means of the SYSTAT 12 software version 12.02.00 for Windows® (copyright SYSTAT® Software Inc. 2007).

Results

AAI and self-report results

All dissociative patients but one (92.3 %) were classified as having unresolved/disorganized (U/d) states of mind with respect to attachment. Eight of 12 were classified as CC as alternative category. The 13 interviews of the control group were classified as follows: 9 (69.2 %) secure/autonomous (F), 3 (23.1 %) dismissing (Ds) and 1 (7.7 %) U/d.

The patients group showed significantly higher scores for both self-report scales compared to the control group (DES: controls = 0.14 ± 0.34, patients = 23.38 ± 5.07 *U* test 0.00, $p < 0.001$; SDQ-20: controls = 22.00 ± 3.39, patients = 36.23 ± 16.11 *U* test 32.00, $p = 0.006$).

EEG spectral analysis results

Visual evaluation of the EEG recordings showed no relevant modifications between the pre-AAI and post-AAI conditions, both in patients and controls. In particular, recordings did not reveal modification of the background rhythm frequency, focal abnormalities or epileptic discharges. No subject showed evidence of drowsiness or sleep during the recordings.

The threshold for statistical significance (corresponding to $p < 0.01$), calculated by nonparametric mapping (SnPM) methodology supplied by the LORETA software, was as follows: for between-groups analysis: baseline $T = 3.607$, post-AAI $\mathrm{T} = 3.714$; for within-groups analysis: controls $T = 4.863$, patients $T = 3.461$.

The comparison of power spectra between controls and patients and within the two groups in the pre-AAI and post-AAI conditions did not show significant differences, neither in absolute nor in relative power, in any of the frequency bands considered.

EEG connectivity results

The threshold for statistical significance (corresponding to $p < 0.01$), calculated by nonparametric mapping (SnPM) methodology supplied by the LORETA software, was as follows: for between-groups analysis: baseline $\mathrm{T} = 4.480$, post-AAI $\mathrm{T} = 4.483$; for within-groups analysis: controls $\mathrm{T} = 5.483$, patients $\mathrm{T} = 5.651$.

In the between-groups analysis of lagged coherence at baseline condition, controls and patients did not reveal significant differences for all pairs of ROIs in all frequency bands. Conversely, significant modifications were observed post-AAI condition (see Fig. 1) for the within-groups comparisons. In particular, in the delta band 37 out of 171 (21.6 %) pairs of ROIs showed significantly increased coherence, in the theta band no modification was observed, in the alpha band 72 out of 171 (42.1 %) pairs of ROIs showed significantly increased coherence; in the beta band 162 out of 171 (94.7 %) pairs of ROIs showed significantly increased coherence; in the gamma band 171 out of 171 (100 %) pairs of ROIs showed significantly increased coherence. In no pair of ROIs, significant decrease in lagged coherence was observed.

In the within-groups analysis, we observed that in the control group, lagged coherence was significantly increased following the AAI with a frequency-dependent

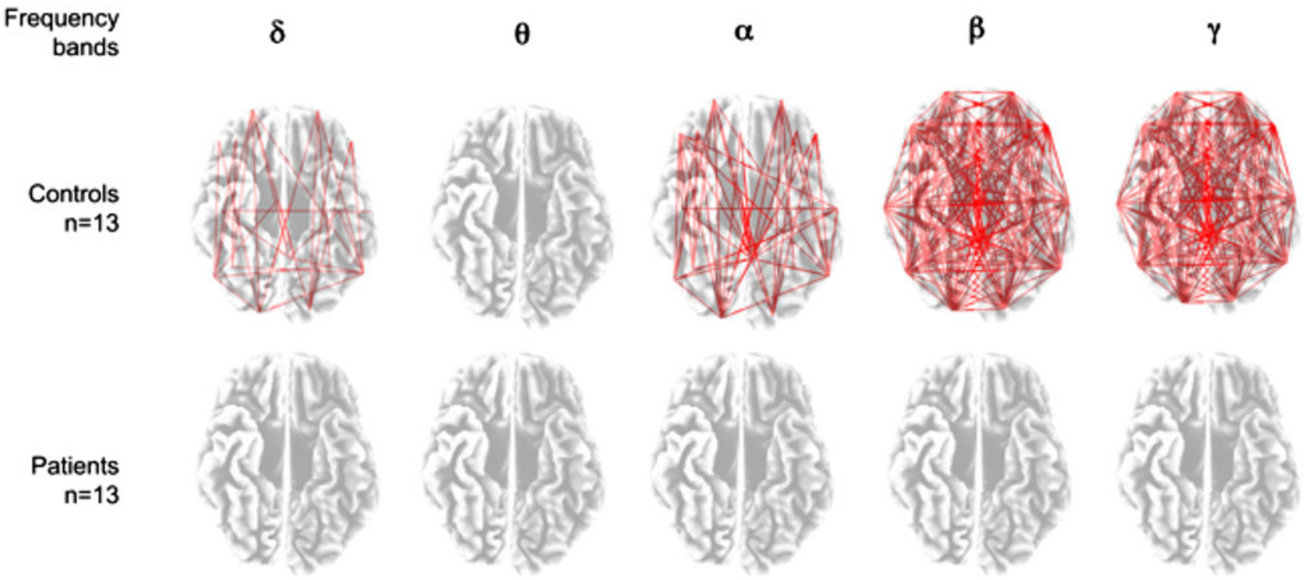

Fig. 1 Comparison of EEG connectivity pre- and post-AAI. Comparison of lagged EEG connectivity pre- and post-AAI in controls and patients: graphic output of the LORETA analysis. *Red lines* indicate couples of ROIs in which significant ($p < 0.01$) increase in lagged coherence was observed. *Upper panel* controls; *lower panel* patients. Greek letters (δ, θ, α, β, γ) indicate EEG frequency bands

pattern, while no modifications were observed in patients. In particular, in the delta band 19 out of 171 (13.4 %) pairs of ROIs showed significantly increased coherence, in the theta band no modification was observed, in the alpha band 42 out of 171 (27.5 %) pairs of ROIs showed significantly increased coherence; in the beta band 170 out of 171 (99.4 %) pairs of ROIs showed significantly increased coherence; in the gamma band 171 out of 171 (100 %) pairs of ROIs showed significantly increased coherence. In no pair of ROIs significant decrease in lagged coherence was observed in control group.

In the patients group no significant modification was observed after the AAI, in any frequency band.

Graphic representations of the results of the connectivity study are shown in Fig. 1.

Discussion

Our study aimed to measure EEG cortical connectivity after the retrieval of attachment memories through the AAI in healthy subjects and in patients with disorders characterized by severe dissociative symptoms. It is the first study focused on EEG functional connectivity after an affective and cognitive stimuli related to the attachment system in patients and healthy subjects. We hypothesized that memories of traumatic attachment lead to a modification of EEG cortical connectivity related to the impairment of high integrative mental function in dissociative patients.

Two main findings emerged. The first is that, as expected, in the control group, memories of attachment promoted a widespread increase in connectivity, in particular in the high-frequency EEG bands (α, β and γ). Notably, increase in EEG connectivity in the control group was not associated with modifications in power and topographic distribution of the frequency bands analyzed. This rules out of any cortical arousal effect. It can be hypothesized that the increase in EEG connectivity in controls is the result of cognitive and affective processing activated by the AAI [37, 38, 40, 56–58]. Recent data indicate that high-frequency EEG rhythms (namely the beta and gamma band) are the most likely to be involved in high-level cognitive processes: Dynamic and widespread cortical connectivity networks operating in the high-frequency range have been found to play a crucial role in high-level integrative cognitive functions such as processing of affective stimuli, executive and attentive tasks, memory and consciousness [37, 38, 40, 58]. Moreover, as stated by Miskovic and Schmidt [58], EEG coherence studies lead to suppose that “affective processes in the brain are not strictly modular, but rather involve the spatio-temporal coordination of extensively distributed networks.”

It can be supposed that a complex task, such as the AAI, involving calls for searches for affective processing, autobiographical memory, opportunities for metacognitive monitoring, and affect regulation, requires the subject a succeeding integrative mental activity, observed in widespread increased cortical connectivity.

The second main finding of this study is that, as hypothesized, compared to controls dissociative patients did not show an increase in EEG connectivity after the AAI, as indicated by a lack of modifications at each frequency band explored. We also observed an increase in sympathetic activity after the AAI in patients but not in the control group. In our opinion, this lack of increase in EEG connectivity after the AAI, unlike the control group, could be the expression of the *disintegrative* effect of traumatic memories and could account for their typical, state dependent and momentary difficulties, in cognitive and affective regulation [11]. This result is compatible with the idea that the failure in functional cortical connectivity in the patients group is related to the impairment of high-level integrative mental functions caused by the activation of mental processes related to attachment contingent on the disorganized state of mind revealed by AAI. Individuals classified as U/d, as well as dissociative patients, usually show typical outcomes of integration failure, such as an apparent temporary or global alteration in consciousness during discussions of potentially traumatic experiences, as if the topic had triggered a "peculiar, compartmentalized or even partially dissociated state of mind" [59, p. 570]. The dissociative response to frightening memories of attachment experiences leads to a loss of subjective coherence and undermines the continuity of the individual's experience, disrupting the normally integrative functions of mental activity.

These findings provide empirical support for the hypothesis that relational traumatic memories could activate dissociative processes in patients suffering from disorders characterized by dissociative symptoms (dissociative disorders, the dissociative subtype of PTSD, BPD and the dissociative disorders of movement and sensation listed in the IDC-10). They are consistent with the findings of studies in the developmental psychopathology and in the neurobiology of dissociation [1, 11, 19, 22, 33]. Studies of the neurobiological underpinnings of traumatic dissociation and early relational trauma show alterations of normal integration between different areas of the cerebral cortex and between cortical and subcortical structures [1, 8, 19, 43, 45, 60–62]. Most of these studies, however, have focused on the functionality of brain structures and hardwired connections [8] or were performed without any specific emotional stimulation. We intended to measure EEG coherence in a resting phase after the highly emotion-evocative questioning of the AAI, expecting to observe an ongoing effect of the stimulus on the integrative mental functions. Whereas we did not identify significant differences between patients and controls in the pre-stimulus resting phase, it is possible that the differences observed in the post-AAI phase were determined by the activation of the attachment system, triggered by memories related to early attachment experiences. Memories related to traumatic attachment may have negatively affected cortical connectivity.

Although other studies have shown EEG coherence abnormalities in maltreated children and adolescents [41, 63], our results are not comparable with these previous findings because of methodological differences. In our study, we used the lagged coherence, which is readily interpretable as a "pure" measure of activation of functional networks, whereas other studies based on EEG coherence parameters cannot differentiate true connectivity from other brain cortex cortical activities generated by synchronization or volume conduction [53] (see also "Connectivity analysis" in "Methods"). To the best of our knowledge, the only study of dissociation based on EEG lagged coherence is that by Hopper and colleagues. They compared EEG lagged coherence of 5 DID patients in their so-called host and alter personalities and also with a control group of professional actors simulating alter personalities. Remarkably only DID patients during alter personalities showed statistically significant lower EEG coherence [43]. In our opinion, these results are consistent to those of the present study and support the hypotheses that dissociative states are correlated with lower degree of EEG lagged coherence. The similarity between the present results and those from Hopper et al. may be explained also on the base of the theory of the trauma-related structural dissociation of the personality [64]. According to this hypothesis, it can be argued that the AAI activated in our patients dissociative parts of the personality fixated (or represented by) in their traumatic memories. As stated by Hopper and colleagues, the lowering of EEG coherence could be interpreted as the functional disconnection between parts of the personality.

In support of these neurophysiological results, we observed an extremely high prevalence of U/d, or even CC, states of mind in patients whose disorders were characterized by dissociative symptoms. A growing number of clinical studies demonstrate that "unresolved loss or trauma as assessed with the AAI is an almost perfect marker for dissociative disorders" [25, p. 249]. For dissociative patients, retrieval of traumatic memories would interfere with the reporting of one's attachment history, enhancing the vulnerability to dissociative experiences and thus supporting the link between attachment-related traumas, tendency toward dissociative states and dissociated mental operations during a task involving autobiographical memory [14]. It is interesting to note that in our sample, CC interviews were also rated high for unresolved traumas and/or losses [59, 65]. As suggested by Liotti [14], we could suppose that this kind of dissociative process is characterized by poor metacognitive monitoring and by autobiographical memories that are split as to the meaning attributed to relational events.

Propensity toward dissociation was by definition a feature of our patients group and was evidenced by their high DES and SDQ-20 scores. This finding, together with the high prevalence of U/d classifications in patients suggested a significant association between U/d classifications and dissociative symptoms as observed by several clinical and research studies [30–32, 66].

Although our study does not allow for a clear-cut identification of developmental determinants (e.g., we cannot take for granted that our dissociated/unresolved patients were disorganized in their infant attachments), a developmental psychopathology model of dissociation [67] suggests that early traumatic experiences with attachment figures, associated with attachment disorganization, are likely to play a significant role in the development of a range of disorders that involve deficits in the integrative functions of consciousness [13, 67–69].

One of the most intriguing questions that arise from this study is about the exact origin of the lack of connectivity in the patients group after the AAI. It is not clear if this result should be attributed to specific states of mind activated by traumatic memories during the AAI or caused by a non-specific disintegrative emotional response to the AAI stimulus in a group of dissociative patients. The study design does not allow for a definite answer to this question. However, it is plausible that the two psychopathogenetic processes are tightly interwoven or even identical.

Further studies are required to clarify whether the impairment of connectivity after the exposure to attachment memories retrieval is related to U/d attachment, the present clinical condition or both. To address this question, it will be necessary to compare the response to the AAI in different groups of U/d subjects, with and without dissociative disorders. Further studies including different psychiatric disorders groups such as schizophrenia and mood disorders are also required to understand whether the impairment of EEG connectivity after the exposure to AAI is typical of dissociative clinical conditions or not.

Limitations

A possible limitation of the present study is the use of scalp EEG recordings, which have an intrinsic limit in space resolution, particularly in the identification of deep subcortical sources. A further limit could be the low number of electrodes (19) in the montage applied. It is known that spatial resolution of EEG sources increases with the number of electrodes, and therefore, high-density recordings are more reliable in the EEG rhythms source analysis. Moreover, magneto-encephalographic (MEG) recordings are even more reliable in identifying deep EEG sources. However, Cohen et al. [70] performed a study in which they evaluated the localization of signal sources by means of scalp EEG and MEG. In this study, they used as signal sources intracerebral electrodes implanted for seizure monitoring; the signal was a weak current pulse that was passed in the implanted electrodes. In this study, they demonstrated that a scalp EEG array of 16 electrodes allowed source localization with an average error = 10 mm; this accuracy was not different from that obtained with MEG recordings (average error = 8 mm). Moreover, our results suggest that U/d attachment hampers EEG cortical connectivity in a widespread way, rather than between specific, and discrete, brain areas. In this regard, a more detailed definition of brain sources would not add much to the main result of the study: the impairment of a diffuse cortical networking after the AAI in dissociative patients after the exposure to the AAI.

Concluding remarks

Although preliminary and in need of confirmation, our results throw light on the neurobiological basis of the disintegrative effect of relational traumatic memories in dissociative patients. They promise to identify some of the possible mechanisms of dissociative processes of early trauma involving attachment figures and their psychiatric outcomes. Moreover, our results along with other data are a step toward identifying non-invasive neurobiological markers of vulnerability to disintegrative psychopathology. They are relevant for clinicians involved in retrieving attachment memories during the treatment of trauma and dissociation.

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Conflict of interest None.

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