Electroencephalographic correlates of body shape concerns: an eLORETA functional connectivity study

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Received: 13 February 2020 / Revised: 23 June 2020 / Accepted: 16 July 2020 / Published online: 23 July 2020
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Abstract

The main aim of the present study was to investigate the association between body shape concerns and electroencephalography (EEG) functional connectivity within body image network in a sample of university students ($N = 68$). EEG was recorded during 5 min of resting state. All participants were asked to complete self-report measures assessing certain psychopathological dimensions (i.e., body shape concerns, depression, anxiety, obsessive-compulsive symptoms). EEG analyses were conducted by means of the exact low-resolution electromagnetic tomography software (eLORETA). Our results showed that body shape concerns were positively associated with increased gamma functional connectivity between the left and right prefrontal cortex (PFC). Furthermore, our data revealed that this EEG pattern was independently associated with body shape concerns after controlling for potential socio-demographic and clinical confounding variables. This finding seems to suggest that increased EEG gamma connectivity between the left and right PFC might be a relevant neurophysiological alteration involved in the development and/or maintenance of dysfunctional concerns about one's body.

Keywords Body shape concerns · EEG connectivity · Psychopathology · eLORETA

Introduction

Body image is a complex multidimensional construct characterized by perceptual, behavioral and cognitive-affective components (Cash 2004). Body image dissatisfaction (BID; i.e., negative thoughts and feelings about one's body) is considered an important public health problem (Fiske et al. 2014). Indeed, extreme and dysfunctional concerns about body shape are core features of eating

disorders (EDs) and are potentially involved in a whole variety of psychiatric conditions (Fassino and Marzola 2018). Furthermore, BID is frequently detected in non-clinical samples influencing a wide range of behavioral risk factors (e.g., increased pro-smoking attitudes) for chronic diseases (Fiske et al. 2014). Therefore, it is not surprising that scholars are attempting to detect risk factors that contribute to BID (Allen and Walter 2016).

In the last decades, beyond psychopathological and psychosocial variables, neurobiological and neurophysiological mechanisms have been consistently investigated in order to elucidate the neural underpinnings of body image disturbance (Gaudio et al. 2016, 2018; Gaudio and Quattrocchi 2012). In clinical samples, resting state (RS) and body-tasks related neuroimaging studies showed that a complex brain network is involved in body image distortion. Specifically, neuroimaging studies detected (Gaudio et al. 2016, 2018; Gaudio and Quattrocchi 2012) that body image disturbances are related to alterations in the functional and structural integration between several brain areas (i.e., a neurophysiological index called connectivity), including the prefrontal cortex (PFC), the extrastriate body area (EBA), the posterior parietal cortex (PPC; which

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Electronic supplementary material The online version of this article (<https://doi.org/10.1007/s11571-020-09618-1>) contains supplementary material, which is available to authorized users.

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comprises the inferior parietal lobe and precuneus) and the insula.

Compared to psychopathological and psychosocial factors, investigating the neurophysiological correlates of BID in non-clinical samples is still an underdeveloped research area, notwithstanding the study of its neural underpinnings could be a relevant target in the prevention and in early etiology understanding of mental illnesses and related consequences associated to this serious public health problem. Moreover, although an increasing number of reports have used electroencephalographic (EEG) measurements in the assessment of EDs pathology (Blume et al. 2019; Jauregui-Lobera 2012), to the best of our knowledge, no studies have selectively investigated the EEG connectivity correlates of body shape concerns.

Therefore, the main aim of the present study was to extend previous findings exploring, in undergraduate students, the association between body shape concerns and RS EEG functional connectivity, a suitable tool for the assessment of network dynamics and functional integration across brain areas (Hata et al. 2016; Whitton et al. 2018) in a relatively non-invasive and low cost way (Yao et al. 2020). A further aim of the preset research was to determine the unique contribution of EEG functional connectivity within the body image network on body shape concerns, controlling for potential confounding variables such as sex, body mass index (BMI) and psychopathology (Fassino and Marzola 2018).

Materials and methods

Participants

Participants were recruited through advertising material posted around the university campus (i.e., briefly explanation of the study procedure including EEG recordings and self-report measures administration). The enrolment lasted from September to December 2019. After receiving information about the aims of the study, all participants provided a written informed consent to participate in the study that was performed according to the Helsinki declaration standards and that was approved by the local research ethics review board. Participants were enrolled if they met the following inclusion criteria, investigated through dichotomous screening questions (Adenzato et al. 2019; Imperatori et al. 2019): negative past or current diagnosis of any psychiatric disease (including intellectual disability), negative lifetime history of neurologic disease or head trauma, right handedness, negative psychoactive medications use and illegal drugs consumption in the past 2 weeks prior to the EEG recordings. One hundred undergraduate students were assessed for eligibility. Sixty-

eight healthy undergraduate students (twenty-nine men and thirty-nine women, 64 Caucasian and 4 Hispanics; mean age: 22.26 ± 3.55 years) fulfilled the inclusion criteria and were enrolled in the present research.

EEG recordings and analysis

After the enrollment, all participants performed a 5 min of eyes-closed RS EEG recording. In order to avoid the possible effect of alcohol and caffeine on EEG data, participants were asked to refrain from them immediately before their EEG recording (i.e., at least 4 h). All EEG recordings were performed in the afternoon (between the 03.00 and 06.00 p.m.). EEG was recorded by means of a Micromed System Plus digital EEGraph (Micromed© S.p.A., Mogliano Veneto, TV, Italy). EEG recordings included 31 standard scalp leads placed according to the 10–20 system. Furthermore, both Electrooculography and Electrocardiography were recorded. The reference electrodes were placed on the right mastoid during the recording session and then were re-referenced offline to the algebraic average of the left and right mastoids. Impedances were kept below 5 k Ω before starting EEG recording and checked again at the end of EEG session for each participant. Sampling frequency was 256 Hz (time constant 0.16 s); A/D conversion was made at 16 bit; preamplifiers amplitude range was $\pm 3200 \mu\text{V}$ and low-frequency pre-filters were set at 0.15 Hz. The following band-pass filters were used: high-frequency filter = 1 Hz; low-frequency filter = 100 Hz. Offline artifacts rejection (e.g., cardiac pulses, muscular or movement activities) were performed visually on the raw EEG trace, by posing a marker at the onset of the artifact signal and a further marker at the end of the artifact. The vigilance levels (e.g., evidence of drowsiness or sleep) were checked during the recording.

At least 3 min of clean EEG data (not necessarily consecutive) were selected for each participant and artifact-free data were fragmented into epochs of 2 s for the EEG coherence analysis (Canuet et al. 2012; Hata et al. 2016; Imperatori et al. 2020).

All EEG analyses were performed using the exact low-resolution electromagnetic tomography (eLORETA) software (Pascual-Marqui et al. 2011), a well validated instrument to localize brain electrical activity, characterized by satisfactory localization agreement with other neuro-imaging techniques (Jatoi et al. 2014). The eLORETA defines the topographic sources of EEG activities assuming that connected neurons are activated both simultaneously and synchronously (Pascual-Marqui et al. 2011). The brain templates of eLORETA coordinates were determined according to the Montreal Neurological Institute (MNI) and its solution space was limited in the cortical grey matter, including 6239 voxels of 5 cubic mm spatial resolution (Hata et al. 2016).

In the present study, the connectivity analysis was performed using the lagged phase synchronization method (Pascual-Marqui et al. 2011) a largely used index in neurophysiology studies (Adenzato et al. 2019; Canuet et al. 2012; Whitton et al. 2018). Functional connectivity was evaluated within the main cortical brain areas involved in body image distortion, with the construction of a source-space network according to previous neuroimaging studies (Zhang et al. 2014). Specifically, 8 Regions of Interest (ROIs) were defined according to Gaudio et al. (2018): bilateral PFC, bilateral insula, bilateral PPC, and bilateral EBA (Fig. 1).

The eLORETA computed the lagged phase synchronization values between all the “ROIs” (i.e., 64 connections). According to previous reports (Adenzato et al. 2019; Canuet et al. 2012; Imperatori et al. 2020), the “single nearest voxel” option (i.e., each ROI consisted of a single voxel, the closest to each seed) was chosen, and the following frequency bands were considered: delta (1–4 Hz); theta (4.5–7.5 Hz); alpha (8–13 Hz); beta (13.5–30 Hz); gamma (30.5–60 Hz).

Psychopathological assessment

At the end of EEG recording, in addition to providing socio-demographic/background information (i.e., sex, age,

tobacco and alcohol use in the last 6 months), all participants were asked to complete self-report measures assessing certain psychopathological dimensions related to body shape concerns (Fassino and Marzola 2018). Participants were also previously instructed (Barberio et al. 2019) to measure and accurately report their current height and weight in order to calculate BMI.

Body shape concerns were assessed using the short 14-item version of the Body Shape Questionnaire (BSQ-14; Dowson and Henderson 2001), a widely used scale to evaluate body dissatisfaction. The total score ranges from 14 to 84 with higher scores indicating more severe body shape concerns. In the present study, the Cronbach’s α in our sample was 0.94.

The 26-item version of the eating attitude test (EAT-26; Garner et al. 1982) was used to assess EDs psychopathology, with higher scores reflecting greater severity. In the present study, Cronbach’s α for the EAT-26 total score was 0.86.

Depressive and anxiety symptoms were respectively investigated with the Teate Depression Inventory (Balsamo and Saggino 2014) and with the trait version of the state-trait inventory for cognitive and somatic anxiety (STICSA; Ree et al. 2000). The TDI is a 21 item self-report rated on a 5-point Likert scale (the total score ranges from 0 to 84), with higher scores indicating more severe depressive symptoms (Balsamo and Saggino 2014). The STICSA is

Fig. 1 eLORETA regions of interest of body image network and Montreal Neurological Institute coordinates (Axial, Sagittal and Coronal view). Abbreviations: PFC = prefrontal cortex, PPC = posterior parietal cortex; EBA = extrastriate body area. (Color figure online)

composed of 21 items rated on a 4-point Likert scale (the total score ranges from 21 to 84), with higher scores indicating more severe anxiety symptoms (Ree et al. 2000). In the present study, the TDI and the STICSA showed satisfactory internal consistency, respectively 0.88 and 0.86.

Obsessive-compulsive symptoms were assessed with the short 18-item version of the obsessive compulsive inventory (OCI-R; Foa et al. 2002). Items are rated on a 5-point Likert scale (the total score ranges from 0 to 72), with higher scores indicating more severe symptoms. In the present study, the internal consistency was 0.90 for OCI-R total score.

Statistical analysis

In order to investigate the association between EEG connectivity data and the BSQ-14 scores, we used the regression analysis option provided by the eLORETA software (i.e., BSQ-14 scores were correlated with the strength of the connection between each ROIs, in each frequency band). Correlations between connected ROIs and non-physiological variables (e.g., self-report measures) provide a way to sufficiently explore the relevance of particular brain areas involved in mental functions (Fehr and Milz 2019). Correction for multiple comparisons was performed using the statistical nonparametric mapping (SnPM) methodology included in the eLORETA program package methodology (Nichols and Holmes 2002). Briefly, this procedure computes 5000 data randomizations to determine the critical probability threshold of r values corresponding to a statistically corrected (i.e., after the multiple comparisons among all voxels in each frequencies) p values (see Hata et al. 2016 for more details).

Furthermore, in order to investigate the unique contribution of any significant interconnected ROIs on body shape concerns, a hierarchical linear regression analysis was performed using the BSQ-14 total score as the dependent variable. Socio-demographic/background variables (i.e., sex, age, ethnicity, BMI, tobacco and alcohol use in the last 6 months) as well as psychopathological dimensions were entered in the model as covariates. The standard method of entry, also known as “enter method” (i.e., at each step all independent variables entered into the equation simultaneously), was used and the associations between variables were reported as standardized beta (β) coefficients. We also computed zero-order correlations in order to provide useful data points for potential future meta-analyses (see Table S1) considering $r = \pm 0.1$ as a small, ± 0.30 as a medium, and ± 0.50 as a large effect size (Cohen 1988). Non-normally distributed variables (i.e., EAT-26 total score, BMI, age, OCI-R total score and EEG connectivity data) were transformed into normality

using the Rankit approximations (Bliss et al. 1956), the most accurate method for score normalization in the social and behavioral sciences (Soloman and Sawilowsky 2009). Statistical analysis was performed using IBM SPSS Statistics for Windows, version 18.0.

Results

EEG recordings suitable for the analysis were acquired for all participants. Examples of raw EEG data and the corresponding spectral and topographical maps (performed using EEGLab’s “plotting channel spectra and maps” function; Delorme and Makeig 2004) are reported in Fig. S1.

No relevant modifications of background rhythm frequency as well as evidence of drowsiness or sleep during the recordings were observed. The correlation between BSQ-14 total score (mean values in the overall sample: 38.82 ± 16.11) and EEG connectivity data was investigated in all frequency bands. The eLORETA software detected a significant positive correlation between BSQ-14 scores and EEG connectivity data in the gamma frequency band ($r = 0.40$; corrected $p < 0.05$): higher scores in BSQ-14 were positively associated with an increase of functional connectivity between the left and right PFC (Fig. 2a). No significant associations were observed in the other frequency bands. The results of zero-order correlations (using normalized data) have been reported in Table S1.

Hierarchical linear regression analysis is reported in Table 1. The models explained between 9% and 51% of the variability in the BSQ-14 total score. The connectivity between the left and right PFC was uniquely associated with body shape concerns in each block, even when controlling for potential confounding variables (Fig. 2b). Thus, more severe body image concerns were related to increased gamma connectivity between the left and right PFC (β coefficients ranging between 0.33 [$p = 0.006$] and 0.23 [$p = 0.012$] across three blocks).

Discussion

The primary purpose of the present study was to assess the association between body shape concerns and EEG functional connectivity within the body image network. Our results showed that, during RS, body shape concerns were positively associated with increased gamma functional connectivity between the left and right PFC. Furthermore, our data revealed that this EEG pattern was uniquely associated with BSQ-14 total score after controlling for

Fig. 2 Panel A Significant correlation between left-right PFC connectivity and BSQ total score in the gamma frequency band. Red lines indicate increased functional connectivity between ROIs positively associated with BSQ-total scores; blue lines (not present) would indicate decreased functional connectivity between ROIs positively associated with BSQ-total scores. Panel B Scatterplot of

the correlation between left-right PFC connectivity values and BSQ-total score (values are adjusted for sex, age, BMI, ethnicity, tobacco and alcohol use, and psychopathological dimensions). Abbreviations: PFC = prefrontal cortex, BSQ-14 = body shape questionnaire. (Color figure online)

Table 1 Descriptive statistics and hierarchical linear regression analysis in all sample ($N = 68$)

Dependent variable	Independent variables	Mean $\pm$ SD	Count (%)	Block	Adjusted R^2	F	R^2 change	F change	β
BSQ-14 total score		38.82 $\pm$ 16.11	–	1	0.09	7.96 ^{1***}	0.11**	7.96**	
	Left-right PFC connectivity	0.02 $\pm$ 0.32	–						0.33**
	Left-right PFC connectivity	–	–	2	0.21	3.57 ^{2***}	0.19*	2.64**	0.31**
	Females	–	39 (57.4)						0.31*
	Age	22.26 $\pm$ 3.55	–						– 0.27*
	Tobacco use	–	17 (25.5)						– 0.02
	Alcohol use	–	43 (63.2)						– 0.08
	BMI	23.15 $\pm$ 4.41	–						0.28*
	Caucasian ethnicity	–	64 (94.1)						0.08
	Left-right PFC connectivity	–	–	3	0.51	7.24 ^{3***}	0.29***	9.94***	0.23*
	Females	–	–						0.21*
	Age	–	–						– 0.16
	Tobacco use	–	–						– 0.05
	Alcohol use	–	–						– 0.06
	BMI	–	–						0.25*
	Caucasian ethnicity	–	–						0.09
	EAT-26 total score	6.88 $\pm$ 8.48	–						0.40***
	OCI-R total score	16.57 $\pm$ 12.26	–						0.13
	STICSA-T total score	38.60 $\pm$ 9.77	–						0.11
	TDI total score	31.87 $\pm$ 11.95	–						0.16

* = $p < 0.05$, ** = $p < 0.01$, *** = $p < 0.001$, Degree of freedom: ¹1:66, ²6:61, ³10:57; β = standardized beta

BSQ-14 body shape questionnaire, PFC prefrontal cortex, BMI body mass index, EAT-26 eating attitude test, OCI-R obsessive-compulsive inventory-revised, STICSA-T state-trait inventory for cognitive and somatic anxiety trait version, TDI teate depression inventory

potential socio-demographic and clinical confounding variables. This finding seems to suggest that increased EEG gamma connectivity between the left and right PFC might be a relevant neurophysiological alteration involved in the development and/or maintenance of dysfunctional concerns about one's body more than other clinical dimensions (e.g., depressive and anxiety symptoms).

Our results converge with those of previous neuroimaging studies in clinical samples (Gaudio et al. 2018; Gaudio and Quattrocchi 2012), highlighting the crucial role of the PFC in body image disturbances, especially in the cognitive-affective components (i.e. thoughts and emotions regarding one's own weight and shape and their influence on self-esteem). Intriguingly, in the present study, the association between EEG gamma connectivity and BSQ-14 total score was observed during RS condition, which is thought to reflect the brain intrinsic activity revealing significant information on how different structures communicate with each other (Deco et al. 2011; Deli et al. 2017). It is known that the PFC (both the medial and the dorsolateral region) contributed to self-referential processing and it is involved in the semantic judgments about themselves (Davey et al. 2016). Furthermore, abnormally increased brain gamma functional connectivity has been recognized as a neurophysiological index related to negative affective stimuli processing (Li et al. 2015). Thus, it is tempting to speculate that the independent association between BSQ-14 total score and increased gamma connectivity within the left and right PFC reflects the neurophysiological substrate of the negative cognitions and feelings about one's body.

It is also noteworthy, that beyond neurophysiological data, consistent with previous studies (Fassino and Marzola 2018; Radwan et al. 2019), our results showed that female gender, EDs psychopathology as well as higher BMI were independently associated with body shape concerns, detecting these variables as important risk factors.

Although the present findings are interesting, some limits should be underlined in order to be investigated in future studies. First, although participants self-reported the absence of past and/or current mental disorders (including intellectual disability), a formal structured clinical interview was not performed and the intelligence quotient was not assessed. Secondly, this is a cross-sectional study, thus causal relationships between the associated variables cannot be established and should be investigated through longitudinal studies. Thirdly, we did not investigate EEG functional connectivity during a body-related task, which make our results limited to the RS condition. Fourth, we focused on a sample of university students (i.e., with a limited age range). Previous studies showed that body dissatisfaction could be different across age groups (Fiske et al. 2014), suggesting the possibility that the association

between EEG connectivity patterns and body shape concerns is different across age groups. Furthermore, the socio-economic status has not been assessed as we focused on undergraduate students. Lastly, although the eLORETA software is a reliable tool extensively used in neurophysiological studies to investigate brain connectivity, it has an intrinsic limit in space resolution, particularly in the identification of deep subcortical sources (e.g., ventral striatum), which may be involved in body image disturbances (Gaudio and Quattrocchi 2012).

Despite these limitations, to the best of our knowledge, this is the first RS study, which have investigated the association between EEG connectivity within body image network and body shape concerns in a sample of university students. Investigating the neurophysiological correlates of body shape concerns in non-clinical samples could be a relevant aim in the prevention as well as early understanding of mental illnesses etiology associated to this construct. In conclusion, our results showed that increased gamma connectivity between the left and right PFC might be considered a crucial feature in the development and/or maintenance of body shape concerns, reflecting the neurophysiological substrate of the negative thoughts and feelings about one's body.

Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

Ethical approval All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards.

Informed consent Informed consent was obtained from all individual participants included in the study.

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