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ORIGINAL ARTICLE

The effect of acute effort on EEG in healthy young and elderly subjects

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Abstract The effects of physical exercise on mental health have been extensively investigated, mainly in older people. Recent studies have looked into the acute effect of exercise on the brain using standardized low-resolution brain electromagnetic tomography (sLORETA). We assessed EEG power and mood changes after 20 min of aerobic exercise in elderly ($N = 10$) and young ($N = 19$) healthy individuals. Both groups showed improvement in total mood disturbance (TMD) post exercise (young: $P = 0.03$; elderly: $P = 0.02$). Only the young group showed significant improvement in anger ($P = 0.05$) and vigor ($P = 0.006$). Comparison pre versus post-exercise for each group separately revealed significant changes in the young group (an increase in alpha, beta-1 and beta-2 activity in Brodmann areas 24, 33 and 23, respectively). However, the elderly group did not show significant changes. An inverse correlation was found between alpha asymmetry and STAI (rs = −0.50; $P = 0.029$) in the young group. On the other hand, a significant correlation between beta-1 activity and TMD was observed in the elderly group (rs = 0.67; $P = 0.045$). We conclude that acute exercise can have distinct effects on brain activity and mood variables in young individuals when compared with elderly adults. However, additional studies are necessary to further investigate the role of exercise intensity in these results.

Keywords Exercise · LORETA · Electroencephalogram · Mood · Aging

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Introduction

The effects of physical exercise on mental health have been extensively investigated (Deslandes et al. 2009; Deslandes et al. 2010). Studies have concluded that chronic (Netz and Wu 2005) as well as acute exercise (Reed and Ones 2006) can produce significant improvement in mood and anxiety. A possible mechanism that explains these responses are the release of neurotransmitters, endocabinnoides, and opioids upon exercise (Boecker et al. 2008; Sarbadikari and Saha 2006; Dietrich and McDaniel 2004). However, it is necessary to apply neuroimaging techniques such as positron emission tomography (PET) and single-photon emission computed tomography (SPECT) to investigate neurotransmitter activity in the brain. These tools are infrequently used due to their high cost and the methodological difficulties involved. The electroencefalogram (EEG) is a common and affordable technique in clinical and sports research. To understand the effects of exercise on the brain, several studies have investigated EEG activity either after or during exercise (Kubitz and Mott 1996; Kubitz and Pothakos 1997; Mechau et al. 1998; Oda et al. 1999; Woo et al. 2009; Schneider et al. 2009a; Moraes et al. 2007). EEG activities originate in cortical generators and are modulated via neurotransmitters (Olejniczak 2006). Glutamate and GABA modulations occur during states of alertness, and cholinergic, adrenergic, and serotonergic modulations occur during transitional states of alertness or recovery after exercise (Sterman 1996; Olejniczak 2006).

Although EEG studies have shown that increases in alpha (8–12 Hz) power after exercise are associated with mood improvement, anxiety decrease and calmness, these results are empiric. Recently, standardized low-resolution brain electromagnetic tomography (sLORETA) (Schneider et al. 2009b, 2010) has been used to evaluate the effects of exercise on the brain. This analysis shows cortical activity changes at EEG derivations and their corresponding Brodmann areas (BA) or cerebral gyri, and it offers reliable spatial and temporal detection of brain cortical activity (Pascual 2002). Thus, it is possible to make inferences about the brain areas activated after exercise. Recent studies using EEG and sLORETA found changes mostly in frontal areas responsible for emotional processing and areas associated with language processing and motor coordination (Woo et al. 2009; Schneider et al. 2009b, 2010).

Nonetheless, the beneficial effects of acute exercise are not specific to any age over the life cycle. Several studies have shown an improvement in mood for elderly people after exercise (Netz and Wu 2005; Arent et al. 2000; Pierce and Pate 1994). According to a previous meta-analysis, the magnitude of the effects of exercise on mood in older adults is similar to that found in younger adults (Arent et al. 2000). However, psychological well-being is a multifaceted phenomenon consisting of emotional functioning as well as satisfaction with life (Gauvin and Spence 1996). Also, it is worth noting that older adults can show greater effects in constructs related to self-perception and global well-being (Netz and Wu 2005). Moreover, few studies have investigated the acute effects of exercise on the EEG in older adult. Shibata et al. (1997) have observed increase of the alpha activity following aerobic exercise.

Studies have shown that the relationship between alpha activity and emotional processes might depend on the hemisphere being analyzed. A relatively left frontal alpha increase might be associated with negative affect, whereas relatively right alpha increase might be related to positive affect (Davidson et al. 1990). However, whether this hypothesis remains throughout the aging process is still inconclusive. Hall and Petruzzello (1999) showed that frontal asymmetry significantly predicted positive affect in physically fit elderly adults, while in the low-active group frontal asymmetry significantly predicted negative affect. Therefore, it is still necessary to study the effects of exercise in other frequency bands of the EEG, in different cortical areas, and to investigate these changes in BA areas through sLORETA analysis in elderly individuals.

Our purpose in the present study was to examine the effects of a single bout of aerobic exercise on the EEG (using sLORETA) and mood in young and elderly healthy subjects. We hypothesized that after exercise both groups would present mood improvement and anxiety decreases. Also EEG changes were expected predominantly in frontal alpha for the young and the elderly group. However, changes would be less evident in elderly individuals due to the aging process.

Methods

Participants

Elderly ($n = 10$) (age above 60 years) and young ($n = 19$) (age between 20 and 30 years) healthy subjects were recruited in local fitness centers. They were considered to be in good physical and mental health according to a questionnaire (First et al. 1997). Subjects who were left-handed, illiterate, and/or had any psychiatric or clinical comorbidity were excluded from the sample. We included individuals who were classified at least as moderately active according to the American College of Sports Medicine and the American Heart Association (Haskell et al. 2007) for at least 6 months prior to entering the study. They were instructed not to drink any alcohol the day before and also not to drink anything containing caffeine on the day of the experiment. Each participant signed the informed consent form, and the experiment was approved by the institutional ethics committee.

Procedure

The procedure consisted of two visits to the laboratory in the afternoon: subjects were evaluated before and 15 min after a single bout of aerobic exercise. All subjects completed the Profile of Mood States (POMS) (Mc Nair et al. 1971) and the State Trait Anxiety Inventory (STAI) (Spielberg et al. 1970) before and after exercise. Moreover, resting EEG was collected for 8 min. A scale for perceived exertion (Borg Scale) (Borg 1998) was applied before and during (10 min approximately) the aerobic exercise. The exercise consisted of 20 min of cycle exercise at an intensity of 80% of their age-predicted maximal heart rate (Karvonen et al. 1957).

Instruments

Anxiety inventory

The state and trait anxiety inventory (STAI) is used to quantify subjective components associated with anxiety (Spielberger et al. 1970). The state scale consists of 20 statements that evaluate how respondents feel “right now, at this moment” (1, not at all; 2, somewhat; 3, moderately so; 4, very much so), and the trait scale assesses how respondents feel “generally”. Only the state scale was used in the study.

Mood scale

Profile of mood states (POMS) was used to assess mood states prior and following exercise (Mc Nair et al. 1971). All subjects in the present study were asked to indicate how they felt “right now”. Measures of tension, fatigue, depression, vigor, confusion, and anger were assessed through the use of 35 adjectives. The respondent rated each item on a 5-point scale ranging from “Not at all” to “Extremely”. Additionally, a global measure of Total Mood Disturbance (TMD) was calculated using the algorithm [(tension + depression + anger + fatigue + confusion) − vigor] and added to a constant of 100 to prevent a negative global result. An increase in TMD score is associated with worsening of mood, whereas a decrease in TMD is associated with mood improvement.

Rating of perceived exertion

Ratings of overall perceived exertion and perceived exertion in the active muscle were assessed using the Borg’s scale with scores ranging from 6 to 20, where 6 means “no exertion at all” and 20 means “maximal exertion”.

EEG data reduction and analysis

The EEG was recorded for 8 min in a relaxed sedentary position from the 20 monopolar electrodes sites (Fz, Cz, Pz, Oz, Fp1, Fp2, F3, F4, F7, F8, C3, C4, T3, T4, T5, T6, P3, P4, O1, O2). International 10/20 system (referred to linked earlobes) for electrode placement was used with a Braintech 3000 (EMSA-Medical Instruments, Brazil). Eye-movement (EOG) artifact was monitored with a bipolar electrode montage using two 9-mm diameter electrode attached superior to and on the external canthus of right eye. Impedance for EEG and EOG electrodes were under 5 and 20 KΩ, respectively. The EEG was recorded by means of the software ERP Acquisition (Delphi 5.0®, Borland-Inprise), developed at the Brain Mapping and Sensorimotor Integration Lab, employing the following digital filters: notch (60 Hz), high-pass of 0.16 Hz and low-pass of 35 Hz. Data were digitized at 240 Hz with a 12-bit resolution, an average reference was used a posteriori.

EEG data were analyzed with two methods: (1) EEG asymmetry according to Davidson’s hypothesis (Davidson et al. 1990) and (2) sLORETA analysis. Each analysis will be described in detail next.

1. EEG asymmetry: visual inspection was employed for detection and elimination of artifacts. Epochs contaminated by blinks, eye movements, and movement-related artifacts were excluded from analyses using a rejection criterion of ±100 µV on any channel. This criterion produced artifact-free data, as verified by direct visual inspection of the raw data. Moreover, Independent Component Analysis (ICA) in EEGLAB was applied to remove other possible sources of artifacts, such as sweating and muscular tension (Delorme and Makeig 2004). A classic Power Spectral Density (PSD) estimator was used (i.e. based on the squared absolute value of the Fourier Transform) for artifact-free 2-s EEG epochs (spectral resolution: 0.25 Hz) with Hamming windowing. An overlapping factor of 50% (2 s) was used for consecutive epochs. EEG measures were log-transformed (i.e. $X' = \log_n X$) to acquire Gaussianity. The resulting frequency spectra were divided into six frequency bands (delta = 0.5–3.5 Hz; theta = 4–7.5 Hz; alpha = 8–12 Hz; beta1 = 13–18 Hz; beta2 = 18–30 Hz) (Niedermeyer and Silva 2005). For the asymmetry calculation, the delta of a homologous pair of electrodes (lnF4–lnF3) was computed for delta, theta, alpha, beta-1 and beta-2 frequency bands (Davidson et al. 1990). Moreover, analysis of absolute power for specific hemispheric was performed.
2. Localization of EEG activity—sLORETA analysis: low-resolution brain electromagnetic tomography (LORETA) represents a new approach to addressing the limited spatial resolution of the EEG and, moreover, permits a 3-dimensional tomography of electrical brain activity. Thus, sLORETA images represent the standardized electric activity at each voxel in neuroanatomic Montreal Neurological Institute (MNI) space as the exact magnitude of the estimated current density. Anatomical labels as Brodmann areas are also reported using MNI space, with correction to Talairach space (Brett et al. 2002). The intracerebral volume is partitioned in 6,239 voxels at 5 mm spatial resolution. A minimum of 120 2-s epochs of artifact-free resting EEG were exported for further analysis using the sLORETA software provided by the KEY Institute for Brain-Mind Research (University Hospital of Psychiatry, Zurich, Switzerland; http://www.uzh.ch/Keyinst/NewLORETA/LORTA01.htm). Next, data were log-transformed and calculated in delta, theta, alpha, beta-1

and beta-2 activity for each subject in each group. Using the sLORETA transformation matrix, cross-spectra of each subject and for each frequency band were transformed to sLORETA files.

Statistical analysis

General measures

For age, weight, height, heart rate, and Borg scale scores a *t* test for independent samples was used to assess differences between the two groups.

sLORETA

An independent *t* test was used to compare the difference between groups and moments ("elderly group post-exercise" minus "elderly group pre-exercise") versus ("young group post-exercise" minus "young group pre-exercise"). Furthermore, a pre- versus post-exercise comparison was carried out for each group separately, using a paired sample *t* test. After a critical threshold was defined ($t_{critical}$), voxels with statistical values exceeding this threshold were accepted. The omnibus hypothesis (that all the voxel hypotheses are true) was rejected if a voxel value exceeded the critical threshold for $P < 0.05$ defined by 5000 randomizations. Voxel-by-voxel *t* values in Talairach space were displayed as Statistical Parametric Maps (SPMs).

Frontal asymmetry and absolute power

The association between frontal alpha asymmetry (lnF4–lnF3) and mood scale values after exercise was assessed using Spearman's correlation for each frequency band and each group. Moreover, an analysis of variance (ANOVA) with repeated measures was used for each frequency band (delta, theta, alpha, beta-1 e beta-2). Hemispheres (lnF4 vs. lnF3) and moments (pre-exercise vs. post-exercise) were the two within-subjects factors, and group (young vs. elderly) was the between-subjects factor.

Mood scales

Shapiro–Wilk test revealed a non-normality of distribution and Levene's test showed heterogeneity of variance for POMS and STAI data. Therefore, a Mann–Whitney test was used to compare delta scores ("post-exercise" minus "pre-exercise") between groups for the POMS and STAI tests. For the comparison between moments (pre-exercise vs. post-exercise), Wilcoxon test was employed for each group separately. The level of significance adopted for this study was $P < 0.05$.

Results

General measures

Age and heart rate values (during exercise) were significantly different between groups ($P < 0.001$; $P < 0.001$). Height, weight, and Borg scale scores were not statistically different ($P = 0.14$; $P = 0.32$; $P = 0.99$) (Table 1).

sLORETA

Although changes ("post exercise" minus "pre-exercise") between groups did not reach significance ($t_{critical}$ for $P < 0.1 = 5.37$; $P < 0.05 = 5.84$; $P < 0.01 = 6.85$), the results revealed higher theta ($t = 3.73$), alpha ($t = 3.25$), beta1 ($t = 4.38$), beta2 ($t = 2.70$), and lower delta ($t = 4.60$) non-significant values in the young compared with the elderly group. However, when a pre- versus post-exercise comparison was made separately for each group, different results were obtained. Specifically, the young group ($t_{critical}$ for $P < 0.1 = 6.77$; $P < 0.05 = 5.66$; $P < 0.01 = 5.14$) revealed a significant increase of alpha ($t = 6.20$) in the cingulate gyrus (BA 24). Moreover, beta-1 ($t = 6.19$) and beta-2 ($t = 6.47$) activities increased in the anterior cingulate (BA33) and posterior cingulate cortex (BA23), respectively. Delta ($t = 2.76$) and theta ($t = 4.10$) increases were not statistically significant (Fig. 1). The result of the elderly group, on the other hand, did not achieve statistical significance ($t_{critical}$ for $P < 0.1 = 15.05$; $P < 0.05 = 10.94$; $P < 0.01 = 9.35$). There was a non-significant increase in theta ($t = 6.09$), alpha ($t = 4.07$), beta1 ($t = 4.73$) and beta2 ($t = 7.34$), and a non-significant decrease in delta ($t = 4.67$).

Frontal asymmetry analyses and absolute power

The correlation between lnF4–lnF3 asymmetry and mood scales (POMS and STAI) was performed with post-exercise values for each group separately. An inverse correlation was found between alpha asymmetry and STAI (rs = −0.50; $P = 0.029$) for the young group (Fig. 2). In

Table 1 Descriptive analysis

	Elderly ($N = 10$)	Young ($N = 19$)
Age (years)*	70.4 ± 7.0	25 ± 1.5
Weight (Kg)	62.1 ± 9.4	67 ± 13.9
Height (cm)	162.2 ± 6.8	167.3 ± 9.6
RPE (score)†	12.2 ± 0.41	12.2 ± 0.42
Heart rate (bpm)*,†	119.6 ± 5.6	155.9 ± 1.1

Data are reported as mean ± SE

RPE ratings of perceived exertion (Borg scale)

* Difference between groups $P \leq 0.01$

† During the exercise

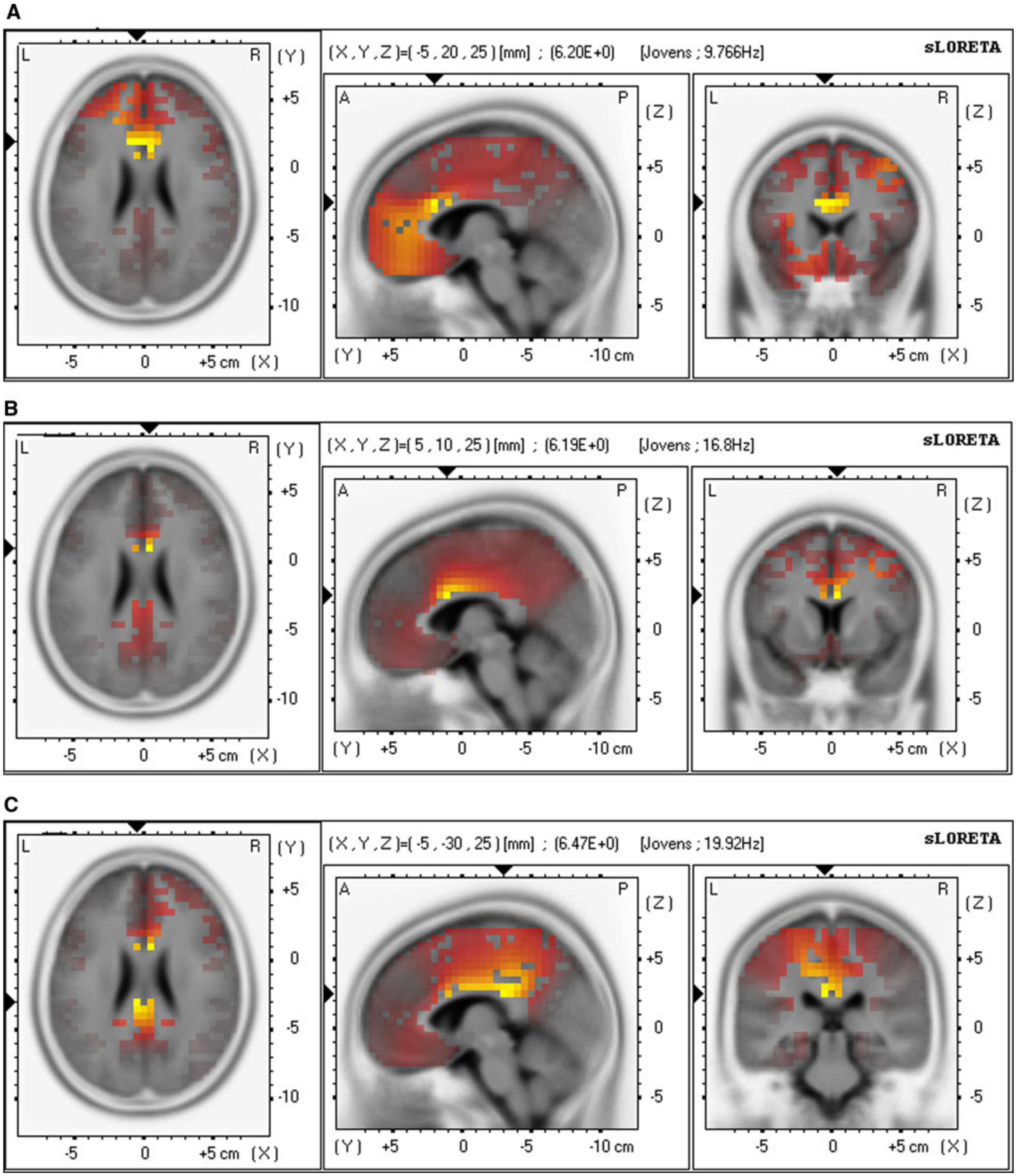

Fig. 1 Statistical parmetrics maps (voxel-by-voxel) of sLORETA differences comparing pre versus post exercise in the young group. **a** alpha activity, **b** beta1 activity, **c** beta2 activity. *Red* and *yellow colors* indicate significant increase in POST measurement shown for BA 24 (**a**), BA 33 (**b**) and BA 23 (**c**). For *X* (− represent left, + represent right), *Y* (− represent posterior, + represent anterior), *Z* (− represent inferior, + represent superior)

addition, a significant correlation between beta-1 activity and TMD (rs = 0.67; $P = 0.045$) was observed for the elderly group (Fig. 3).

The ANOVA run for alpha power values revealed a main effect of moment ($F = 11.037$; $P = 0.003$) (Fig. 4) and an interaction between hemisphere and moment ($F = 3.887$;

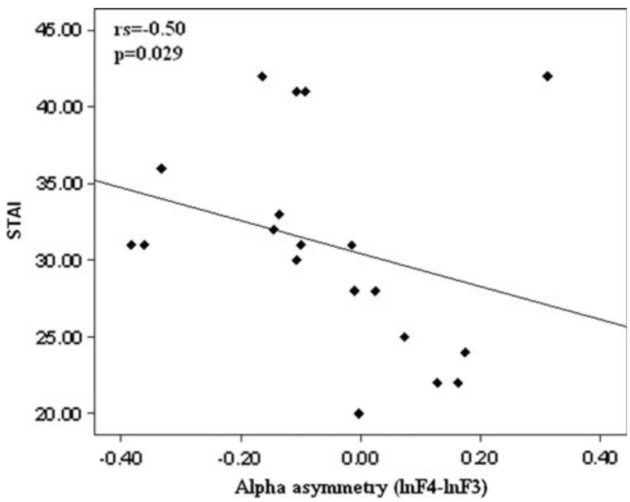

Fig. 2 Correlation between State and Trait Anxiety Inventory (STAI) and alpha asymmetry in the young group after exercise

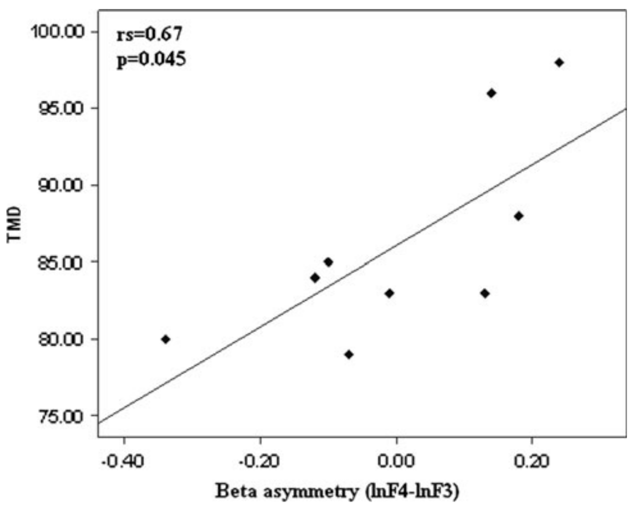

Fig. 3 Correlation between TMD (Total Mood Disturbance) and frontal beta asymmetry in the elderly group after exercise

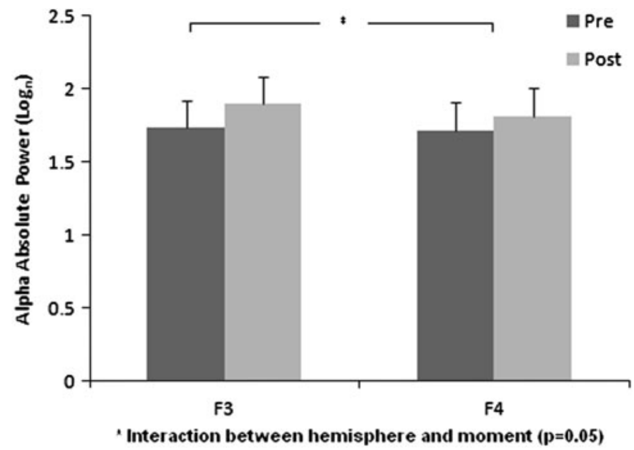

Fig. 4 Alpha log absolute power in the two homologous sites (F3 and F4) pre and post exercise. Data are reported as mean ± SE

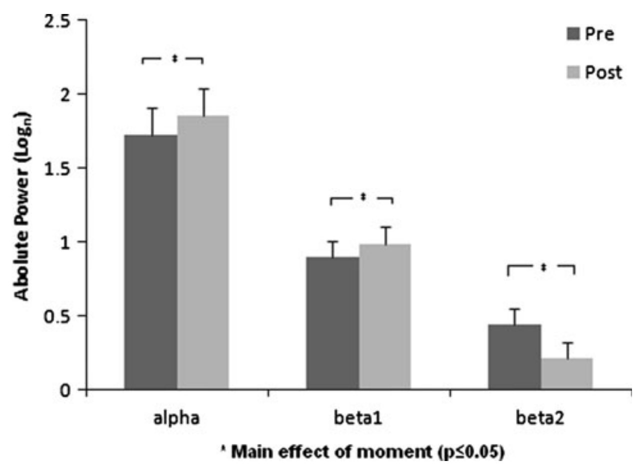

Fig. 5 Alpha, beta1 and beta2 log absolute power values pre and post exercise. Data are reported as mean ± SE

$P = 0.054$) (Fig. 5), with a more prominent increase of alpha power in the left hemisphere after exercise. Although there was a significant main effect of group ($F = 4.303$; $P = 0.048$), it should be noted that this significance was possibly pre-existent, since there was no interaction between moment and group ($F = 0.50$; $P = 0.486$). As for delta, there was only a main effect of hemisphere ($F = 7.43$; $P = 0.011$) and no difference was observed between groups ($F = 2.552$; $P = 0.122$). Moreover, there was no significant result for theta. For beta1 and beta 2, only a main effect of moment was observed ($F = 10.02$, $P = 0.004$; $F = 15.03$, $P = 0.001$, respectively) (Fig. 4).

Mood scale

Young and elderly groups did not show any significant difference with respect to the delta scores (tension: $P = 0.92$; depression: $P = 0.66$; anger: $P = 0.66$; vigor: $P = 0.26$; fatigue: $P = 0.43$; confusion: $P = 0.92$; STAI: $P = 0.18$; TMD: $P = 0.69$). However, the pre- versus post-exercise comparison revealed statistical differences. Significant decreases were found in TMD scores, indicating mood improvement for both groups (young: $P = 0.03$; elderly: $P = 0.02$). Moreover, only the young group showed significant improvement in the anger ($P = 0.05$) and vigor ($P = 0.006$) subscales of the POMS (Table 2).

Discussion

The purpose of the study was to examine the effects of acute exercise on mood and EEG activity in young and elderly individuals. Both groups showed a decrease in TMD, but only the young group showed a significant increase in vigor and a decrease in anger. sLORETA results revealed

Table 2 Results of mood and anxiety scales in the young and the elderly groups [median (interquartil 25–75%)]

		Elderly ($N = 10$)	Young ($N = 19$)
STAI	Pre	22.5 (20.0–29.0)	32.0 (28.5–38.0)
	Post	21.5 (20.0–8.5)	30.0 (26.0–34.0)
Tension	Pre	1.0 (1.0–2.7)	4.0 (2.5–6.0)
	Post	1.0 (0.0–2.0)	3.0 (1.0–4.5)
Depression	Pre	0.0 (0.0–0.0)	0.0 (0.0–0.0)
	Post	0.0 (0.0–0.0)	0.0 (0.0–0.0)
Anger	Pre	0.0 (0.0–0.0)	0.0 (0.0–0.5)*
	Post	0.0 (0.0–0.0)	0.0 (0.0–0.0)
Vigor	Pre	18.0 (15.7–19.7)	16.0 (13.0–20.0)**
	Post	19.0 (19.0–20.7)	18.0 (15.0–21.5)
Fatigue	Pre	2.5 (1.0–3.7)	2.0 (0.0–5.5)
	Post	0.0 (0.0–1.5)	2.0 (1.0–4.0)
Confusion	Pre	2.5 (2.0–3.7)	3.0 (2.0–4.5)
	Post	2.0 (2.0–2.7)	3.0 (1.0–4.0)
TMD	Pre	88.5 (87.2–95.0)*	93.0 (87.5–95.0)*
	Post	84.5 (83.0–87.2)	90.0 (86.0–97.0)

Comparison between groups and pre- versus post- exercise

* Difference between moments $P \leq 0.05$

** Difference between moments $P \leq 0.01$

significant alpha, beta-1, and beta-2 increases in BA 24, 33, 23, exclusively in the young group. In contrast, the elderly group did not show significant changes. Frontal asymmetry correlations between EEG activity and mood scale also revealed different results between groups. These results were partially consistent with the study hypothesis.

The mood results of the present study are in line with previous studies that also found increases in vigor (Bartholomew et al. 2005; Hoffman and Hoffman 2008; Pierce and Pate 1994) and decreases in anger (Bartholomew et al. 2005; Pierce and Pate 1994) after acute exercise in young adults. On the other hand, the results of the elderly group were discrepant from previous studies that showed a decrease in pleasant-feeling states (Focht et al. 2007), as well as an improvement in vigor and decrease in tension, depression, anger, and fatigue in older adults after exercise (Pierce and Pate 1994). However, these studies focused on sedentary elderly subjects (Focht et al. 2007) and different types and intensities of exercise (Focht et al. 2007; Pierce and Pate 1994). In the present study, the intensity of exercise may have influenced the different results between the groups. The intensity of exercise was based on the age-predicted maximal heart rate, which may provide higher estimates in young and lower estimates in elderly subjects. In this context, the 80% HR_{max} intensity might be associated with different effort levels and might be influenced by age and training level. Moreover, according to Ekkekakis (2009), positive psychological results after exercise can be more significant when self-selected exercise intensities are used. Several factors related to the participants' characteristics (past activity behavior), to exercise itself and also to subjective psychological well-being need further investigation (Focht et al. 2007; Netz and Wu 2005).

We did not observe any difference between groups on the EEG using sLORETA. However, separate pre- versus post-exercise comparisons showed significant results only for the young group. In the present study, the sLORETA analysis revealed an increase in alpha and beta-1 activity after exercise localized in the cingulate gyrus and anterior cingulate area (BA 24, BA33, respectively), and beta-2 increase in the posterior cingulate (BA23). However, previous studies showed different results employing specific exercise methodologies (Schneider et al. 2009a, 2010). A recent study found an alpha increase in BA8 (left frontal gyrus) after treadmill exercise (Schneider et al. 2010). Using exhaustive bike exercise, another study found increases in alpha and beta in BA7 (parietal lobe) and BA 23, 31 (limbic lobe) (Schneider et al. 2009b, 2010). Several variables, such as room temperature (Nybo and Nielsen 2001), type of exercise (Oda et al. 1999; Youngstedt et al.1993), intensity (Schneider et al. 2009a, b), duration of exercise (Woo et al. 2009), and the time frame of measurement after exercise (Kubitz and Pothakos 1997; Schneider et al. 2009b, 2010), could influence the effects of exercise on the EEG. Specifically with respect to the sLORETA results, the findings of the present study may diverge from previous studies due to the lower number of electrodes used.

The lack of significant sLORETA results for the elderly group could be explained by brain changes associated with aging. Some studies suggest that brain electrical activity from multiple recording sites becomes more homogeneous in old age due to less neural specificity in the cortical system (Dustman et al. 1996). Moreover, Kubitz et al. (1997) postulated that during recovery after exercise, brain activation is regulated by graded frequency generators via cholinergic, adrenergic, and serotonergic inputs to thalamic relay cells. However, such mechanism can be different in elderly groups since alterations in numerous neurotransmitters occur during normal aging (Mattson and Magnus 2006). Although the effects of exercise in the elderly group can be explained by the aging process, the small number of subjects included in this group might also have influenced the results.

The alpha absolute power analysis showed a more pronounced increase (i.e. decrease in activity) in the left frontal area when compared with the right frontal area after exercise, but with no significant differences between the groups. Such an analysis done separately for each electrode is helpful in identifying the changes specific to each hemisphere. However, for the correlation with mood, the asymmetry index should be used instead (Coan and Allen 2004). We observed an inverse correlation between frontal alpha asymmetry and anxiety in the young group. The results are in line with Davidson's hypothesis, i.e. that frontal asymmetry is positively correlated to positive affect and inversely correlated to negative affect (Davidson et al. 1990). In contrast, beta-1 was positively correlated to TMD in the elderly group. These findings could have been influenced by several factors, such as age, frequency band analyzed, and exercise intensity.

The changes in cortical activity produced by exercise can be associated with an increase in body temperature (Rasmussen et al. 2004) and hyperventilation (Kraier et al. 1992). Moreover, the visceral afferent feedback hypothesis predicts a decrease in brain activity during exercise due to neuroregulatory feedback from the heart to the brain (Lacey and Lacey 1978). However, studies have questioned if these effects are maintained after exercise. On the other hand, responses in specific Broadmann areas might be explained by other factors. The cingulate cortex may integrate affective and cognitive information (Pizzagalli et al. 2001). Specifically, BA 24 and BA 33 are associated with affect and have extensive connections with the amygdala and periaqueductal gray areas (Devinsky et al. 1995). Moreover, the increased cingulate cortex activity might be a consequence of dopamine release, since this area receives dense dopamine innervations from the ventral tegmental area (Devinsky et al. 1995). Exercise has been shown to promote dopamine release (Sutto and Akiyama 2003) associated with motor movement regulation, motivation, and reward behavior (Knab and Lightfoot 2010). Therefore, significant changes may not have been found in the elderly group due to dopamine system changes particular to the aging process (Allard et al. 2010). Moreover, the effects of exercise in neurotransmitter activity/concentration may be initiated by the activation of brain neurotrophic factors (BDNF) (Sarbadhikari and Saha 2006) and aging itself appears to be associated with decreased BDNF signaling in the brain (Mattson et al. 2004). An animal study showed a higher rate of neurogenesis in young mice runners compared with aged runners (Van Praag et al. 2005), a result which may be interpreted as a sign of diminished response to exercise in the elderly.

In conclusion, it is suggested that acute exercise can produce significant effects on mood in young and elderly individuals, and some specific changes in mood subscales in the young group. Our findings suggest that 20 min of exercise produce changes in cingulate cortex in young subjects. However, elderly individuals did not show significant changes on EEG data. Frontal asymmetry was inversely correlated to anxiety in the young group. On the other hand, frontal asymmetry was positively correlated to total mood disturbance in the elderly group. Future studies are necessary to explain the interaction among physical exercise, EEG, and aging.

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

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