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Cortical alpha rhythms are correlated with body sway during quiet open-eyes standing in athletes: A high-resolution EEG study

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Electroencephalographic (EEG; Be-plus Eb-Neuro©) and stabilogram (RGM©) data were simultaneously recorded in 19 elite karate and 18 fencing athletes and in 10 non-athletes during quiet upright standing at open- and closed-eyes condition in order to investigate the correlation between cortical activity and body sway when the visual inputs are available for balance. Our working hypothesis is that, at difference of non-athletes, athletes are characterized by enhanced cortical information processing as indexed by the amplitude reduction of EEG oscillations at alpha rhythms (about 8–12 Hz) during open- referenced to closed-eyes condition (event-related desynchronization, ERD). Balance during quiet standing was indexed by body "sway area". Correlation between alpha ERD and event-related change of the sway area was computed by a non-parametric test ($p<0.05$). It was found that alpha ERD (10–12 Hz) is stronger in amplitude in the karate and fencing athletes than in the non-athletes at ventral centro-parietal electrodes of the right hemisphere ($p<0.02$). Furthermore, there was a statistically significant correlation in the karate athletes between right ventral centro-parietal alpha ERD and body sway area ($r=0.61$; $p<0.008$): specifically, the greater the alpha ERD, the greater the percentage reduction of the body sway area when the visual inputs were available. These results suggest that parasylvian alpha ERD of the right hemisphere may reflect the cortical information processing for the balance in elite athletes subjected to a long training for equilibrium control.

Keywords: Event-related desynchronization (ERD); Alpha rhythms; Stabilogram; High-resolution electroencephalography (EEG); Sport science; Elite athletes

Introduction

In humans, control of balance during upright standing depends upon the central integration of afferent information from vestibular, somatosensory (proprioceptive, tactile), and visual systems, which constitute a multilink neural network for the control of neck, hip, and ankle joints (Allum and Honegger, 1992). When sensory information from vestibular, somatosensory, or visual systems is inaccurate, balance can be compromised (Horak et al., 1996; Horak and Hlavacka, 2001).

In the above framework, an important issue is the extent to which visual inputs contribute to ensure balance (Amblard and Carblanc, 1980). It has been shown that these inputs are able to reduce self-generated body sway by about 50% in static conditions and might explain part of wide inter-individual differences in the maintenance of balance (Cremieux and Mesure, 1994; Collins and De Luca, 1995).

For a long time, integration of visual, somatosensory, and vestibular inputs for the balance has been investigated at the level of brainstem vestibular nuclei and vestibular–cerebellum (see Kitahara et al., 1998 and Barmack, 2003 for a review). More recently, it has been studied at the level of cerebral cortex; vestibular inputs would reach face/neck representation of primary somatosensory cortex (area 3aV) and would be then integrated with visual and somatosensory inputs in intraparietal (area 2v), posterior end of the insula (parietal insular vestibular cortex, PIVC), and medial superior temporal (MST) cortices (Faugier-Grimaud and Ventre, 1989; Fredrickson et al., 1996; Guldin and Grusser, 1998; Odkvist et al., 1974; Bottini et al., 1994; Fasold et al., 2002; Mikheev et al., 2002). These functional data have extended previous pioneering observations obtained during intra-operative cortical stimulation in humans (Penfield, 1957). On the whole, it can be speculated that posterior parietal and parasylvian

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areas receive vestibular and somatosensory information from face/neck representation of primary somatosensory cortex, visual information from the occipital/parieto-occipital cortex, and motor information from primary, secondary, and supplementary motor cortices (Wise et al., 1997).

Several lines of evidence support the hypothesis that cerebral mechanisms integrating visual, somatosensory, and vestibular inputs for balance become more effective after prolonged sports activities (Sforza et al., 2003). It has been reported that sports activities reduced the risk of falling and improved postural performance in aged people (Bulbulian and Hargan, 2000). Furthermore, it has been documented that, compared to non-athletes, athletes such as gymnasts, soccer players, and swimmers were superior in balance performance (Davlin, 2004). The same was true for athletes of ironman triathlon (Nagy et al., 2004). The peculiar cerebral mechanisms at the basis of the mentioned results are poorly understood, despite their potential importance for sports science and for postural rehabilitation in patients with motor and balance deficits. This might be due to the fact that neurophysiological measurements during upright standing were not systematically co-registered and correlated with subjects' body sway.

In the present study, electroencephalographic (EEG) and stabilogram data were simultaneously recorded in elite karate and fencing athletes and in non-athletes during quiet upright standing at open- and closed-eyes condition in order to investigate the correlation between cortical activity and body sway when the visual inputs are available for balance. Our working hypothesis is that, at difference of non-athletes, athletes are characterized by enhanced cortical information processing as indexed by the amplitude reduction of EEG oscillations at alpha rhythms (about 8–12 Hz) during open- referenced to closed-eyes condition (event-related desynchronization, ERD). Indeed, alpha ERD has been repeatedly associated with active cortical sensorimotor information processing in humans (Pfurtscheller and Aranibar, 1979; Pfurtscheller and Neuper, 1994; Pfurtscheller et al., 1997; Pfurtscheller and Lopes da Silva, 1999; Babiloni et al., 1999, 2002, 2004, 2005). Balance during quiet standing was indexed by body "sway area". Correlation between alpha ERD and event-related change of the sway area was computed by a non-parametric test ($p<0.05$).

Methods

Subjects

Nineteen (9 females) karate athletes, eighteen (12 females) fencing athletes, and ten (4 females) non-athletes participated in the present study. The karate athletes were members of the Italian national karate team who regularly attended international competitions; none of them played fencing at amateur or competitive level. The fencing athletes were members of the Italian national fencing team (sword) who regularly attended international competitions; none of them played karate at amateur or competitive level. The non-athletes were healthy subjects who never played karate and fencing at amateur or competitive level. The subjects' age ranged from 19 to 32 years in the karate athletes, from 19 to 36 years in the fencing athletes, and from 21 to 34 years in the non-athletes (age and gender were used covariates in the statistical analyses). All subjects gave their informed consent according to the Declaration of Helsinki and could freely request an interruption of the investigation at any time. The experimental procedure was approved by the local Institutional Ethics Committee.

Experimental procedure and experimental recordings

The subjects were asked to quietly stand upright upon a 60×60 cm stabilometric force platform (ARGO® by RGM) in front of a white wall (1 m distance from subjects' eyes), in the typical posture of Romberg test (Norre, 1993). Specifically, the subject's feet were closed together, and the arms were kept by the side. The stabilometer recorded amplitude of the subject's body sway in the anteroposterior and medial–lateral directions with an acquisition rate of 100 Hz.

Experiments included four separate recording blocks lasting 40 s each. In two blocks, subjects were asked to keep their eyes open; in the other two blocks, they were asked to keep their eyes closed. Of note, normal individuals tend to sway to some extent in the closed-eyes condition. Therefore, all subjects were reassured that the experimenters would have supported them in the case of imbalance. None of the subjects did require support during the experiments.

While subjects were on the stabilogram, EEG data were continuously recorded (bandpass: 0.01–100 Hz, sampling rate: 256 Hz; EB-Neuro Be-plus©) from 56 scalp electrodes (cap) positioned according to an augmented 10–20 system (see the map in Fig. 1). Electrical reference was located between AFz and FCz, whereas ground electrode was located between Pz and Oz. Electrode impedance was kept lower than 5 kΩ.

In parallel, the recording of bipolar electrooculogram data (EOG; bandpass: 0.1–100 Hz; sampling rate: 256 Hz) served to monitor blinking and eye movements. Furthermore, electromyogram (EMG; bandpass: 0–100 Hz; sampling rate: 256 Hz) from right *anterior tibialis* muscle, right *gastrocnemius lateralis* muscle,

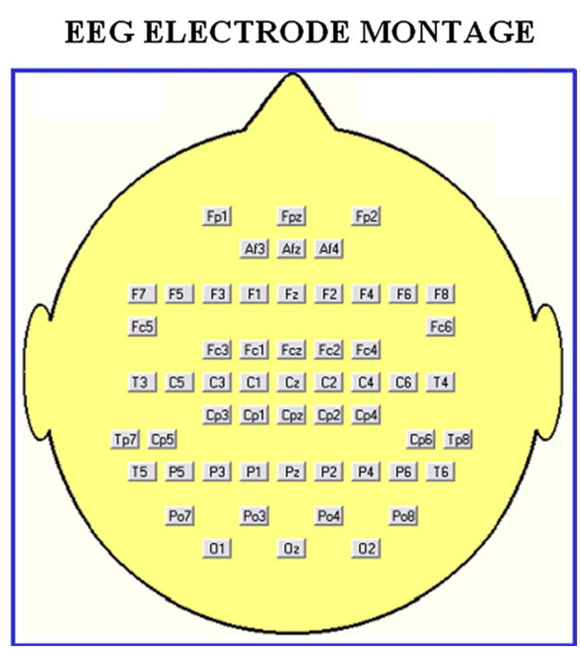


Fig. 1. Electroencephalographic (EEG) electrode montage used in the present study. EEG data were continuously recorded (bandpass: 0.01–100 Hz, sampling rate: 256 Hz; EB-Neuro Be-plus©) from 56 scalp electrodes (cup) according to an augmented 10–20 system (electrical reference between AFz and FCz; ground between Pz and Oz). The EEG recordings were performed while subjects (karate athletes, fencing athletes, non-athletes) were quiet upright standing on a stabilometric platform (stabilogram) in two conditions (open- and closed-eyes).

and right *external oblique* muscle was collected to control muscle activity involved in quiet standing.

Stabilometric data analysis

The stabilometer recorded data allowing the computation of "Sway Area" (SA), which is expressed in mm^2/s. It measures the mean area spanned by the body's center of pressure (COP) during the period of interest for each block (i.e. 40 s). The SA was calculated as the ratio between the following two terms: (i) the area swept by the radius connecting the mean center of pressure (COP) position with each point of the COP described path and (ii) the recording time.

Preliminary EEG data analysis

Recorded EEG–EOG–EMG data were segmented in epochs lasting 2 s each. The EEG epochs with ocular, muscular, and other types of artifacts were identified by a computerized procedure using EEG, EOG, and EMG signals as an input (Moretti et al., 2003). The EEG epochs affected by ocular artifacts were corrected by an autoregressive method (Moretti et al., 2003). The selected EEG epochs were manually verified by expert electroencephalographists (namely, D.P.C. and B.A.) and were used for further analysis.

The spatial information content of the artifact-free EEG epochs was enhanced by surface Laplacian estimation (regularized 3-D spline function; Babiloni et al., 1996, 1998), which acts as a spatial filter of the EEG potential distribution that reduces the effects of head volume conductor and annuls the influence of electrode reference (Nunez, 1995; Babiloni et al., 1996). Laplacian-transformed EEG epochs showing computational artifacts were manually discarded by the mentioned electroencephalographists. The number of Laplacian-transformed artifact-free EEG epochs was lower than 20 in 1 karate athlete and in 1 fencing athlete, thus the data of these two athletes were not further considered. In total, the final results referred to 18 karate athletes, 17 fencing athletes, and 10 non-athletes. In these subjects, the mean number of Laplacian-transformed artifact-free EEG epochs was 34 (±3 standard error, SE) for each condition (i.e. open or closed eyes).

Determination of individual alpha sub-bands

Laplacian-transformed artifact-free EEG epochs of the two corresponding recording blocks were used as an input for EEG power spectrum analysis, which was performed by a standard (Matlab) FFT algorithm using Welch technique and Hanning windowing function. For the determination of the alpha sub-bands, individual alpha frequency (IAF) peak was identified according to literature guidelines (Klimesch, 1996, 1999; Klimesch et al., 1998). Practically, the IAF was defined as the frequency showing the higher power density at 6–12 Hz range of the individual EEGs. With reference to the IAF, the alpha sub-bands of interest were as follows: low-frequency alpha band as IAF − 2 Hz to IAF and high-frequency alpha band as IAF to IAF + 2 Hz. Mean IAF values were 10.2 Hz (±0.2 SE) for the open-eyes condition and 10.3 Hz (±0.3 SE) for the closed-eyes condition in the karate athletes; they were 10.3 Hz (±0.2 SE) for open-eyes condition and 10.3 Hz (±0.2 SE) for closed-eyes condition in the fencing athletes; and they were 10.6 Hz (±0.3 SE) for open-eyes condition and 10.4 Hz (±00.3 SE) for closed-eyes condition in the non-athletes. The IAF values were used as covariate (together with age and gender) in the statistical analyses.

Computation of alpha event-related desynchronization/ synchronization (ERD/ERS)

Changes of the alpha power density during open- referenced to closed-eyes condition were calculated using the popular formula for the computation of event-related desynchronization/synchronization (ERD/ERS; Pfurtscheller and Aranibar, 1979; Pfurtscheller and Neuper, 1994; Pfurtscheller et al., 1997; Pfurtscheller and Lopes da Silva, 1999):

$$\mathrm{ERD/ERS\%} = \frac{(E-R)}{R} * 100,$$

where E indicates the alpha power density during the open-eyes condition and R the alpha power density during the closed-eyes condition. The procedure was repeated for low- and high-frequency alpha sub-bands. Percent negative values (i.e. weaker alpha power density during open- than closed-eyes condition) represented the alpha ERD (Pfurtscheller et al., 1997; Pfurtscheller and Lopes da Silva, 1999), indicating the enhancement of cortical sensorimotor information processing when the visual input was available. On the contrary, percent positive values (i.e. stronger alpha power density during open- than closed-eyes condition) represented the alpha ERS (Pfurtscheller and Lopes da Silva, 1999), indicating the corresponding reduction of cortical sensorimotor information processing.

Topographic mapping of the alpha ERD/ERS

Topographic maps (256 hues) of the ERD/ERS at the two alpha sub-bands were calculated on a 3-D cortical model by a spline interpolating function (Babiloni et al., 1995, 1996). This model is based on the magnetic resonance data of 152 subjects digitized at Brain Imaging Center of the Montreal Neurological Institute (SPM96, www.mni.mcgill.ca) and is commonly considered as an acceptable template for the rendering of group neuroimaging data.

Statistical analysis

Statistical comparisons were performed by analysis of variance (ANOVA). With the ANOVA analysis, Mauchley's test evaluated the sphericity assumption when necessary. Correction of the degrees of freedom was made by Greenhouse–Geisser procedure and Duncan test was used for post hoc comparisons ($p < 0.05$). In total, three statistical analyses were performed to evaluate the main hypotheses of the present study.

Firstly, an ANOVA tested the control hypothesis relative to validity and reliability of the stabilometric data collected during the EEG recordings. The ANOVA had sway area magnitude as a dependent variable, whereas the factors were Group (karate, fencing, non-athletes), Condition (open eyes, closed eyes), and Time (i.e. first and second recording block). The reliability of the stabilometric data implied no statistical difference in sway area in the two blocks of each condition (i.e. first vs. second open-eyes condition; first vs. second closed-eyes condition). The validity of the stabilometric data implied larger sway area in the closed- compared to open-eyes condition, in line with the well known stabilization of the balance given by visual inputs.

Secondly, two ANOVAs (one for each alpha sub-band) tested the hypothesis that, compared to the non-athletes, the elite athletes have alpha power density weaker during open- than closed-eyes condition (i.e. alpha ERD), indicating enhanced cortical information processing when the visual inputs are available. The ANOVA had ERD/ERS amplitude as a dependent variable, whereas the factors were Group (karate, fencing, non-athletes) and Electrode (C5, CP5, Pz, CP6, C6). Age, education and IAF were used as covariates. Remarkably, in the statistical data analysis of the ERD/ERS, we decided to select C5, CP5, Pz, CP6, and C6 electrodes why these electrodes roughly overly face/neck representation of primary sensorimotor areas, posterior parietal, and parasylvian regions supposed to integrate visual, somatosensory, and vestibular information in humans (Fasold et al., 2002). The selection of C5, CP5, Pz, CP6, and C6 electrodes did not make it useless the EEG recordings from the remaining 51 electrodes since the precision of the surface Laplacian estimate improves increasing the number of recording electrodes (Babiloni et al., 1995, 1996).

Thirdly, we correlated alpha ERD and percentage change of the sway area provoked by the visual inputs. This allowed the evaluation of the hypothesis that, compared to the non-athletes, the elite athletes present enhanced correlation between cortical information processing and balance stabilization when the visual inputs are available. The percentage change of the sway area due to the visual inputs was calculated with the same formula used for the computation of the alpha ERD; namely, the percentage of the difference of the sway area during open- and closed-eyes conditions divided by the sway area during the closed-eyes condition. For each group (karate, fencing, non-athletes), the correlation analysis was computed with non-parametric Spearman test ($p<0.05$). The correlation analysis was performed for low- and high-frequency alpha on the electrodes of interest (C5, CP5, Pz, CP6, and C6) showing statistically significant differences at the above ANOVA. Bonferroni correction was applied for the multiple repetition of the correlation analysis (threshold at $p<0.05$ corrected).

Results

Stabilometric data

Fig. 2 shows mean (±standard error, SE) values of subjects' body sway area during the first and the second recording block of both conditions (open and closed eyes). These values referred to all three groups (karate athletes, fencing athletes, non-athletes). It is noted that, within each condition, there was no marked difference between first and second recording block, and no marked difference among groups. The ANOVA of the sway area showed a main effect ($F=60.8$, $p<0.0001$) of the factor Condition (open eyes, closed eyes), indicating that all groups had lower body sway area (better balance) during open- referenced to closed-eyes condition. No other statistical effect was observed ($p>0.4$). These results globally confirmed the reliability and validity of the sway area measurements obtained during the EEG recordings.

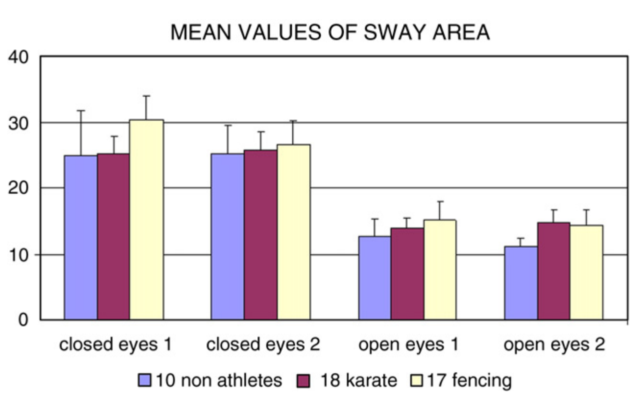


Fig. 2. Mean values (±standard error, SE) of "sway area" indexing the static balance during the first and second recording block of both conditions (open and closed eyes). These values refer to the three groups (karate athletes, fencing athletes, non-athletes).

EEG data

The power density spectra (grand average) of Laplacian-transformed EEG data are shown in Fig. 3 for the electrodes of interest (C5, CP5, Pz, CP6, and C6) roughly overlying face/neck representation of primary sensorimotor, posterior parietal, and parasylvian regions. The figure represents the power density around the alpha range for closed- and open-eyes condition in the karate athletes, fencing athletes, and non-athletes during quiet standing. In all groups, there was a certain decrement of the alpha power density during open- than closed-eyes condition (i.e. alpha ERD). Fig. 4 maps fine topographical details of low- and high-frequency alpha ERD/ERS during open- referenced to closed-eyes condition as a baseline. In all groups, the alpha ERD was more represented in the parietal-occipital regions. Furthermore, its amplitude was higher in the athletes than in the non-athletes.

The ANOVA for the low-frequency alpha ERD/ERS showed no statistically significant results ($p>0.1$) and was not further considered.

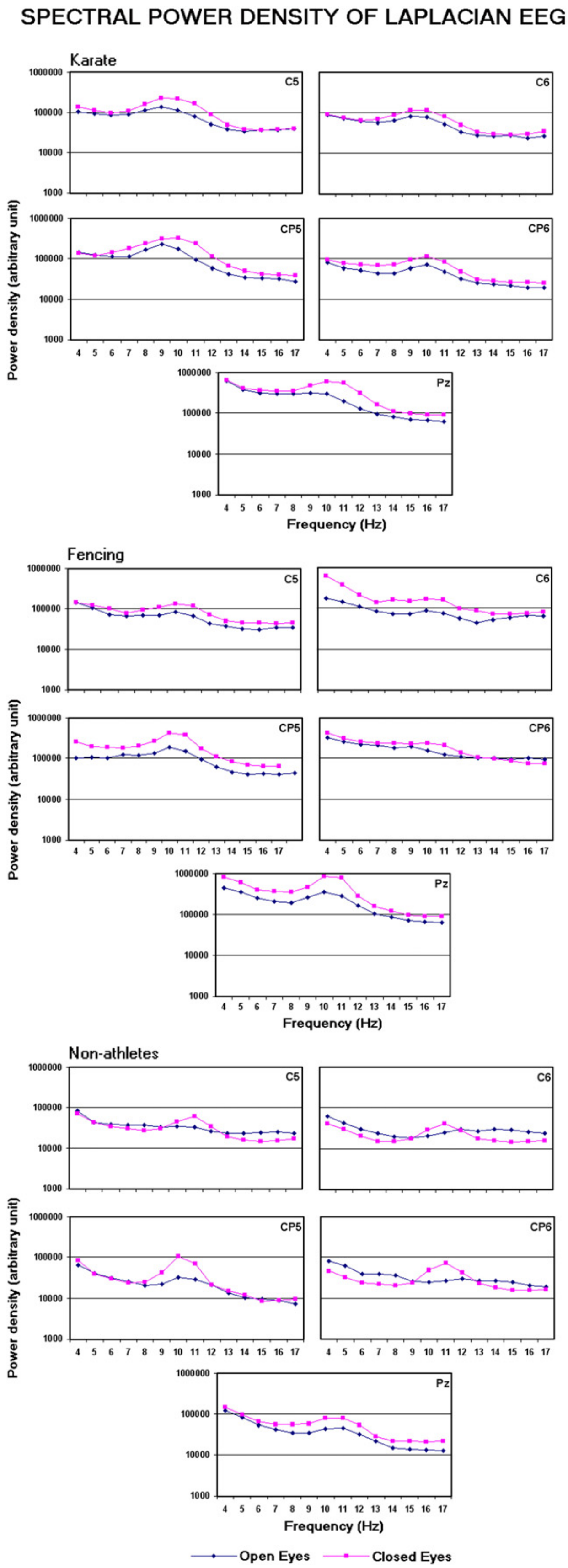
The ANOVA for the high-frequency alpha ERD/ERS pointed to a statistically significant interaction ($F=1.98$; $p<0.05$) between the factors Group (karate athletes, fencing athletes, and non-athletes) and Electrode (C5, CP5, Pz, CP6, and C6). Duncan post hoc testing indicated that the high-frequency alpha ERD was higher in amplitude in the karate athletes than in the non-athletes at C6 ($p=0.02$) electrode. Furthermore, the high-frequency alpha ERD was higher in amplitude in the fencing athletes than in the non-athletes at CP6 ($p=0.01$) and C6 ($p=0.004$) electrodes. The fencing athletes showed an increase of the alpha ERD compared to the non-athletes, but it did not reach the statistical threshold. Fig. 5 illustrates the mean alpha ERD/ERS values relative to this statistical interaction.

Correlations between stabilometric and EEG data

According to the above ANOVA results, the correlation analysis was performed between high-frequency alpha ERD and stabilometric data in the karate athletes, fencing athletes, and non-athletes at CP6 and C6 electrodes (6 repetitions of the correlation analysis gave a Bonferroni corrected statistical threshold of $p<0.008$). Results of the Spearman test showed no statistically significant results in the fencing athletes and in the non-athletes at the mentioned electrodes ($p>0.05$). In the karate athletes, the high-frequency alpha ERD at CP6 correlated with the percentage change of the body sway area due to the visual inputs ($r=0.61$, $p=0.008$, $N=18$) (Fig. 6).

Control analysis

As previously mentioned, a statistically significant correlation between alpha ERD and body sway area was found only in the karate athletes (CP6 electrode), who have been subjected to a long



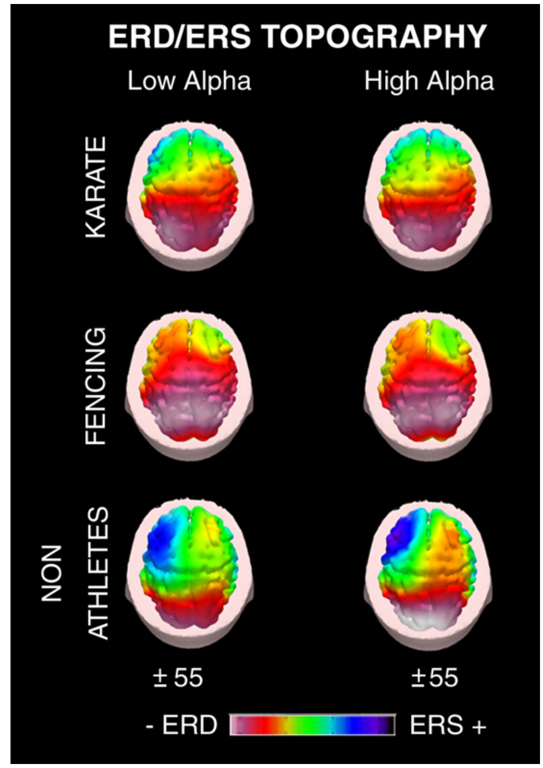


Fig. 4. Topographical distribution of low- and high-frequency alpha event-related desynchronization/synchronization (ERD/ERS) relative to open-referenced to closed-eyes condition in the karate athletes, fencing athletes, and non-athletes. Color scale: maximum ERD and ERS are coded in white and violet, respectively. The maximal (%) value of the ERD/ERS is reported under the maps.

training for equilibrium control. A control analysis was performed to evaluate whether the present result changes as a function of the degree of training in athletes. To do so, we recorded EEG and stabilogram data of nine (3 female) amateur karate athletes wearing yellow or orange belt. The subjects' age ranged from 18 to 26 years. We correlated high-frequency alpha ERD at CP6 electrode and percentage change of the sway area provoked by the visual inputs. There was no a significant correlation (r=0.16, p=0.66). However, it should be remarked that the values of correlation were in between that of the non-athletes and that of the elite athletes. Fig. 7 shows the regression lines between high-frequency alpha ERD at CP6 electrode and the percentage change of the sway area due to the visual inputs in the non-athletes, amateur karate athletes, and elite karate athletes.

Discussion

How do elite athletes integrate visual, somatosensory, and vestibular inputs for the balance during upright standing? EEG alpha rhythms are an important neural correlate of thalamo-

Fig. 3. Power density spectra (grand average) of Laplacian-transformed EEG data for the electrodes of interest C5, CP5, Pz, CP6, and C6 (augmented 10–20 system) overlying face/neck representation of primary sensorimotor and parasylvian regions. The graphs represent the power density spectra around the alpha range for the closed- and open-eyes conditions in the karate athletes, fencing athletes, and non-athletes.

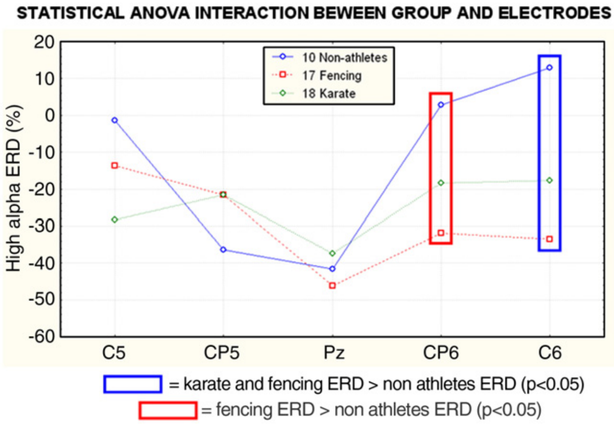


Fig. 5. Across subject means of the high-frequency alpha ERD amplitude illustrating a statistical ANOVA interaction between the factors Group (karate athletes, fencing athletes, and non-athletes) and Electrode (C5, CP5, Pz, CP6, C6). Legend: the rectangles indicate the electrode sites at which alpha ERD presented statistically significant differences among groups (Duncan post hoc testing, $p<0.05$).

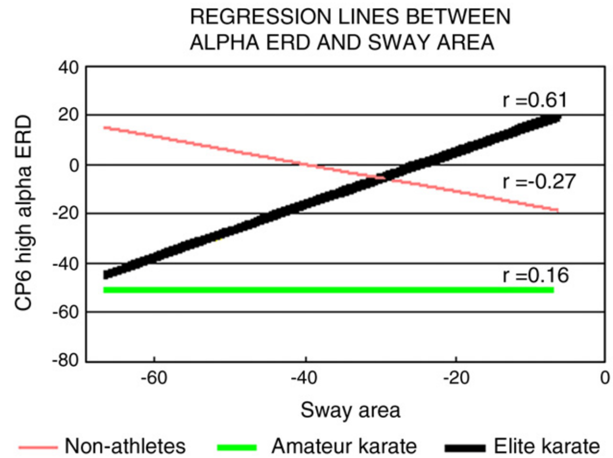


Fig. 7. Regression lines between high-frequency alpha ERD at CP6 electrode and the percentage change of the sway area due to the visual inputs in non-athletes, amateur karate athletes, and elite karate athletes.

cortical and cortico-cortical integrating processes (Nunez, 1995). Indeed, pyramidal cortical neurons generate a pattern of alpha rhythms that changes in amplitude (alpha ERD/ERS at about 8–12 Hz) in association with the opening/closure of bidirectional connections among cortical regions and thalamic nuclei (Pfurtscheller and Lopes da Silva, 1999). In this theoretical framework, we hypothesized that in elite athletes, cortical alpha ERD was related to balance during open-eyes standing. To test that, we recruited elite karate and fencing athletes. Across their career, karate athletes have received a long training to cope with highly demanding visual–somatosensory–vestibular integration. Karate performance includes frequent leg attacks in which one foot remains on the ground to maintain the balance and the other foot is quickly projected very near (without contact) a mobile visuo-spatial target. Instead, fencing performance can be considered as moderately depending on visual–somatosensory–vestibular integration. Indeed, fencers use both feet to maintain the balance in the large majority of the assaults, and their weapon can touch the visuo-spatial target.

The results of the present study showed that the alpha ERD (about 10–12 Hz) was stronger in amplitude in the fencing and karate athletes than in the non-athletes at CP6 and C6 electrodes (right hemisphere). At these electrodes, the fencing athletes just showed a trend for an increase of the alpha ERD compared to the non-athletes. The CP6 and C6 electrodes are situated in the ventral aspect of the central and parietal scalp regions roughly overlying face/neck representation of primary sensorimotor, posterior parietal, and parasylvian areas, which are supposed to integrate visual, somatosensory, and vestibular information in humans (Fasold et al., 2002). In the interpretation of the present results, it should be remarked that surface Laplacian estimation cannot resolve fine topographical details of the cortical activity. Nevertheless, we preferred the surface Laplacian estimation to other advanced techniques for EEG source location (i.e. equivalent current dipole, linear inverse estimation, beamformers) since it does not require a priori assumptions on EEG sources (shape, number, extension, etc.) and on linear vs. nonlinear relationship between these sources and scalp potentials. The mentioned advantages were supposed to be convenient at a so early stage of the research.

One may argue that the above modulation of the right central–parietal alpha ERD could not be fully related to open-eyes standing. At least in part, it could be provoked by mere visual information processes unrelated to balance. To address this issue, we tested the correlation of that alpha ERD with body sway area indexing balance during the quiet standing. It was shown that such a correlation was statistically significant only in the elite karate athletes ($p<0.008$; CP6 electrode), who have been subjected to a long training implying intensive cortical information processing. Specifically, the greater that alpha ERD, the greater the percentage reduction of the body sway area with the use of visual inputs (i.e. greater the improvement of the balance). Of note, this statistically significant correlation was not found in a group of amateur karate athletes, not subjected to a long training for equilibrium control. Furthermore, the values of

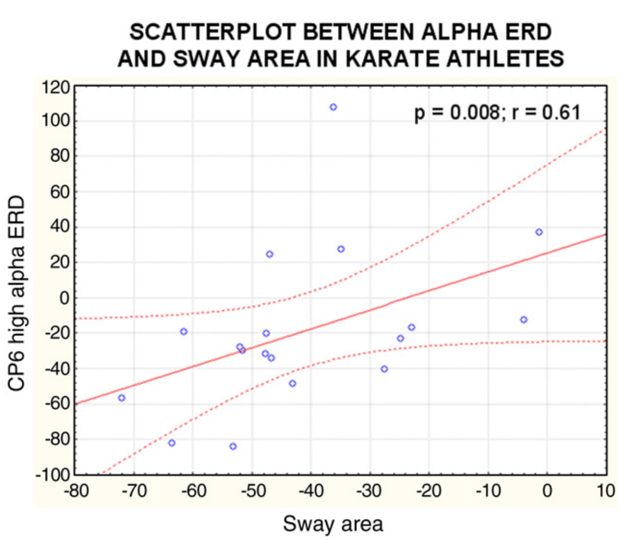


Fig. 6. Scatterplots showing in the karate athletes the correlation between the high-frequency alpha ERD at CP6 and the percentage change of the sway area due to the visual inputs ($r=0.61$, $p=0.008$, $N=18$).

correlation were in between that of the non-athletes and that of the elite athletes in line with the idea that sport training affects alpha rhythms in athletes.

Keeping in mind the limited spatial resolution of the surface Laplacian estimation, the present modulation of the right ventral central–parietal alpha ERD could not be ascribed with precision to the vestibular cortical areas reported in previous studies using high-resolution techniques, namely face/neck representation of primary sensorimotor cortex (area 3a), anterior tip of the intraparietal sulcus (area 2v; Fredrickson et al., 1996), posterior parietal cortex (area 7; Faugier-Grimaud and Ventre, 1989), and parietal insular vestibular cortex (PIVC; Grusser et al., 1990a,b; Fasold et al., 2002). Rather, the merit of the present study was to disclose that modulation of the cortical alpha rhythms may reflect a possible cortical information processing for the balance in elite athletes subjected to a long training for equilibrium control. These alpha rhythms might sub-serve the integration of intra- and extrapersonal space information coming from somatosensory and visual systems with motor and postural memories. The above speculation is compatible with the notion that ventral central–parietal cortices especially of the right hemisphere are concerned with visuo-spatial search, vestibular, and somatic perceptive processes in humans (Penfield, 1957; Rizzolatti and Berti, 1990; Wallace, 1994; Baudena et al., 1995; Farah and Feinberg, 1997; De Renzi, 2000). The present results extend previous findings showing alpha ERD over central and parietal areas during the movement preparation and execution (Pfurtscheller and Neuper, 1994; Neuper and Pfurtscheller, 1996; Andrew and Pfurtscheller, 1997; Pfurtscheller et al., 1997; Babiloni et al., 1999) as well as during the observation of movements performed by others (Babiloni et al., 2002). Furthermore, the present results motivate further studies on elite athletes using vestibular evoked potentials elicited by short-duration angular accelerations to localize with more precision alpha ERD within human vestibular cortical networks. In this regard, previous relevant studies (Schneider et al., 2001; Gacek, 1994; Schwarz, 1994) have shown that the vestibular sensory representation area in humans was located in the posterior part of the frontal lobe (BA4) and the anterior parts of the cerebral parietal lobe (BA1, BA2, BA3). Finally, although the present study is supported by previous literature unveiling that cerebral mechanisms for balance become more effective after prolonged sports activities (Sforza et al., 2003), our results motivate further investigations to address the relationships between cortical activity and body sway in patients with impaired balance.

In conclusion, we hypothesized that cortical alpha ERD was related to balance during open-eyes standing in elite athletes. The results showed that the alpha ERD (about 10–12 Hz) was stronger in amplitude in the karate and fencing athletes than in the non-athletes at ventral centro-parietal electrodes of the right hemisphere ($p<0.02$). At these electrodes, the fencing athletes just showed a trend for an increase of the alpha ERD compared to the non-athletes. Furthermore, there was a statistically significant correlation in the karate athletes between right ventral centro-parietal alpha ERD and body sway area ($p<0.008$): specifically, the greater the alpha ERD, the greater the percentage reduction of the body sway area when the visual inputs were available. These results suggest that parasylvian alpha ERD of the right hemisphere may reflect the cortical information processing for the balance in elite athletes subjected to a long training for equilibrium control.

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