NeuroImage 42 (2008) 1544–1553

Contents lists available at ScienceDirect

NeuroImage

journal homepage: www.elsevier.com/locate/ynimg

Is there a "neural efficiency" in athletes? A high-resolution EEG study

Claudio Del Percio [a,*], Paolo M. Rossini [b,c,d], Nicola Marzano [e], Marco Iacoboni [e], Francesco Infarinato [c,e], Pierluigi Aschieri [f,g], Andrea Lino [f], Antonio Fiore [h], Giancarlo Toran [h], Claudio Babiloni [b,c,i], Fabrizio Eusebi [e,j]

[a] IRCCS S. Giovanni di Dio- Fatebenefratelli, via Pilastroni, 4 – 2512 Brescia, Italy
[b] Associazione Fatebenefratelli per la ricerca, S. Giovanni Calibita- Isola Tiberina, Roma, Italy
[c] Casa di Cura SAN RAFFAELE Cassino and IRCCS SAN RAFFAELE PISANA Roma – Italy
[d] Neurology, Campus Biomedico University, Via Emilio Longoni, 83 - 00155 Rome, Italy
[e] Dipartimento di Fisiologia Umana e Farmacologia, Università "La Sapienza", Roma – Italy
[f] Federazione Italiana Judo Lotta Karate ed Arti Marziali (FIJLKAM), Roma – Italy
[g] Facoltà di Scienze Motorie, Università de L'Aquila, L'Aquila – Italy
[h] Federazione Italiana di Scherma, Roma, Italy
[i] Dipartimento di Scienze Biomediche. Università di Foggia, Foggia – Italy
[j] Neuromed IRCCS, Via Atinense 18, 86077Pozzilli (IS), Italy

ARTICLE INFO

Article history:
Received 26 February 2008
Revised 14 May 2008
Accepted 31 May 2008
Available online 12 June 2008

Keywords:
Movement-related potentials (MRPs)
Electroencephalography (EEG)
Sport science
Elite athletes

ABSTRACT

"Neural efficiency" hypothesis posits that cortical activity is spatially focused in experts. Here we tested the hypothesis that compared to non-athletes, elite athletes are characterized by a reduced cortical activation during visuo-motor tasks related to the field of expertise, as a function of movement side. EEG data (56 channels; EB-Neuro) were continuously recorded in the following right-handed subjects: 11 non-athletes, 11 elite fencing athletes, and 11 elite karate athletes. During the EEG recordings, they observed pictures with fencing and karate attacks, and had to quickly click a right (left) keyboard button for the attacks at right (left) monitor side. The EEG data were averaged with respect to the movement onset, and were spatially enhanced by surface Laplacian estimation. The potentials related to the preparation (readiness potential) and initiation (motor potential) of the movements were measured. For the right movement, the potentials overlying supplementary motor and contralateral sensorimotor areas were higher in amplitude in the non-athletes than in the elite karate and fencing athletes. Furthermore, the amplitude of the motor potential over ipsilateral sensorimotor area was higher in the elite karate than fencing athletes, and its distribution over bilateral sensorimotor areas was less asymmetrical in the karate than in the other two groups. For the left movement, these potentials showed no difference between the groups. The present results suggest that "neural efficiency" hypothesis does not fully account for the organization of motor systems in elite athletes. "Neural efficiency" would depend on several factors including side of the movement, hemisphere, and kind of athletes.

Introduction

Previous neuroimaging studies using positron emission tomography (PET), single photon emission computed tomography (SPECT), and functional magnetic resonance imaging (fMRI) have shown that subjects best-scorers to tests probing intelligent quotient, word fluency, spatial skills, and working memory, present weakest fronto-parietal activation during cognitive tasks (Haier et al., 1988, 1992, 2004; Charlot et al., 1992; Parks et al., 1988; Rypma and D'Esposito 1999; Rypma et al., 2002, 2005; Ruff et al., 2003). These results support the so called "neural efficiency" hypothesis, which postulates a more efficient cortical function as represented by the best results with the minimal energy consumption. However, the "neural efficiency" hypothesis has been challenged by other neuroimaging evidence showing that task-related fronto-parietal cortical activation was stronger in subjects best-scorers to cognitive tasks (Newman et al., 2003; Gray et al., 2003).

To enlighten the physiological mechanism at the basis of the "neural efficiency" hypothesis, electroencephalographic (EEG) techniques have been used. Indeed, cortical activity can be indexed by an event-related power decrease of resting alpha rhythms at about 8–12 Hz (alpha event-related desynchronization, ERD; Pfurtscheller and Lopes da Silva, 1999). It has been shown that most intelligent people (high intelligent quotient, IQ) present lowest alpha ERD during

* Corresponding author. Dipartimento di Fisiologia Umana e Farmacologia, Università "La Sapienza", P.le Aldo Moro 5, 00185 Roma, Italy. Fax: +39 06 4991 0917.
E-mail address: claudio.delpercio@uniroma1.it (C. Del Percio).

1053-8119/$ – see front matter
doi:10.1016/j.neuroimage.2008.05.061

different types of cognitive tasks such as sentence–picture verification test (Neubauer et al., 1995), Posner's letter matching test (Neubauer et al., 1999), forward digit span task (Grabner et al., 2004), attention-switching task (Grabner et al., 2004), working memory task (Grabner et al., 2004), and Stankov's triplet numbers test (Neubauer and Fink, 2003). The same was true in subjects highly trained for specific skills ("experts") during the performance of retrieval short-term memory tasks related to these skills: alpha ERD was lower in experts than in non-experts (Grabner et al., 2006). On the whole, these results have indicated a reduced (selective) event-related cortical activation in line with the "neural efficiency" hypothesis (Grabner et al., 2004).

In the last years, several lines of evidence have extended the "neural efficiency" hypothesis to cortical motor systems of "experts". Firstly, cortical activity, as revealed by alpha ERD, decreased in skilled marksmen compared to novice shooters, during the preparation of a shoot (Haufler et al., 2000). Secondly, there was a decrease of cortical activity, as revealed by fMRI, in professional piano players compared to control subjects, during complex finger movement tasks (Krings et al., 2000). Thirdly, averaged scalp potentials related to the preparation of right voluntary wrist extensions (readiness potential, RP) were smaller in amplitude over supplementary motor and bilateral sensorimotor areas in elite kendo and gymnastic athletes compared to non-athletes (Kita et al., 2001). Fourthly, the RP modeled in contralateral sensorimotor area was smaller in amplitude in elite shooters compared to non-athletes during the preparation of self-paced voluntary right but not left finger movements (Di Russo et al., 2005). This raises the intriguing idea that in athletes, "neural efficiency" depends on the side of the movement and, hence, on functional hemispherical asymmetry of motor systems.

The "neural efficiency" hypothesis has been challenged by other lines of evidence analyzing visuo-triggered motor tasks rather than voluntary self-paced movements. These studies have typically used standard EEG techniques, namely without procedures for the enhancement of spatial information contents of EEG activity. Compared to non-athletes, elite table tennis players have shown higher rather than lower RP amplitude over contralateral sensorimotor area, during a typical Posner's visuo-attentional task in which subjects had to press a button after cued target stimuli (Hung et al., 2004). Similarly, amateur university athletes (several disciplines) have shown higher rather than lower RP amplitude over sensorimotor areas for movements triggered by simple visual stimuli or by stimuli signaling Go or Nogo commands (Endo et al., 2006).

To contribute to the vivid debate on the "neural efficiency" hypothesis in elite athletes, the present study evaluated MRPs recorded during the preparation and execution of unilateral hand movements triggered by visual stimuli depicting sport situations. To improve the comparison of cortical activity in elite athletes vs. non-athletes, spatial information content of the MRPs was enhanced by surface Laplacian estimation (Babiloni et al., 1996, 1998). We expected that "neural efficiency" hypothesis was confirmed in these conditions.

Methods

Subjects

Eleven (5 women) elite karate athletes, eleven (8 women) elite fencing athletes, and eleven (5 women) non-athletes were recruited. All subjects were right-handed as revealed by Edinburgh inventory. The elite karate and fencing athletes were part of Italian national karate and fencing team, regularly attending international competitions. All elite karate and fencing athletes practiced karate/fencing from more than 10 years, and they usually practiced five times a week. The non-athletes did not play fencing, karate or sports similar to karate (i.e. kung fu, etc.) at competitive or amateur level. The mean subjects' age was 25.3 years in the elite karate athletes (±1.5 standard error, SE; range from 19 to 31 years), 25.5 years in the elite fencing athletes (±1.5 SE; range from 19 to 33 years), and 29.6 years in the non-athletes (±1.2 SE; range from 21 to 34 years). Two ANOVA using the factor Group (non-athletes, fencing athletes, and karate athletes) were computed to evaluate the presence or absence of statistically significant differences among the non-athletes, fencing athletes, and karate athletes for age and gender. No statistically significant differences were found (age: $p>0.06$; gender: $p>0.35$). However, the age and gender values were used as covariates in the subsequent statistical analysis to exclude that small difference in age and gender could influence the subsequent statistical analysis. 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

The subjects comfortably sat in an armchair in front of a computer monitor. The distance between subjects and monitor was about 90 cm. They were presented with a series of 200 different pictures, depicting fencing (50%) or karate (50%) attacks taken during real actions in elite athletes (Fig. 1). The pictures were presented for 1 s. The dimension of the fencing and karate picture was 500×500 pixels. In the inter-stimulus interval (4.5–5.5 s), a central cross was presented as a target for eyes. Left and right attacks were presented with equal probability (50%) for both sports. The pictures represented standard medium- (about 50 cm) and long-distance (about 100 cm) fencing attacks with legs and arms of both sides. The same was true for karate attacks. The selection of the figures was done in order to equalize their spatial features (size of the antagonist, etc.). The order of fencing and karate pictures was pseudo-randomized. The task consisted in judging the side (left/right) of the attack (instruction was "Is it a right or left attack?"). In both conditions, the subjects were requested to immediately respond by pressing "v" or "n" buttons of the computer keyboard with left or right finger, respectively. The subjects were requested to minimize eye movements. A proper software (Presentation; Neurobehavioral Systems, http://nbs.neuro-bs.com/) was used to register the side of the pressed button, the response time (i.e. the interval time from the stimulus onset to the response), and the accuracy of the response for each trial.

EEG recordings

The EEG data were continuously recorded (bandpass: 0.01–100 Hz, sampling rate: 256 Hz; EB-Neuro Be-plus©, Firenze, Italy) from 56 scalp electrodes (cap) positioned over the whole scalp according to a 10–10 system (Fig. 2). Electrical reference was located between the AFz and Fz electrodes and the ground