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Effects of tiredness on visuo-spatial attention processes in élite karate athletes and non-athletes

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ABSTRACT

"Attentional" adaptations are fundamental effects for sport performance. We tested the hypothesis that tiredness and muscular fatigue poorly affect visuo-spatial attentional processes in élite karate athletes. To this aim, 14 élite karate athletes and 11 non-athletes were involved in an isometric contraction exercise protocol up to muscular fatigue. Blood lactate and attention measurements were taken. Posner's test probed "endogenous" (i.e. internally planned allocation of spatial attention) and "reflexive" (i.e. brisk variation of endogenous spatial attention due to unexpected external stimuli) attention. Lactate and attentional measurements were performed before (Block 1, B1) and after the fatiguing exercise (B2) and at the end of a recovery period (B3). Compared to the non-athletes, the athletes showed a better performance in the fatigue protocol, confirmed by the higher absolute lactate values in B2. The correct responses in the "valid trials" probing "endogenous" attention were 92.4% (B1), 93.9% (B2), and 95.8% (B3) in the non-athletes, and 98.5%, 96.4%, 95.5% in the élite karate athletes. The correct responses in the "invalid trials" probing "reflexive" attention were 95.4%, 89.7%, 93.2% in the non-athletes, and 96.4%, 97.3%, 98.5% in the élite karate athletes. The percentage of correct responses in the "invalid" trials significantly decreased from B1 to B2 in the non-athletes but not in the élite karate athletes. In conclusion, tiredness and muscular fatigue do not affect "reflexive" attentional processes of élite karate athletes, which is crucial to contrast attacks coming from an unexpected spatial region.

Key words

Posner's test • Endogenous attention • Reflexive attention • Muscle fatigue

Introduction

Previous studies on muscular fatigue and cognitive performance in humans have unveiled the mutual interaction between cognitive functions and central mechanisms driving motor behavior, and the significant interference between the level of force production and cognitive performance (Tomporowski and Ellis, 1985; Lorist et al., 2002; Zijdewind et al., 2006). Moderate but not low or high muscular tension improved cognitive performance (Tomporowski and Ellis, 1985; Zijdewind et al., 2006).

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The issue of muscular fatigue and cognitive performance is of particular interest for the training of élite athletes involved in combats. Several studies have shown that élite karate athletes are characterized by outstanding sensorimotor performances in terms of speed and power during offensive strikes (Kato, 1958; Vos and Binkhorst, 1966; Cavanagh and Landa, 1976; Wilk et al., 1983). They are also characterized by efficient attentional processes ensuring quick and correct responses to visuo-spatial stimuli (Scott et al., 1993; Kim and Petrakis, 1998; Williams and Elliott, 1999; Mori et al., 2002; Fontani et al., 2006). Specifically, it has been shown that compared to amateur karate athletes, expert karate athletes reacted faster and/or more accurately in simple reaction time (Fontani et al., 2006), choice reaction time (Scott et al., 1993; Williams and Elliott, 1999), and identical pictures test (Kim and Petrakis, 1998). Furthermore, they performed better when external stimuli regarded their favorite sport than control events (Mori et al., 2002). As an exception, expert karate athletes have reacted slower in a divided attention task with respect to amateur karate athletes (Fontani et al., 2006), probably due to mechanisms for refraining from impulse responses in the case of problematic or ambiguous external stimuli (Del Percio et al., 2007).

Much less known are the features of cognitive-motor processes in élite karate athletes during tiredness. In the present study, we compared the visuo-spatial attentional processes of élite karate athletes and non-athletes during an exercise protocol inducing tiredness, which was characterized by series of isometric muscle contractions. The working hypothesis was that tiredness and muscle fatigue affect visuo-spatial attentional processes less in élite athletes compared with non-athletes. Blood lactate measurement were used to ensure the effort of the subjects. Posner's test probed "endogenous" and "reflexive" attention. Lactate and attentional measurements were performed before (Block 1, B1) and after the fatiguing exercise (B2) and at the end of a recovery period (B3). Of note, "endogenous" and "reflexive" visuo-spatial attentional processes were probed for their clear importance in the context of karate performance (Posner, 1980; Shore and Klein, 2000). The "endogenous" visuo-spatial attention occurs when top-down mechanisms are voluntarily induced by cognitive plans or external cue stimuli indicating the spatial region to be covertly or overtly kept under the focus of attention (Posner, 1980; Posner and Cohen, 1984; Castellani et al., 2007; Castellani and Sebastiani, 2008). Effects of the endogenous visuo-spatial attention are typically observed at 200÷300 ms after the stimulus presentation (Muller and Rabbitt, 1989). In contrast, the "reflexive" attention occurs when warned relevant stimuli appearing at unexpected peripheral locations automatically trigger "reflexive" (i.e. bottom-up) mechanisms of information processing (Posner, 1980; Posner and Cohen, 1984). Effects of the reflexive visuo-spatial attention develop within the first 100 ms after the stimulus presentation. With respect to the "endogenous" and "reflexive" attention, "exogenous" attention occurs when unpredictable external stimuli are perceived.

Materials and methods

Subjects

Fourteen (6 women, mean age and standard error, SE = 24.1 ± 1.3 years; range from 19 to 32 years) élite karate athletes and eleven (5 women, mean age and standard error, SE = 23.3 ± 0.6 years; range from 21 to 27 years) non-athletes were recruited. The élite karate athletes were part of Italian national, regularly attending to international competitions. All the élite karate athletes practiced karate from more than 10 years, and they usually practiced five times a week. The non-athletes did not play karate or sports similar to karate (i.e. kung fu, etc.) at competitive or amateur level. Two ANOVAs using the factor Group (non-athletes, karate athletes) were computed to evaluate the presence or absence of statistically significant differences between the non-athletes and élite karate athletes for age and gender. No statistically significant differences were found (age: $p > 0.5$; gender: $p > 0.6$). 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 were right-handed except one élite karate athletes and two non-athletes who were left-handed. They 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 paradigm

The subjects comfortably sat in a chair in front of a computer monitor. They kept their arms resting on a keyboard connected to the computer. The computer monitor was placed in front of them at a distance of about 80 cm. To evaluate the effects of tiredness on visuo-spatial attentional processes, a typical variant of the Posner paradigm was repeated along the experimental session (Posner, 1980; Posner and Cohen, 1984).

The features of the Posner paradigm are depicted in Fig. 1. Subjects maintained fixation on a small white cross (subtending 0.7° of visual angle), displayed on a black background at the center of the screen. Every 5.9 ± 1 seconds (s) a cue stimulus (a white small filled rectangle subtending about 0.2° visual angle and overlapping the left or right horizontal segment of the fixation cross) was presented for 200 ms duration, cueing randomly (50%) either a left or right visual field location.

After 2 s (stimulus onset asynchrony, SOA), a target stimulus was briefly presented for 70 ms at one of two target locations positioned in the left or right visual field along the horizontal meridian, at ±7° degrees of visual angle from the fixation point. The target stimulus was either the letter L (50%) or the letter T (50%), shown in the canonical upright orientation. Both letters had a diameter of 0.7° visual angle. The target stimulus appeared on 80% of the trials at the location indicated by the cue (valid trials), and on 20% of the trials at the uncued location (invalid trials; Posner et al. 1980). Immediately after the target stimulus, a mask stimulus (130 ms duration) formed by all the possible line segments forming the letter stimuli L or

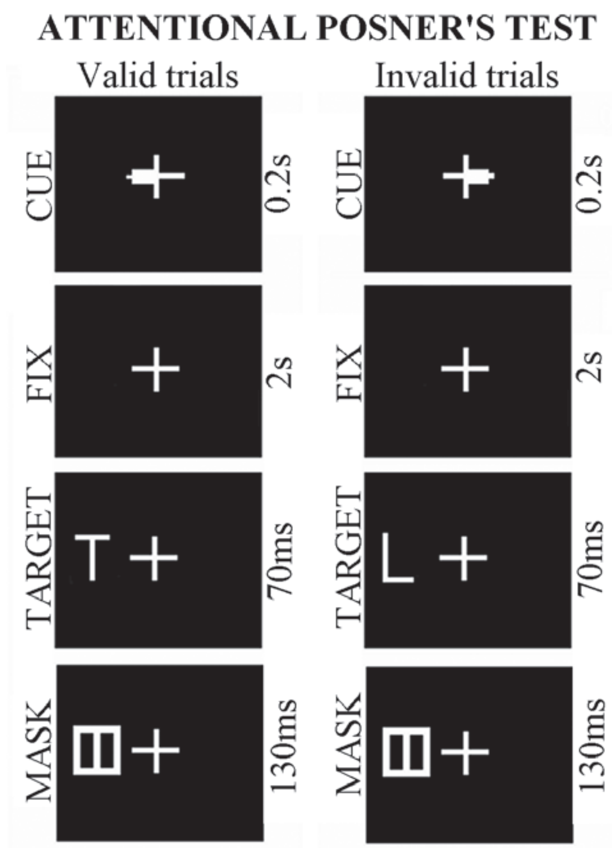

Fig. 1. - Sequence of events during a trial of the attentional Posner's test: (i) cue stimulus (white box, 200 ms duration) appeared either on the right (50%) or left (50%) horizontal segment of the central white cross, it indicates that the subsequent target stimulus will appear with high probability (80%) at the right or left hemifield, respectively, (ii) fixation point (white cross in the center of the black screen) lasting 2 s, (iii) target stimulus, either the letter L (50%) or the letter T (50%), lasting about 70 ms, (iv) masking stimulus presented at the same location of the target stimulus, lasting about 130 ms. The ISI was 5.9 ± 1. During the whole session, a fixation point was presented at the center of the screen. The computer receiving the keyboard inputs registered the corresponding reaction time and the side of the button pressed.

T was presented to interrupt the visual processing of the target shape. The subject's task was to maintain fixation throughout the trial, to pay attention covertly and to the location indicated by the cue. Furthermore, the subject had to discriminate the shape of the target by typically pressing a left keyboard button (key A) when he/she saw the letter T, and a right keyboard button (key L) when he/she saw the letter L. The task was designed to induce an equal amount of right and left hand performance. The correspondence between hand and letter was not randomized, since we had no knowledge of peculiar effects of a correspondence between key letter A or L and the hands. Therefore, the spatial cue indicated the position of the stimulus, but did not provide any information about the response. This is important to insure that preparatory processes are indeed visuo-spatial and perceptual in origin. Each session of the Posner's test lasted 2 minutes and included 24 "valid" trials probing "endogenous" attention and 8 "invalid trials" probing "reflexive" attention. Reaction time and the percentage of correct responses were registered by software Presentation (Neurobehavioural Systems, http://nbs.neuro-bs.com/). Of note, a so short administration time of the Posner's test allowed a punctual evaluation of the effects of actual muscular fatigue on attentional process, reducing the confound of different fatigue recovery processes in athletes compared with non-athletes.

Tiredness protocol

To evaluate the visuo-spatial attentional processes during increasing tiredness and muscular fatigue, we used a standardized 60 min-long fatiguing protocol (Esposito et al., 1998), which consisted of a series of isometric contractions of quadriceps femoris muscle of the right thigh. Blood lactate (Lactate Pro, Arkrai, Japan) and Posner's test measurements were taken before fatiguing exercise (lactate 1, L1; block 1, B1), immediately after fatiguing exercise (L2, B2), and after a recovery period (L3, B3). The complete study design is shown in Fig. 2, where downwards arrows indicate when the Posner's test was administrated and upward arrows indicate the timing of the blood lactate sampling. During exercise, the subjects were positioned on an anatomical ergometer specially designed for the assessment of isometric force of knee extensor muscles (quadriceps femoris muscle). A load cell (mod. Interface SM-2000N, Scottsdale USA; Linear from 0 to 2000 Newton) was connected by a non extendible cable applied to the distal third of the tibia and the distance between the center of instantaneous rotation and the cable was measured. Force signal was sampled at 1000 Hz, low-pass filtered at 5 Hz, digitally converted and stored on a portable computer. It was constantly monitored the test and it was used as a visual feed-back of the force exerted by the subjects during muscle exercise. That visual feed-back helped the subjects to maintain a defined percentage of the maximal isometric force.

The fatiguing protocol included, in a chronological order, a first maximal voluntary contraction (MVC) assessment, a warm-up phase, a fatiguing phase, a further MVC measurement and a recovery phase. The MVC was defined as the highest of three contractions in which the subject, verbally encouraged, was requested to apply his maximal strength. This maximum effort lasted 3 s and was separated by at least 2 min of recovery. After 5 min from the MVC identification, the warm-up exercises started. It consisted of series of continued with a isometric task, which included isometric contractions at 20% MVC (5 s), 40% MVC (5 s), 60% MVC (5 s), and 80% MVC (20 s). The interval between two consecutive isometric contractions lasted 3 min, to assure a complete recovery. After the warm up exercises, the first measurements of blood lactate (L1) and Posner's test (B1) was taken. Successively, the fatiguing phase started. It consisted of 6 s long 50% MVC of the quadriceps femoris muscle repetitive cycles separated by 4 s of rest. The fatiguing phase was interrupted when the subject was unable to apply the required force for the requested 6 s period. After the fatiguing exercise, the lactate testing (L2) and the Posner's test (B2) were carried out for the second time. Right after these measurements, a new quadriceps femoris muscle MVC was performed. After 3 min and in accordance with the new MVC measurement, the subjects were required to recovery using the same isometric contraction protocol of the warm up phase. At the end of the recovery phase, a third lactate testing (L3) and a third Posner's test (B3) were carried out.

It should be remarked that all subjects became familiar with the procedures included in the tiredness protocol prior to the experiment, up to a relatively stable performance as strength of the isometric muscle contraction and reaction time/accuracy to the Posner's test.

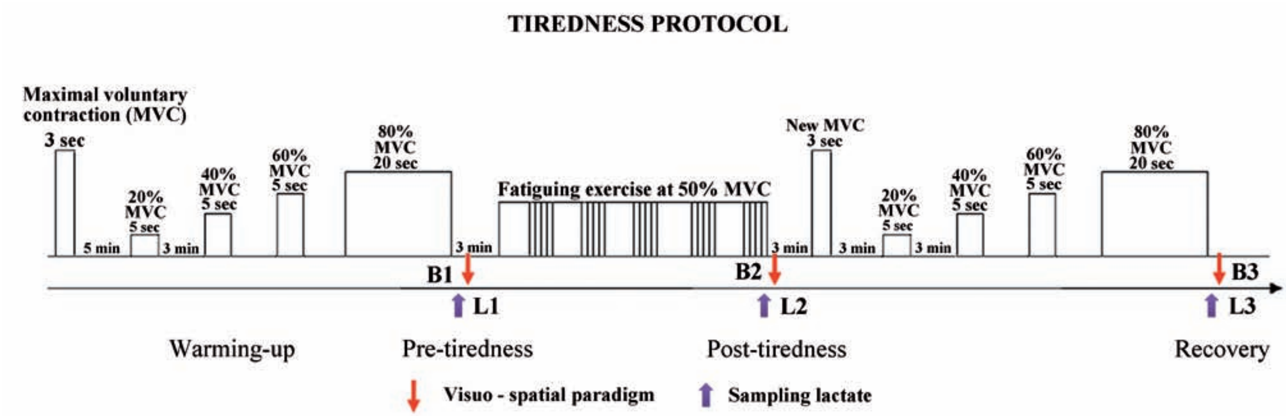

Fig. 2. - Sequence of events during the tiredness protocol. Downward arrows indicate the instant in which the Posner's test was administrated. Upward arrows indicate the blood lactate measurements.

Statistical analysis

Statistical comparisons were performed by analysis of variance (ANOVA). Mauchley's test evaluated the sphericity assumption and the correction of the degrees of freedom was made by Greenhouse-Geisser procedure. Duncan test was used for post-hoc test comparisons ($p < 0.05$). In particular, the following two statistical sessions were performed.

In the first session (lactate data), we tested the control hypothesis that the absolute "anaerobic lactic muscular work" along the experiment was greater in the élite karate athletes compared to the non-athletes (compared to non-athletes, athletes are typically able to prolong their muscle exercise before reaching the muscle fatigue). To this purpose, an ANOVA having the blood lactate values (L1, L2, L3) as dependent variables and the subjects' age and gender served as covariates was performed. The ANOVA comprised the factors Group (élite karate athletes, non-athletes; independent variable), and Block (B1, B2, B3). The control hypothesis would be confirmed by a statistical ANOVA effect including the factor Group ($p < 0.05$). In addition, we performed a second control ANOVA to evaluate whether the relative "anaerobic lactic work" for each cycle was similar in the élite karate athletes and the non-athletes. For each subject, the lactate values were normalized to the number of repetitive cycles of 6 s of fatiguing exercise. The ANOVA comprised the factors Group (élite karate athletes, non-athletes; independent variable), and Block (B1, B2, B3). No statistical ANOVA effect including the factor Group was expected.

In the second session (Posner's data), we tested the working hypothesis that the effects of tiredness on the valid (i.e. endogenous attention) and invalid (i.e. reflexive attention) trials of the attentional Posner's test were weaker in the élite karate athletes compared to the non-athletes. To this purpose, two ANOVAs were performed. The ANOVAs had the percentage of correct responses and the reaction time as dependent variables. Subjects' age, gender, lactate values, and normalized lactate values served as covariates. Each ANOVA comprised the factors Group (élite karate athletes, non-athletes; independent variable), Trial (Valid, Invalid), and Block (B1, B2, B3). The working hypothesis would be confirmed by a statistical ANOVA effect including the factor Group and Block ($p < 0.05$) and post-hoc tests showing that after tiredness-muscular fatigue levels of attention are relatively stable in the athletes and decrease in the non-athletes.

Results

Fatiguing protocol

The number of cycles of maximal muscular isometric contractions was higher in the élite karate athletes (mean ± SE: 37.4 ± 3.1) than in the non-athletes (mean ± SE: 32.8 ± 2.6). Fig. 3 (top) shows the mean (± SE) values of the lactate at L1, L2, and L3 blocks in the élite karate athletes and in the non-athletes. The ANOVA of absolute lactate values showed a main effect of the factor Group ($F(1,21) = 5.3$, $p = 0.03$), suggesting that the élite karate athletes carried out along the experiment a greater amount of

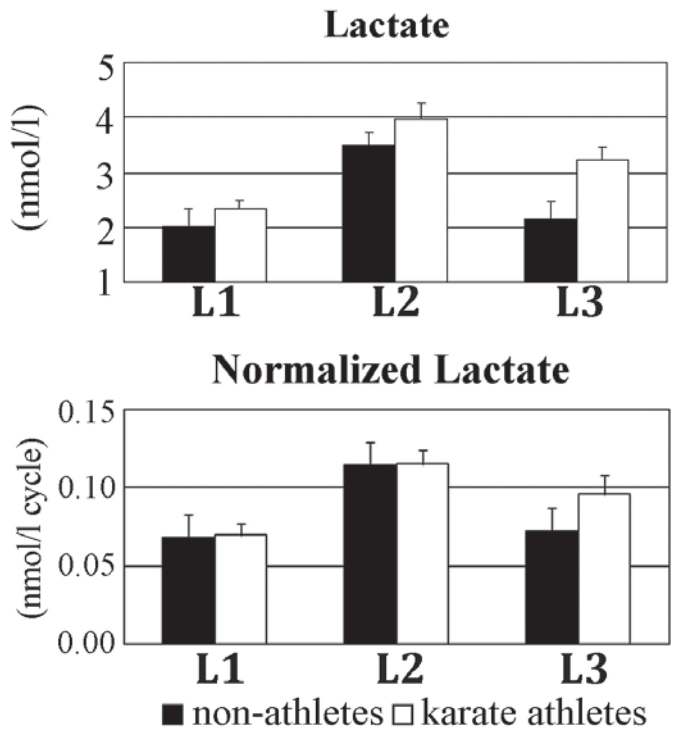

Fig. 3. - (Top). Mean (± SE) of the lactate values at L1, L2, and L3 blocks in the élite karate athletes and non-athletes. (Bottom) Mean (± SE) of the normalized lactate values at L1, L2, and L3 blocks in the élite karate athletes and non-athletes.

lactic anaerobic work than the non-athletes did, due to the higher number of cycles of muscular activity. Furthermore, the ANOVA pointed to a main effect of the factor Block ($F(2,46) = 42.3$, $p = 0.0001$). Duncan post hoc testing of the Block main effect indicated higher lactate values for the L2 than L1 block ($p = 0.00006$), and lower lactate values for the L3 than L2 block ($p = 0.0001$), which reflected the fatigue along the experiment in the two groups.

Fig. 3 (bottom) also shows the mean (± SE) of the lactate values normalized for the number of cycles of maximum isometric muscular contractions at L1, L2, and L3 blocks in the élite karate athletes and non-athletes. The ANOVA of the normalized lactate values did not show statistical ANOVA effects including the factors Group, suggesting that the metabolic effect of each cycle was similar in the élite karate athletes and the non-athletes. As expected, the ANOVA pointed to a main effect of the factor Block ($F(2,46) = 36.4$, $p = 0.0001$). Duncan post hoc testing of the Block main effect indicated higher lactate values for the L2 than L1 block ($p = 0.00006$), and lower lactate values for the L3 than L2 block ($p = 0.0001$), which reflected respectively the efficacy of the test protocol in inducing fatigue and recovery along the experiment in the two groups.

Posner's test data

Fig. 4 illustrates the percentage mean (± SE) of correct responses for the valid and invalid trials at B1, B2, and B3 blocks in the élite karate athletes and non-athletes. The ANOVA of the percentage of correct responses showed a statistical interaction ($F(2,46) = 5.7$, $p = 0.006$) among the factors Group (élite karate athletes, non-athletes; independent variable), Trial (Valid, Invalid), and Block (B1, B2, B3). As a main result, Duncan post-hoc testing indicated that in the invalid trials (i.e. reflexive attention), the percentage of correct responses was lower at B2 than B1 in the non-athletes ($p = 0.005$), but not in the élite karate athletes (confirmed by Newman-Keuls test; $p < 0.01$). This result showed that immediately after the fatiguing phase (B2), the percentage of correct responses in the "invalid" trials (indexing "reflexive"

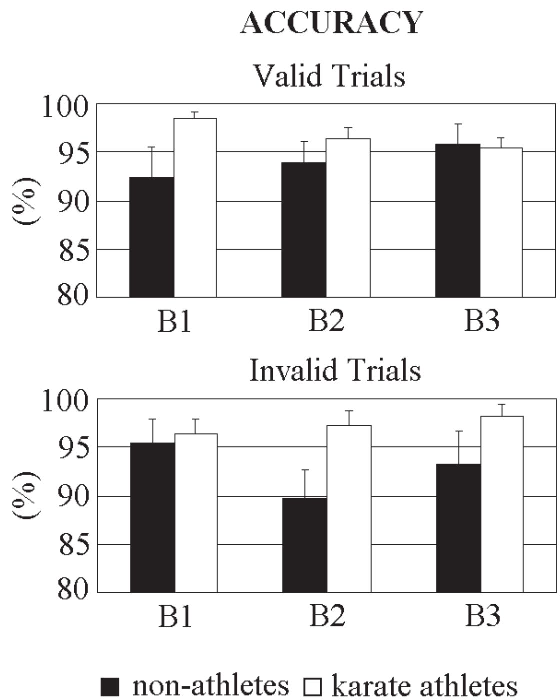

Fig. 4. - Percentage mean (± standard error, SE) of correct responses for the valid and invalid trials at B1, B2, and B3 blocks in the élite karate athletes and non-athletes.

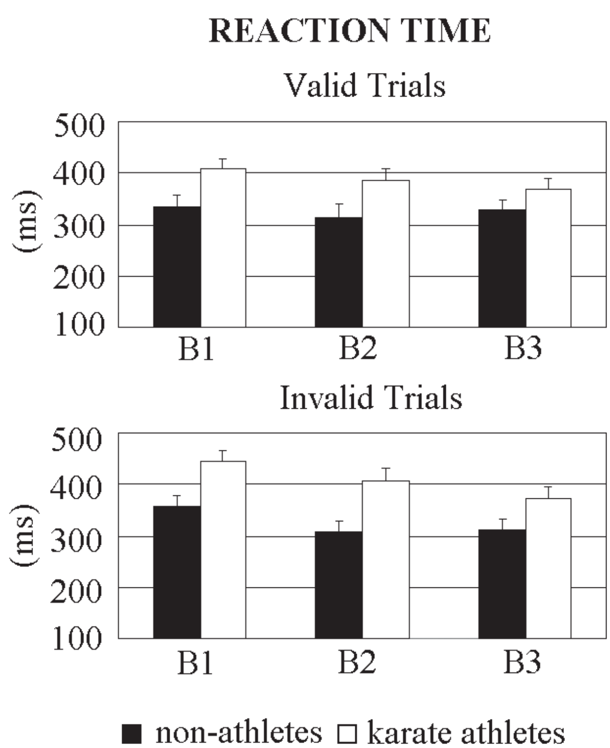

Fig. 5. - Mean (± SE) of reaction time (ms) for the valid and invalid trials at B1, B2, and B3 blocks in the élite karate athletes and non-athletes.

attention) significantly decreased in the non-athletes but not in the élite karate athletes. As supplementary results, Duncan post-hoc indicated that the percentage of correct responses was higher in the élite karate athletes than non-athletes at B1 ($p = 0.004$) in the valid trials (i.e. endogenous attention), and at B2 ($p = 0.0003$) and B3 ($p = 0.01$) in the invalid trials (confirmed by Newman-Keuls test; $p < 0.05$).

Fig. 5 illustrates the mean (± SE) of reaction time (ms) for the valid and invalid trials at B1, B2, and B3 blocks in the élite karate athletes and non-athletes. The ANOVA of the reaction time did not show statistical ANOVA effects including the factors Group and Block ($p > 0.1$). Instead, there was a statistically significant main effect Group ($F(1,24) = 7.04$; $p < 0.02$), indicating that the reaction time was slower in the athletes than in the non-athletes, regardless the fatiguing protocol.

Discussion

This study evaluated the effects of a protocol inducing tiredness and muscular fatigue on visuo-spatial attentional processes in élite karate athletes and non-athletes. As a novelty, we compared these effects on "endogenous" (i.e. internally planned allocation of spatial attention) and "reflexive" (i.e. brisk variation of endogenous spatial attention due to unexpected external stimuli) components of attention. In particular, we verified the hypothesis that tiredness and muscular fatigue affect visuo-spatial attentional processes more in non-athletes than in élite karate athletes. To address this issue, we used a standardized tiredness protocol, which included repeated isometric muscle contraction and blood lactate sampling, as well as additional attentional Posner's testing. The results showed that reaction time was slower in the athletes than in the non-athletes, regardless the fatiguing protocol, possibly due to highest self-control inhibitory mechanisms. In their disciplines, errors in the interpretation of or reaction to the opponents' acts can be indeed fatal. The results showed also that muscular exercise preceding tiredness was longer in the élite athletes than in the non-athletes. Indeed, the absolute but not normalized lactate values probing muscle anaerobic work were higher in the élite karate athletes compared to the non-athletes. At percentages of MVC similar to that of the present study (50%MVC), the muscle blood flow is completely hindered (Lind, 1983) and muscle work relies on anaerobic metabolism. Because the increasing sarcolemmal lactate is efficiently exchanged with blood flux during the recovery phases between each contraction, blood lactate concentration is an expression of the muscle work carried out through the lactic anaerobic metabolism and, therefore, correlates with the effort during the fatiguing protocol.

Interestingly, the percentage of correct responses in the "invalid" trials significantly decreased in the non-athletes but not in the élite karate athletes immediately after fatiguing exercise. These results suggest that the effects of tiredness and muscular fatigue on reflexive attentional processes were weaker in the élite karate athletes compared to the non-athletes. It can be speculated that in élite karate subjects, brain circuits of reflexive attention are poorly sensitive to the effects of tiredness and muscular fatigue, so that they can effectively react to unexpected kicks and/or punches even during the final part of the match characterized by high tiredness and muscular fatigue. Noteworthy, there is no previous functional neuroimaging evidence on the relationships between "endogenous/reflexive" attention and athletes' cortical responses during fatiguing protocols. The present results agree with the fact that daily training of élite karate athletes is generally characterized by heavy loads of muscular exercise and the fact that karate is a sport in which 70% of the energy demand is obtained by the anaerobic metabolism (Reilly and Secher, 1996). Training and match performance prepare cognitive, muscular, and cardiovascular systems to face with specific task demands such as the unpredictable stress and bioenergetics demands of a fight and the refinement of stereotyped motor sequences based on forward models of the action. However, it cannot be excluded that the present results depend on genetics features of the present athletes rather than on daily training. Future studies should address this interesting issue with functional neuroimaging techniques to investigate the relationships between "endogenous/reflexive" attention and athletes' cortical responses during fatiguing protocols, to shed light on the neural mechanisms associated to the present findings.

As a novelty, the present study focused on the effects of tiredness on both "endogenous" (i.e. internally planned allocation of spatial attention) and "reflexive" (i.e. brisk variation of spatial attention when a planned allocation is discouraged by unexpected external stimuli) attentional processes in élite athletes and non-athletes. In this sense, the results of the present study complement previous findings showing that expert karate athletes are characterized by efficient attentional processes ensuring quick and correct responses to visuo-spatial stimuli (Scott et al., 1993; Kim and Petrakis, 1998; Williams and Elliott, 1999; Mori et al., 2002; Fontani et al., 2006). It should be remarked that the mentioned studies have not been focused on "endogenous" and "reflexive" dimensions of attention. Rather, they have been focused on other dimensions of visual attention such as "exogenous" attentional (i.e. automatic attentional effects related to non-informative external stimuli) as probed by simple (Fontani et al., 2006) and choice reaction time (Scott et al., 1993; Williams and Elliott, 1999; Mori et al., 2002) as well as visual search as probed by identical pictures test (Kim and Petrakis, 1998).

In conclusion, we evaluated the hypothesis that tiredness and muscular fatigue affect "endogenous" and "reflexive" visuo-spatial attentional processes less in élite athletes compared with non-athletes. In spite of the expected result that karate athletes were able to perform a bigger amount of muscular work, their percentage of correct responses in the "invalid" trials did not decrease after a fatiguing exercise protocol. These results show that tiredness and muscular fatigue negatively affects "reflexive" attentional processes in non-athletes but not in élite karate athletes, these processing being crucial to contrast attacks coming from an unexpected spatial region. Future studies should evaluate the effects of several kinds of physical and mental fatigue/stress protocols upon "reflexive" attention both in athletes and in high-responsibility workers such as drivers, pilots, and soldiers.

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