

# Neural Correlates of Attentional and Executive Processing in Middle-Age Fencers

FRANCESCO TADDEI<sup>1</sup>, ALESSANDRO BULTRINI<sup>1</sup>, DONATELLA SPINELLI<sup>1,2</sup>, and FRANCESCO DI RUSSO<sup>1,2</sup>

<sup>1</sup>Department of Education Sciences for Motor Activity and Sport, University of Rome "Foro Italico," Rome, ITALY; and  
<sup>2</sup>Neuropsychology Center, Santa Lucia Foundation, Rome, ITALY

## ABSTRACT

TADDEI, F., A. BULTRINI, D. SPINELLI, and F. DI RUSSO. Neural Correlates of Attentional and Executive Processing in Middle-Age Fencers. *Med. Sci. Sports Exerc.*, Vol. 44, No. 6, pp. 1057–1066, 2012. **Purpose:** Open-skill sports require high levels of visual attention and fast and flexible decision making and action execution. We evaluated whether these sports may counteract the well-known age-related declines in executive processing. **Methods:** Young and middle-age fencers and nonathletes were studied. Participants ( $N = 40$ ) performed visual motor tasks while reaction times (RTs) and event-related potentials were recorded. **Results:** RTs were slower for the older subjects, but accuracy was not impaired. At event-related potential level, the late P3 component was delayed in older subjects, but those who participated in sports showed less delay. The RTs of middle-age and young fencers were comparable; the P1 latency of middle-age fencers was similar to that of the younger subjects; the N1 was enhanced in older, as well as younger, fencers; the N2 component of fencers had shorter latencies and larger amplitudes than nonathletes; and in no-go trials, the P3 component was enhanced in fencers independent of age. **Conclusions:** Overall, the practice of open-skill sports was associated with improvement of the executive functions that are already degraded at middle age. **Key Words:** AGING, MIDDLE-AGE ATHLETES, ERPS, EXECUTIVE FUNCTION, SPORTS

Many cognitive functions decline with age, and the processing speeds of these functions can be particularly affected. From simple motor reactions to memory or reasoning tasks, the performance of various tasks is slower in older individuals (36). In some cases, these processes are not only slower but also impaired. It has been proposed that this cognitive decline is associated with a specific reduction in activity in the frontal lobes and a decrease in inhibitory function (16). Compared with younger individuals, older adults have more difficulty stopping an overt response (20), fail to inhibit a primed movement plan in favor of a novel one (27), and produce more inhibition failures in go/no-go tasks (28). Other authors have noted that older adults are slower but perform with the same level of accuracy as younger adults (34); a trade-off between speed and accuracy characterizes their performance. Thus, depending on the task, accuracy might be reduced or normal in elderly individuals; however, most studies agree that the processing speed is slower in older adults and that defective inhibition could be responsible for this slowing (39,42).

At the perceptual level, defective inhibition fails to limit the processing of task-irrelevant stimuli in older individuals and thus distracts them from the actual task, leading to delayed responses (15). In easy perceptual tasks, a consistent portion of response slowing in older adults is due to slowed response programming and execution rather than perceptual processing. Defective inhibition also plays a role at this level (30). Anticipatory frontally based preparation after a warning signal decreases with age, and this reveals the neural substrate of age-related preparation deficits (40).

Previous studies have described positive effects of physical activity on health and wellness in the elderly (3). Physical activity programs for older adults have been widely recommended. In addition to the advantages of physical fitness, growing evidence suggests that exercise has a positive effect on cognitive processing. A meta-analysis of intervention studies (3) showed benefits of various physical exercises on processing speed, controlled processing, and executive processing that involves planning and inhibition, with maximum effects for these latter processes. A recent meta-analysis (37) reported a modest but reliable effect of aerobic activity on all cognitive domains tested (processing speed, executive control, and memory). In addition, electrophysiological evidence supports the view that aerobic exercise is associated with reductions in cognitive decline in the elderly. For example, age and physical activity influence the amplitude and latency of the P3 component of event-related potentials (ERPs) (for a review, see Kramer and Hillman [19]), particularly under conditions that require task switching. Despite differences in the results (possibly due to different tasks, paradigms, and type of physical activity), the

---

Address for correspondence: Francesco Di Russo, Ph.D., University of Rome "Foro Italico," Piazza Lauro De Bosis, 15, 00135 Rome, Italy; E-mail: francesco.dirusso@uniroma4.it.

Submitted for publication September 2011.

Accepted for publication December 2011.

0195-9131/12/4406-1057/0

MEDICINE & SCIENCE IN SPORTS & EXERCISE®

Copyright © 2012 by the American College of Sports Medicine

DOI: 10.1249/MSS.0b013e31824529c2

data are consistent with the hypotheses that physical activity might modulate executive processing in elderly individuals (18) and the amplitude and latency of the P3 component are especially sensitive to the effect of aerobic fitness (17). However, most studies investigating these hypotheses considered very old populations (typically 60–80 and even 90 yr) and focused on aerobic activity. In the present study, we investigated the effects of fencing, an open-skill sport with a moderate aerobic component (31), on the executive ability level in middle-age people in their 50s.

We selected fencing because it requires fast decisions and execution and places high demands on visual attention and flexibility to inhibit prepared actions to cope with the rapid changes of the opponent's actions (24,32). In short, fencing trains executive functions, i.e., the processes responsible for planning, cognitive flexibility, rule acquisition, the initiation of appropriate actions, the inhibition of inappropriate actions, and the selection of relevant sensory information (38). The task used in the present experiment requires stimulus discrimination, stimulus response mapping, decision making, and response execution or inhibition. All of these processes mimic, in a simplified way, some of the executive processes involved in fencing. Consistent with this claim, in a previous study, we showed that young fencers performing this task exhibit increases in processing speed and executive control compared with the control subjects (7).

In the present study, we used behavioral and electrophysiological measurements because the combination allowed for finer discrimination of the influence of fencing training on cognitive processing; the procedure also allowed us to evaluate possible differences when the overt responses were comparable in the older and younger subjects (41).

On the basis of the literature on aging, we expected to find an effect of age on reaction time (RT). The predictions regarding accuracy were less clear. Some authors find the responses of older subjects to be as accurate as those of the younger subjects, revealing a trade-off between speed and accuracy. In other studies, older individuals have been found to be less accurate than younger people. In particular, a higher number of false alarms would suggest a deficit in inhibitory processing. As for the electrophysiological data, the literature suggests that focus should be placed on the P3 component. Further, as indicated by Hillman et al. (17), we hypothesized that practicing sports would have beneficial effects. ERP data collected from young fencers, nonathletes (7), and boxers (6) of the same age have revealed strong enhancements of visual attention (indexed by the N1 component [44]) and inhibitory processing (reflected by the N2 and the P3 amplitudes in no-go trials [10,39,42]) in fencers relative to the other groups. On the basis of the results observed in young fencers (7), we hypothesized that the effects of fencing would also be present in behavioral and electrophysiological measures of middle-age fencers from the “master category” (hereafter called “older fencers” to distinguish them from “young fencers”) compared with age-matched controls. Specifically, we expected the following

differences in older fencers compared with nonfencing individuals of the same age: a) faster RTs, b) an alteration of the N1 component reflecting improved visual attention, and c) latency and/or amplitude differences in the N2 and P3 components that indicate faster/enhanced executive processing in a discriminative context that requires switching from action to inhibition and vice versa. Our expectations regarding the P3 component are also supported by a vast body of literature, which deals mostly, however, with older subjects and aerobic exercise (17,37).

## METHODS

**Participants.** Forty subjects participated in the study and were divided into four groups: (i) 10 older fencers (mean age = 49.5 yr, SD = 2.9 yr), (ii) 10 young fencers (mean age = 24.0 yr, SD = 3.9 yr), (iii) 10 older nonathletes (mean age = 47.9 yr, SD = 2.6 yr), and (iv) 10 young nonathletes (mean age = 24.6 yr, SD = 4.8 yr). Thirteen participants were females and were approximately equally represented in each group. Fencers were recruited from a fencing club located in Rome; to complete the number of participants in the case of the older fencers group, two participants accepted to participate coming from other cities. Older nonathletes were recruited among friends of one of the authors; young nonathletes were obtained from the local (Roman) student population. The socioeconomic status across the two groups of older participants was quite homogeneous, insofar as participants in both groups were involved in comparable professions (such as, for instance, lawyers, physicians, teachers, businessmen, engineers). Older fencers and older nonathletes were matched for age (see above), education level (years of studying =  $16.2 \pm 2.3$  and  $16.1 \pm 2.2$ , respectively), and cognitive ability as measured by the Mini-Mental State Examination (21) ( $29.3/30 \pm 1.1$  and  $29.0/30 \pm 0.9$ ). Young fencers and young nonathletes were matched for age and education (years of studying =  $14.6 \pm 1.7$  and  $14.9 \pm 1.3$ , respectively). All young fencers had at least 6 yr of sport experience and had participated in national and international championships. On average, they had 13 yr of experience and practiced for  $9.2 \text{ h}\cdot\text{wk}^{-1}$ . Older fencers had an average of 26.4 yr (range = 11–42) of fencing experience (in many cases, they started at an early age and began again after a long break) and regularly participated in master-category competitions. They did not practice other sports; one of them participated in running (approximately once a week), and one had a weekly coached session of athletic preparation. In the older nonathlete group, four participants practiced running (once a week), three regularly practiced fitness exercises (approximately twice per week), and three played soccer (approximately once a week). All young nonathletes occasionally practiced sport activities, although none did so at a competitive level. All subjects reported being free of neurological disorders, cardiovascular disease, and medications; they provided written informed consent to participate in the

experiment after the procedures (which were approved by the local ethics committee) had been fully explained.

**Stimuli.** Four squared configurations made of vertical and horizontal bars subtending  $4^\circ \times 4^\circ$  were presented for 260 ms on a dark gray background. The fixation point was a yellow circle ( $0.15^\circ \times 0.15^\circ$  of visual angle) in the center of the stimuli. The four configurations were displayed randomly with equal probabilities ( $P = 0.25$ ), and the onset asynchrony varied from 1 to 2 s.

**Procedure.** In separate runs, the participants performed two tasks. The first task was a discriminative reaction task (DRT). The second was a simple reaction task (SRT) to stimulus onset. In the DRT, two configurations were defined as targets, and two were defined as nontargets. The subjects were required to press a key with their right hand as quickly as possible when a target appeared on the screen (go stimuli,  $P = 0.5$ ) and withhold their response when a nontarget appeared (no-go stimuli,  $P = 0.5$ ). Go and no-go stimuli were equally likely to minimize the effects of the probability monitoring and conflict detection (see also Vallesi [39]). The mappings of the stimulus features to go or no-go responses were counterbalanced across subjects. In the SRT, the subjects were required to respond to any of the four configurations. The SRT included five runs of 80 trials. The DRT included 10 runs of 40 go and 40 no-go trials. The sequence of go and no-go trials was quasi-random with identical consecutive responses limited to four to ensure frequent switching from inhibition to response and vice versa. The order of the tasks was counterbalanced. Only trials followed by a correct response within 150–1000 ms were considered valid. The first trial of each run was excluded from further analysis to avoid orientation response contamination. Warm-up trials were also provided. Presentation order was randomized across subjects. The duration of each run was 2 min, with a pause between runs (total duration of approximately 45 min).

**Analysis of behavioral data.** Accuracy was measured by counting the number of omissions, anticipations, and false alarms during testing. RTs for correct trials within the 150- to 1000-ms window were analyzed, and the median was calculated. Further, the intraindividual variability was measured using the intraindividual coefficient of variation ( $ICV = \text{the SD of RTs} / \text{the mean of RTs}$ ). ICVs were calculated for each subject within each task. RTs, ICVs, omissions, anticipations, and false alarms were analyzed using  $2 \times 2$  ANOVAs with factors of age (two levels) and sport (two levels). *Post hoc* comparisons were conducted using the Tukey HSD test. The overall  $\alpha$  level was fixed at 0.05 after the Bonferroni correction. To estimate the size of the statistical effects, the partial  $\eta$  squared ( $\eta_p^2$ ) was calculated in addition to probability values. Additional analyses were performed on RTs after introducing the percentage of errors (anticipations in the SRT, false alarms in the DRT) as a covariate.

**Electrophysiological recording and analysis.** Electrophysiological recordings were obtained while the subjects

performed the tasks. Electroencephalograms were recorded using the BrainVision™ system (Brain Products GmbH, Munich, Germany) with 64 sensors that were initially referenced to the left mastoid. Horizontal eye movements, blinks, and vertical eye movements were recorded. The electroencephalogram was digitized at 250 Hz, amplified (with a 0.01- to 60-Hz band-pass and 50-Hz notch filter), and stored for off-line averaging. Computerized artifact rejection was performed before signal averaging to discard contaminated epochs (13% of the trials were rejected). Eye movements and blinks were the most frequent cause for rejection. ERPs were averaged in epochs starting 100 ms before stimulus onset and lasting for 1100 ms. Time-averaged ERPs were rereferenced to averaged mastoids and band-pass filtered from 0.05 to 25 Hz to further reduce high- and low-frequency noise. To visualize the voltage topography of the ERP components, spline-interpolated three-dimensional maps were constructed using the BESA 2000 software (MEGIS Software GmbH, Gräfelfing, Germany).

ERPs from the SRT and DRT runs were sorted into the following three categories: 1) ERPs for SRT stimuli, 2) ERPs for go stimuli, and 3) ERPs for no-go stimuli. Peak amplitudes (measured with respect to the 100-ms prestimulus baseline) and latencies of the major ERP components were calculated for each subject in the following standard time windows: P1 (80–150 ms), N1 (130–200 ms), P2 (180–300 ms), N2 (200–350 ms), and P3 (250–600 ms). The identification of components was also guided by their polarity and topography as previously described (5–7,35). Electrodes at which each component peaked in the individual subjects were used for the analyses (the P1 and P2 on PO7 or PO8, the N1 on O1 or O2, the SRT P3 on Pz, the go-N2 and go-P3 on Cz, and the no-go-N2 and no-go-P3 on FCz or Cz).

Data from the P1 and N1 components were evaluated with  $2 \times 2 \times 3$  ANOVAs that included the following factors: age (two levels), sport (two levels), and condition (three levels: SRT, go, and no go). The P2 component was present only in the SRT condition and was not affected by age or sport; therefore, this component was not analyzed further. The N2 component was not detectable in the SRT. Thus, this component was analyzed by a  $2 \times 2 \times 2$  ANOVA for the two levels of DRT (go and no go). The P3 component was analyzed with two separate ANOVAs: a  $2 \times 2 \times 2$  for the DRT and a  $2 \times 2$  for the SRT; we used two separate analyses because the sources of the P3 were very different in the SRT and DRT.

To estimate the size of the statistical effects, the  $\eta_p^2$  was also calculated. *Post hoc* comparisons were conducted using the Tukey HSD test. The overall  $\alpha$  level was fixed at 0.05 after the Bonferroni correction.

Given that changes in the electric field indicate changes in the underlying generator configuration, we measured the statistical differences among scalp topographies using a nonparametric randomization test, topographic ANOVA (TANOVA), at each time point. For more details on TANOVA, see Murray et al. (23). Before TANOVA, the

average ERP segments for all participants were average referenced and transformed to a global field power (GFP) of 1, which ensured that the dissimilarity was not influenced by higher activity across the scalp for any of the conditions. Thus, this analysis provides a statistical method to determine when and if the brain networks that mediate a particular component differ.

## RESULTS

**Behavioral data (SRT).** Statistical results and mean values are reported in Table 1. Omission errors were nearly absent in this task. The percentage of anticipation was significantly affected by age and sport. The interaction between age and sport was also significant. Young fencers had more anticipations than the other three groups. This interaction is reported in Figure 1A.

RTs were significantly affected by age, indicating that younger individuals were faster than older individuals. RTs were also significantly affected by sport, indicating that fencers were faster than nonathletes. The effect of sport was similar for both young and older participants. The two main effects on RTs are reported in Figures 1B and C. The interaction between age and sport was not significant.

An additional analysis was performed on RTs that introduced anticipation percentages as a covariate. The effect of age canceled out, whereas the effect of sport maintained significance ( $F_{1,35} = 4.31, P < 0.05, \eta_p^2 = 0.110$ ). The ICV was not modulated by age or sport.

**Behavioral data (DRT).** Statistical results and mean values are reported in Table 1. Omissions and anticipations were nearly absent in this task. False alarms were significantly affected by sport, indicating that fencers had more false alarms than nonathletes (Fig. 1D).

RTs were significantly affected by age, indicating that younger individuals were faster than older individuals (Fig. 1E). There was also a significant effect of sport on RTs, indicating that, independent of age, fencers were faster than nonathletes (Fig. 1F). The interaction between age and sport did not reach significance.

An additional analysis was performed on RTs that introduced the percentage of false alarms as a covariate. Both the effect of age and sport maintained significance in this analysis ( $F_{1,35} = 4.74, P < 0.05, \eta_p^2 = 0.119$ ;  $F_{1,35} = 9.60, P < 0.005, \eta_p^2 = 0.215$ ).

The ICV was significantly affected by age, indicating that younger subjects had more RT variability than older subjects (Fig. 1G).

**Electrophysiological data.** The main ERP waveforms are reported in Figure 2. Statistical results and mean values are reported in Table 2.

The earliest component (P1) peaked at bilateral parietal-occipital sites (PO7 and PO8). This component is often ignored in go/no-go studies because of the use of small and unstructured stimuli that evoke barely detectable visual components. In the present study, stimuli contained many horizontal and vertical bars and produced very clear visual responses. The P1 latency was significantly shorter (9 ms) in younger subjects compared with older subjects. Sport significantly affected the P1 as well; the latencies of fencers were significantly faster (8 ms) than those of nonathletes. In addition, the interaction between age and sport was significant, indicating that older fencers' latencies were comparable to the latencies of the two younger subject groups, whereas the older nonathletes had longer latencies. Figure 3A reports this interaction. Neither the main effect of the task performed nor the interactions involving specific tasks were significant. The P1 amplitude was not significantly modulated by age, sport, or task.

The N1 component peaked at bilateral occipital sites (O1 and O2). The N1 latency was significantly affected by task, indicating that SRT latencies were faster than go and no-go latencies.

N1 amplitudes in fencers were significantly larger than those in nonathletes (Fig. 3B). This effect was similar for older and younger fencers. In agreement with previous literature, the task also had a significant effect on the N1 amplitude; the amplitudes were smaller in the SRT than in either the go or no-go conditions.

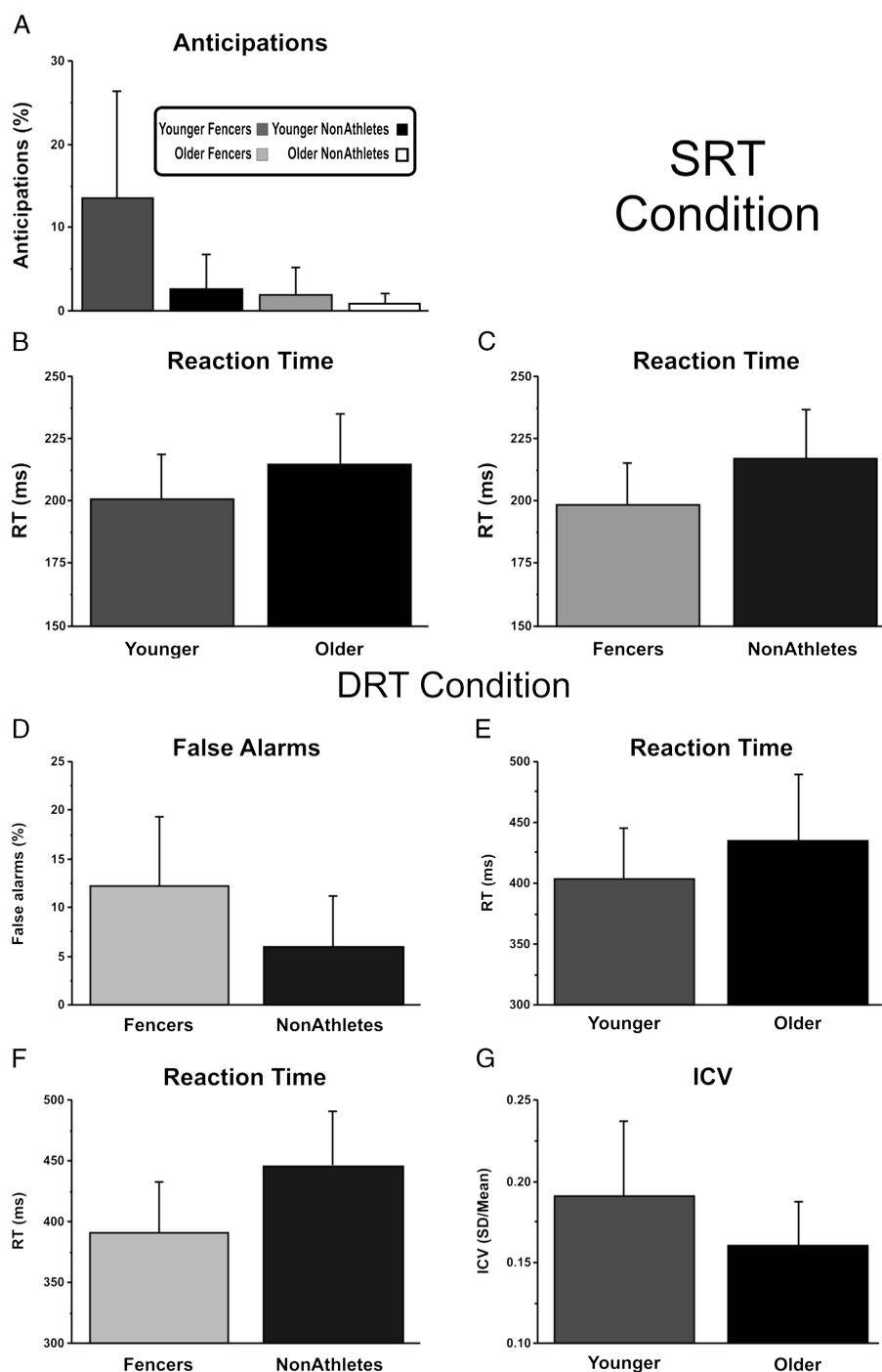
The N2 component peaked at medial central sites in the go condition (Cz) and shifted anteriorly in the no-go condition (FCz). N2 latency was significantly affected by sport, and latencies in fencers were shorter than those in nonathletes (Fig. 3C). This result held true for both the go and no-go trials and was independent of age. The two-level interaction and the three-level interaction between age, task, and sport were not significant.

The N2 amplitudes of the fencers were significantly larger than those of the nonathletes, and this effect of sport was

TABLE 1. Statistical results and mean values of the behavioral data.

		Effect	F	P	$\eta_p^2$	Means
SRT	RTs	Age	6.62	0.0144	0.155	Y = 201, O = 216
		Sport	10.98	0.0021	0.234	F = 198, NA = 217
	ANT	Age	9.33	0.0042	0.206	Y = 8.1, O = 1.4
		Sport	7.55	0.0093	0.173	F = 7.7, NA = 1.7
		Age × Sport	5.28	0.0275	0.128	YF = 13.6, YNA = 2.5 OF = 1.9, ONA = 0.9
DRT	RTs	Age	5.79	0.0213	0.139	Y = 402, O = 434
		Sport	17.80	0.0002	0.331	F = 391, NA = 446
	FA	9.82	0.0034	0.214	F = 12.2, NA = 6.0	
	ICV	Age	6.63	0.0143	0.155	Y = 0.19, O = 0.16

Mean RTs are reported in milliseconds; anticipations (ANT) and false alarms (FA) are reported in percentage (only significant effects and interactions are reported). Y, young; O, older; F, fencers; NA, nonathletes; YF, young fencers; YNA, young nonathletes; OF, older fencers; ONA, older nonathletes.

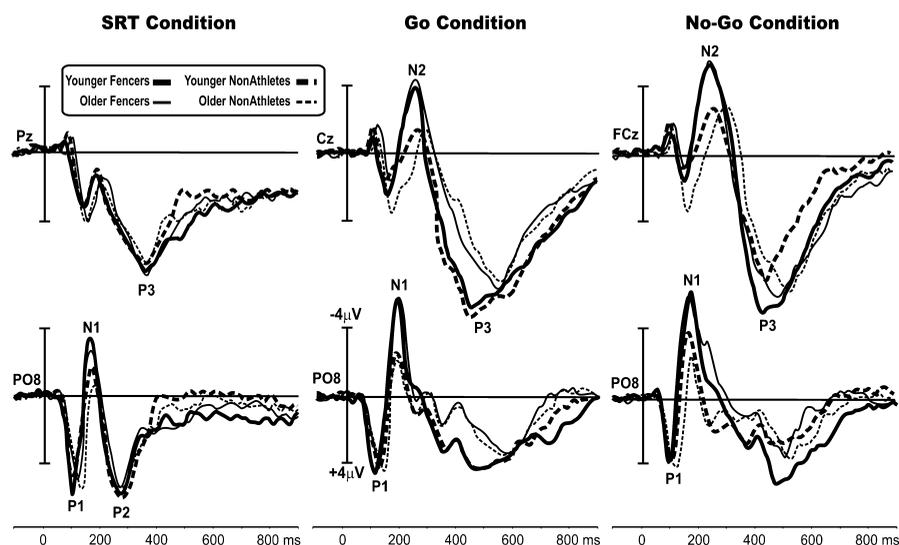


**FIGURE 1—Behavioral data.** *Upper panel:* SRT condition. A, Percentages of anticipations for each of the four groups (interaction between age and sport). B, Main effect of age on RTs. C, Main effect of sport on RTs. *Lower panel:* DRT condition. D, Main effect of sport on the percentage of false alarms. E, Main effect of age on RTs. F, Main effect of sport on RTs. G, Main effect of age on the ICV of RTs.

independent of age (Fig. 3D). Similar to other results in the literature, the task also had a significant effect, with larger amplitudes in the no-go compared with the go condition.

In the SRT, neither age nor sport significantly affected the latency or the amplitude of the P3 component. In the DRT, age significantly affected the P3 latency, with shorter latencies in younger subjects compared with older subjects (Fig. 3E). The effect was present in both the go and no-go

conditions. The condition had a significant effect on the amplitude of the P3; the amplitude of the P3 in the no-go condition was larger than the amplitude recorded in the go condition. Moreover, the interaction between sport and condition was significant. *Post hoc* analysis indicated that the amplitude of the P3 in fencers (both young and older) in the no-go condition was larger than that in the go condition. In nonathletes, the amplitudes did not differ between the go



**FIGURE 2**—Grand-averaged ERPs recorded at selected leads in the SRT (left panel) and in the DRT (middle and right panels) from the four groups. The components P1, N1, P2, N2, and P3 are labeled.

and no-go conditions. Furthermore, the fencers' no-go P3 was larger than the nonathletes' P3 (Fig. 3F).

The P3 component peaked at the medial parietal sites (Pz) in the SRT, at the medial centroparietal sites (CPz) in the go condition and at the medial frontocentral sites (FCz) in the no-go condition (Fig. 4). The spatial distribution of the P3 component shifted anteriorly in the no-go condition. This P3 anteriorization was less distinct in the older groups. Statistical analysis on topographical differences (TANOVA) showed that in the no-go condition, the older groups showed a more posterior P3 ( $P < 0.02$ ) than the younger subjects in the 380- to 530-ms time window.

## DISCUSSION

This study confirms in middle-age people the decline in function observed in many aging studies (e.g., Salthouse [36]) and suggests that an open-skill sport such as fencing might contribute at this age to facilitate attention and executive processes. This result, with the cautions later described,

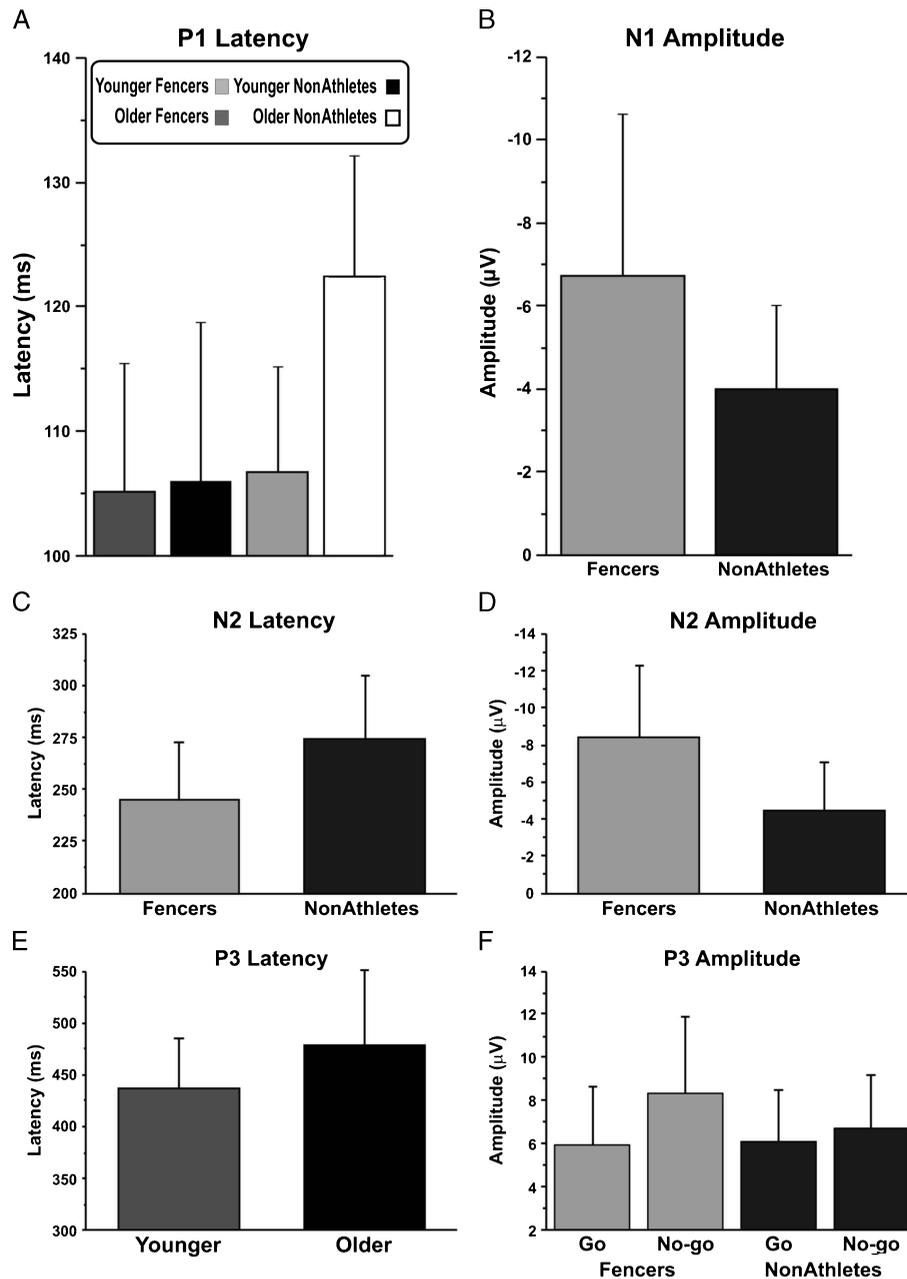
adds to recent studies focusing on the effect of nonaerobic exercise in elderly and middle-age adults (2,9). The RTs of middle-age adults were slower than those of younger participants in both SRT and DRT. Furthermore, RTs were more variable in the younger group; this result is consistent with a U-shaped function of ICV as a function of age (4). In terms of accuracy, we did not find any age effects. This finding is consistent with a speed-accuracy trade-off: although the middle-age subjects were slower, they were just as accurate as the younger subjects. In particular, false alarms did not increase with age.

This study presents novel findings concerning the behavioral and electrophysiological effects associated with the practice of an open-skill sport characterized by a moderate aerobic component in middle-age individuals. Fencers were faster than nonathletes independent of age and task; the RT advantage was particularly large in the discriminative task (an approximately 50-ms advantage in older fencers compared with middle-age nonathletes). In contrast, fencing negatively influenced accuracy; in the DRT, there were a larger number

**TABLE 2.** Statistical results and mean values of the electrophysiological data.

		Effect	F	P	$\eta_p^2$	Means
Latency	P1	Age	8.08	0.0073	0.183	Y = 106, O = 115
		Sport	6.71	0.0137	0.157	F = 106, NA = 114
		Age × Sport	5.48	0.0249	0.132	YF = 105, YNA = 106
						OF = 107, ONA = 123
Amplitude	N1	Task	18.92	<0.0001	0.345	SRT = 172, go = 180, no-go = 182
	N2	Sport	10.33	0.0028	0.223	F = 246, NA = 274
	P3	Age	5.90	0.0202	0.141	Y = 437, O = 479
	N1	Sport	8.99	0.0049	0.200	F = -6.7, NA = -4.0
		Task	42.77	<0.0001	0.543	SRT = -3.7, go = -6.4, no-go = -6.0
	N2	Sport	13.50	0.0008	0.273	F = -8.4, NA = -4.5
		Task	29.62	<0.0001	0.451	Go = -5.9, no-go = -7.0
	P3	Task	17.22	0.0002	0.324	Go = 6.04, no-go = 7.54
		Sport × Task	5.78	0.0215	0.138	F go = 6.1, F no-go = 8.3 NA go = 5.9, NA no-go = 6.7

Mean latencies and amplitude were reported in milliseconds and microvolts, respectively. Only significant effects and interactions are reported.

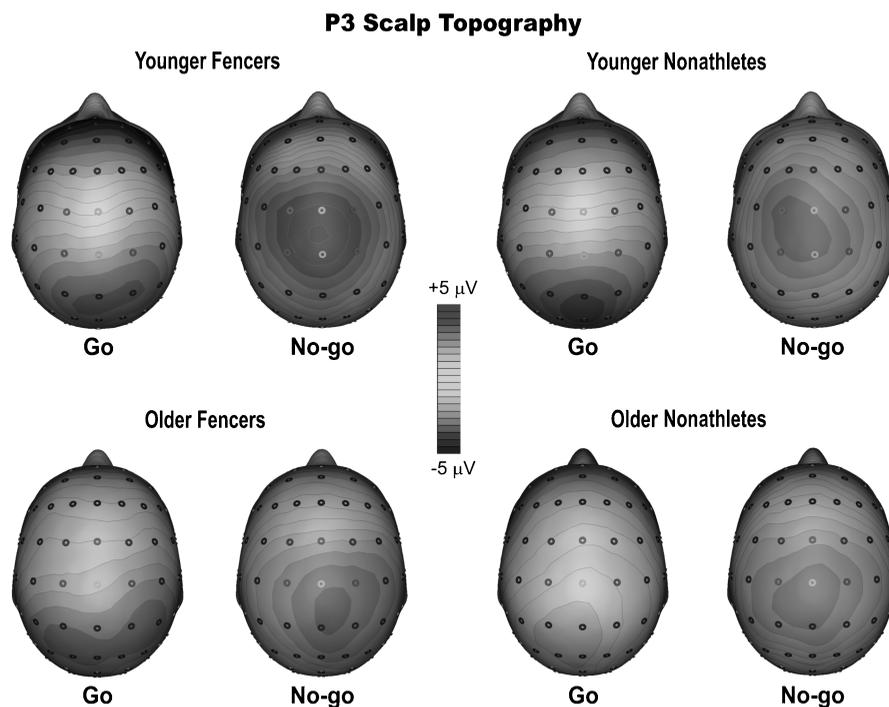


**FIGURE 3—A,** Latency of the P1 component averaged across the SRT and DRT conditions for the four groups (interaction between age and sport). **B,** Main effect of sport on the amplitude of the N1 component. **C,** Main effect of sport on the DRT N2 latency. **D,** Main effect of sport on the DRT N2 amplitude. **E,** Main effect of age on the DRT P3 latency (data are averaged across go and no-go trials). **F,** Interaction between sport and condition on the DRT P3 amplitude. The data of fencers and nonathletes (averaged across age) are reported for the go and no-go conditions.

of false alarms in fencers, independent of age, and in the SRT, there were a conspicuous number of anticipations limited to young fencers. Thus, fencing seems to produce a strategy of very fast responses, even when there is a risk of errors. The increased processing speed of fencers was also significant in the analysis, which introduced accuracy as a covariate; thus, increases in speed are a specific feature of this group.

Brain activity recorded simultaneously with the behavioral tests showed that the effects of age and sport occurred only at specific levels of processing.

Similar to previous studies (e.g., Morrison and Reilly [22], Porciatti et al. [26], Rossini et al. [33]), the latency of the early P1 component was longer in middle-age individuals (an approximately 10-ms difference, independent of the task). This finding suggests that there are age-related changes in the speed of afferent visual signals and the time course of intracortical visual processes. Notably, this decline was reduced in fencers. The P1 latencies of middle-age fencers were comparable to those of the younger subjects (both fencers and nonathletes), suggesting that fencing may circumvent, retard, or compensate for neural changes at this level.



**FIGURE 4—Scalp topography of the P3 component in the go and no-go conditions for the four groups. P3 anteriorization, characteristic of the no-go condition, was less distinct in the older groups.**

In addition, the effect of sport among young subjects was not measurable in the P1 component (see also Di Russo et al. [7]). This result suggests that early visual processing speed plateaus at a young age.

Clear effects of sport (but not age) were found for the N1 and N2 components. Consistent with our hypothesis, fencing enhanced N1 amplitude, possibly reflecting higher levels of attention toward the visual stimulus (6,7,44). It is likely that this N1 enhancement is due to fencing because fencing requires high visual spatial attention. As for the N2 component, we observed larger amplitudes and shorter latencies in fencers compared with nonathletes. We propose that these findings indicate faster processing and enhanced inhibition-related processing in fencers. The lack of an effect of age on the N2 is in agreement with some studies (11) but inconsistent with other results (25); the lack of consistency among these studies may be due to differences in paradigms, sampling, and ages of the groups.

No effect of age was detected on the amplitude of the P3 component in nonathletes, although a reduction in the P3 component in the elderly is generally reported in the literature (e.g., Falkenstein et al. [11]). This lack of an age effect on P3 may be due to the relatively younger age of the “older” group of the present study. The interaction between the condition (go vs no go) and sport factors point to fencing’s specific enhancement of the P3 component in the inhibiting no-go condition. The latency of the P3 component was longer in the middle-age group compared with their younger counterparts. This result suggests that the reductions in speed of the multiple processes reflected by the P3 component are already present in middle-age individuals.

These processes include stimulus-related categorization (e.g., Dien et al. [8]) and response-related processes (43), such as inhibition (11,14,25,39,42).

Overall, the lack of an effect of age on the N2 component, the limited effect of age on the P3 component, and the lack of differences in false alarms between the older and younger subjects do not support the view that inhibitory processing is severely impaired in middle-age individuals. The cortical deterioration that occurs with aging (29) and that is responsible for the defects of inhibition in the elderly is likely comparatively mild in middle-age individuals. Consistent with this idea, performance impairments (longer RTs) and delays in neural processing were mild in middle-age individuals.

The spatial distribution of the P3 did not show a strong anteriorization (13) in the older groups, especially in the no-go trials; this result is consistent with a modest involvement of frontal structures in the task and suggests that the deterioration in middle-age individuals is mild. Previous studies (12,39) have found enhanced anteriorization of the P3 in no-go conditions in older subjects and attributed it to the major involvement of frontal structures in the elderly. For example, Vallesi (39) used a paradigm similar to the present study with equiprobable go and no-go trials. The discrepancy between the results of that study and those of the present study may be due to age differences in the “old” groups of the two studies. In addition, the load of the respective tasks may have played a role in the differing results; in Vallesi’s case, an easy discrimination was required, whereas the discrimination of geometrical configurations in the present study was somewhat more difficult. It is possible that

enhanced anteriorization of no-go P3 is detectable only if the task is easy enough (39).

An interesting effect of sport was the large amplitude of the N2 and no-go P3 in fencers. We speculated that this enhancement should reflect the costs to fencers of increasing their response speed (for a similar consideration in a different context, see Vallesi [39] and Stuss et al. [38]). One strategy for maintaining high-speed responses to target stimuli is to prepare motor responses to all stimuli (both target and nontarget) and then, when a nontarget is detected, inhibit further action. Such strategies could possibly be developed through fencing practice. Thus, inhibition of prepared responses upon presentation of no-go stimuli would require more resources in fencers than in nonathletes.

However, these conclusions merit caution. One intrinsic limit of the study and, more generally, of all studies investigating high-level athletes is that sport was not manipulated. We studied a group of people who deliberately selected fencing in their early years and, after a period of inactivity, turned back to fencing in middle age. We cannot exclude the possibility that these people selected fencing because they had, from the beginning, superior cognitive functioning and very fast RTs (according to the notion of preserved differentiation ably described recently by Bielak et al. [1]). Fur-

thermore, we cannot separate the effects of early and late fencing activity. Future research may, at least in part, evaluate these concerns. In contrast, the results observed in older fencers cannot be attributed to sport activities other than fencing.

In summary, we confirmed that the slowing of visual-motor processing that occurs with aging is already present in middle age; however, accuracy remains very high in middle age. At the cortical level, early visual perception (the P1 component) and late cognitive processing (the N2 and P3 components) were delayed. The practice of an open-skill sport such as fencing was associated with a reduced age-related decline. The cortical visual processing (P1 component) of the older fencers had the same latency as that of the younger subjects, older fencers had enhanced attention (N1 component), and inhibitory processing (N2 and no-go P3 components) was faster and/or enhanced compared with nonathletes.

This research was supported by the University of Rome "Foro Italico" grant RIC1062010.

The authors have no conflicts of interest to disclose.

The results of the present study do not constitute endorsement by the American College of Sports Medicine.

## REFERENCES

- Bielak AA, Anstey KJ, Christensen H, Windsor TD. Activity engagement is related to level, but not change in cognitive ability across adulthood. *Psychol Aging*. 2012;27:219–28.
- Chang YK, Nien YH, Tsai CL, Etmier JL. Physical activity and cognition in older adults: the potential of Tai Chi Chuan. *J Aging Phys Act*. 2010;18:451–72.
- Colcombe S, Kramer A. Fitness effects on the cognitive function of older adults: a meta-analytic study. *Psychol Sci*. 2003;14(2):125–30.
- Deary IJ, Der G. Reaction time, age, and cognitive ability: longitudinal findings from age 16 to 63 years in representative population samples. *Aging Neuropsychol Cogn*. 2005;12:187–215.
- Di Russo F, Bultrini A, Brunelli S, et al. Benefits of sports participation for executive function in disabled athletes. *J Neurotrauma*. 2010;27:2309–19.
- Di Russo F, Spinelli D. Sport is not always healthy: executive brain dysfunction in professional boxers. *Psychophysiology*. 2010;47:425–34.
- Di Russo F, Taddei F, Apnile T, Spinelli D. Neural correlates of fast stimulus discrimination and response selection in top-level fencers. *Neurosci Lett*. 2006;408:113–8.
- Dien J, Spencer KM, Donchin E. Parsing the late positive complex: mental chronometry and the ERP components that inhabit the neighbourhood of the P300. *Psychophysiology*. 2004;41(5):665–78.
- Etmier JL, Chang YK. The effect of physical activity on executive function: a brief commentary on definitions, measurement issues, and the current state of the literature. *J Sport Exerc Psychol*. 2009;31(4):469–83.
- Falkenstein M. Inhibition, conflict and the Nogo-N2. *Clin Neurophysiol*. 2006;117(8):1638–40.
- Falkenstein M, Hoormann J, Hohnsbein J. Inhibition-related ERP components: variation with modality, age, and time-on-task. *J Psychophysiol*. 2002;16:167–75.
- Fallgatter AJ, Mueller TJ, Strik WK. Age-related changes in the brain electrical correlates of response control. *Clin Neurophysiol*. 1999;110:833–8.
- Fallgatter AJ, Strik WK. The NoGo-anteriorization as a neurophysiological standard-index for cognitive response control. *Int J Psychophysiol*. 1999;32(3):233–8.
- Gajewski PD, Stoerig P, Falkenstein M. ERP—correlates of response selection in a response conflict paradigm. *Brain Res*. 2008;1189:127–34.
- Gazzaley A, Clapp W, Kelley J, McEvoy K, Knight RT, D'Esposito M. Age-related top-down suppression deficit in the early stages of cortical visual memory processing. *Proc Natl Acad Sci U S A*. 2008;105(35):13122–26.
- Hasher L, Zacks RT, May CP. Cognitive regulation of performance: interaction of theory and application. In: Gopher D, Koriat A, editors. *Attention and Performance XVII*. Cambridge (MA): MIT Press; 1999. p. 653–75.
- Hillman CH, Erickson K, Kramer AF. Be smart, exercise your heart: exercise effects on brain and cognition. *Nat Rev Neurosci*. 2008;9:58–65.
- Hillman CH, Kramer AF, Belopolsky AV, Smith DP. A cross-sectional examination of age and physical activity on performance and event-related brain potentials in a task switching paradigm. *Int J Psychophysiol*. 2006;59:30–9.
- Kramer AF, Hillman CH. Aging, physical activity, and neurocognitive function. In: Acevado E, Ekkekakis P, editors. *Psychobiology of Physical Activity*. Champaign (IL): Human Kinetics; 2006. p. 45–59.
- Kramer AF, Humphrey DG, Larish JF, Logan GD, Strayer DL. Aging and inhibition: beyond a unitary view of inhibitory processing in attention. *Psychol Aging*. 1994;9:491–512.
- Measso G, Cavazzeran F, Zappala G, et al. The Mini-Mental State Examination: normative study of an Italian random sample. *Dev Neuropsychol*. 1993;9(2):77–85.
- Morrison JD, Reilly J. The pattern visual evoked cortical response in human ageing. *Q J Exp Physiol*. 1989;74:311–28.
- Murray MM, Brunet D, Michel CM. Topographic ERP analyses: a step-by-step tutorial review. *Brain Topogr*. 2008;20:249–64.

24. Nougier V, Rossi B, Alain C, Taddei F. Evidence of strategic effects in the modulation of orienting of attention. *Ergonomics*. 1996;39(9): 1119–33.
25. Pontifex MB, Hillman CH, Polich J. Age, physical fitness, and attention: P3a and P3b. *Psychophysiology*. 2009;46:379–87.
26. Porciatti V, Fiorentini A, Morrone MC, Burr DC. The effects of ageing on reaction times to motion onset. *Vision Res*. 1999;39: 2157–64.
27. Potter LM, Grealy MA. Aging and inhibitory errors on a motor shift of set task. *Exp Brain Res*. 2006;171(1):56–66.
28. Potter LM, Grealy MA. Aging and inhibition of a prepotent motor response during an ongoing action. *Neuropsychol Dev Cogn B Aging Neuropsychol Cogn*. 2008;15(2):232–55.
29. Raz N. Aging of the brain and its impact on cognitive performance: integration of structural and functional findings. In: Craik FIM, Salthouse TA, editors. *The Handbook of Aging and Cognition*. Mahwah (NJ): Erlbaum; 2000. p. 1–90.
30. Roggeveen AB, Prime DJ, Ward LM. Lateralized readiness potentials reveal motor slowing in the aging brain. *J Gerontol B Psychol Sci Soc Sci*. 2007;62(2):P78–84.
31. Roi G, Bianchedi D. The science of fencing: implications for performance and injury prevention. *Sports Med*. 2008;38:465–81.
32. Rossi B, Zani A, Taddei F, Pesce C. Chronometric aspects of information processing in high level fencers as compared to non athletes: an ERPs and RT study. *J Hum Mov Stud*. 1992;23:17–28.
33. Rossini PM, Rossi S, Babiloni C, Polich J. Clinical neurophysiology of aging brain: from normal aging to neurodegeneration. *Prog Neurobiol*. 2007;83:375–400.
34. Rossit S, Harvey M. Age-related differences in corrected and inhibited pointing movements. *Exp Brain Res*. 2008;185:1–10.
35. Salisbury DF, Griggs CB, Shenton ME, McCarly RW. The NoGo P300 ‘anteriorization’ effect and response inhibition. *Clin Neurophysiol*. 2004;115:1550–8.
36. Salthouse TA. Aging and measures of processing speed. *Biol Psychol*. 2000;54(1–3):35–54.
37. Smith PJ, Blumenthal JA, Hoffman BM, et al. Aerobic exercise and neurocognitive performance: a meta-analytic review of randomized controlled trials. *Psychosom Med*. 2010;72:239–52.
38. Stuss DT, Murphy KJ, Binns MA, Alexander MP. Staying on the job: the frontal lobes control individual performance variability. *Brain*. 2003;126(pt 11):2363–80.
39. Vallesi A. Targets and non-targets in the aging brain: a go/nogo event-related potential study. *Neurosci Lett*. 2011;487:313–7.
40. Vallesi A, McIntosh AR, Stuss DT. Temporal preparation in aging: a functional MRI study. *Neuropsychologia*. 2009;47:2876–81.
41. Vallesi A, Stuss DT. Excessive sub-threshold motor preparation for non-target stimuli in normal aging. *Neuroimage*. 2010;50(3): 1251–7.
42. Vallesi A, Stuss DT, McIntosh AR, Picton TW. Age-related differences in processing irrelevant information: evidence from event-related potentials. *Neuropsychologia*. 2009;47(2):577–86.
43. Verleger R, Paehge T, Kolev V, Yordanova J, Jaśkowski P. On the relation of movement-related potentials to the go/no-go effect on P3. *Biol Psychol*. 2006;73(3):298–313.
44. Vogel EK, Luck SJ. The visual N1 component as an index of a discrimination process. *Psychophysiology*. 2000;37(2):190–203.