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Fixation stability and saccadic latency in élite shooters

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Abstract

This study tested the hypothesis that elementary visuo-motor functions involved in visual scanning, as measured by fixation and saccadic tasks, are better in a group of high-level clay target shooters ($N = 7$) than in a control group ($N = 8$). In the fixation task, subject were told to keep fixation as still as possible on a target for 1 min, both in the presence and absence of distracters. For shooters, time did not have an effect on fixation stability, and they had more stable fixation than controls in the distracters condition. Results indicate a difference between groups on both the temporal span of attention and selective attention. In the saccadic task, subjects were asked to saccade, as fast as possible, towards a peripherally displayed target. Two conditions were used: simple reaction to target onset and discrimination between targets and distracters. Shooters had faster saccadic latency to targets than controls in both conditions. Finally, to evaluate the effect of exercise on saccadic latency, we trained one control subject to saccade to a target displayed at a constant spatial position. At the end of the training, saccadic latency reached a value comparable to that recorded in shooters. Learning was largely retinotopic, not showing transfer to untrained spatial positions.

Keywords: Shooters; Eye-movements; Eye-fixation; Saccadic latency; Learning

1. Introduction

In sport-specific conditions, there exists athletes' superiority in complex visuo-motor performance compared to non-athletes. On the contrary, their superiority in *elementary* visuo-motor tasks is not clear. Various studies have failed to find significant differences between athletes and control groups in basic visuo-motor functions outside sport-specific conditions. For instance, reaction times to stimulus onset differ little, if any, from those of control subjects (e.g., Abernethy, 1996; Abernethy & Neal, 1999; McLeod, 1987).

There are however some specific non-sport conditions where differences arise. For example, athletes show an advantage when a warning signal is used, also when there are long time intervals between it and the imperative stimulus (Enns & Richards, 1997; Turatto, Benso, & Umiltà, 1999). Using the Posner paradigm (Posner, Snyder, & Davidson, 1980), some athletes (volleyball, basket and hockey players) show a broader attentional focus than controls (Castiello & Umiltà, 1992; Enns & Richards, 1997; Nougier, Azemar, Stein, & Ripoll, 1992; Pesce-Anzender & Bosel, 1998), while others athletes (e.g., pistol shooters) show a narrowing of attentional focus upon the target (Tremayne & Barry, 2001). Thus, the effect of sport practise on elementary visuo-motor tasks, such as manual response to a visual stimulus, seems related to the specific skills required by the sport.

Shooting sports (such as trap, double trap and skeet) pose heavy requirements on spatial attention, scanning ability and resilience to fatigue. Top-level shooters are able to strike targets subtending less than 0.1° of visual angle, with a starting speed of 33 m/s and, in some specialties (such as trap), starting from unpredictable portions of space and in unpredictable directions.

Evidence on basic visuo-motor tasks in shooters is contrasting. Abernethy and Neal (1999) found no differences with respect to a control group in rapid tachistoscopic detection, and coincidence timing detection. However, an advantage (23 ms) in simple, but not choice, manual reaction time was present (Abernethy &

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Neal, 1999). On the other hand, Czigler, Balazs, and Lenart (1998) found that shooters were faster (48 ms) and more accurate than the control group in a task requiring fast information processing and simultaneous evaluation of visual features.

To investigate the performance of élite shooters in elementary visuo-motor tasks, we selected two functions involved in visual scanning, and measured their efficiency by recording eye-movement. In the first experiment, we measured the stability of target fixation in a long-lasting (i.e., 1 min) staring task. The experimental conditions (time and presence vs. absence of distracters) allowed the evaluation of the effect of fatigue and selective attention. In the second experiment, we measured the saccadic reaction time in a simple detection task and in a choice paradigm. Comparison between groups and conditions provides an estimate of the effect of sport practise on elementary visuo-motor tasks. To support the interpretation of the differences observed between shooters and non-athletes in terms of effect of sport exercise, we performed a learning experiment on a saccadic task in one control subject.

2. Methods

2.1. Subjects

Seven professional shooters (all males; mean age 27.0 years) and eight control subjects (four females, four males; mean age 29.4 years) participated in the experiment. All subjects had normal visual acuity. The dominant eye, hand and foot were assessed by a modified version of the Edinburgh inventory (Salmaso & Longoni, 1985). Only one subject in the control group was left-handed; in all cases the right eye was dominant. Shooters had at least four years of training (mean 9 years) in at least two of the three Olympic disciplines (trap, double trap and skeet). They practised shooting at least 16 h per week and participated in National and International championships. Subjects provided informed, written consent.

2.2. Stimuli

A PC generated stimuli on a 17 in. SVGA monitor. The screen subtended $37 \times 28°$ of visual angle. For the *fixation task* the target stimulus was a cross inside a white circle, subtending 0.3°, displayed in the centre of the screen for 60 s on a black background. In the standard condition, the target was displayed alone. In the distracter condition, visual stimuli appeared around the fixation point. Distracters were red circles subtending 0.4° and displayed at 1.5° or 3° of eccentricity, at one out of eight equidistant polar angles. These parafoveal distracters were flashed one at time for 150 ms at random intervals (range 500–1500 ms). In the *saccadic task*, the fixation point (the same as described above) was displayed continuously at the centre of the screen. Every 2200 ms, a stimulus (a circle subtending 0.5° of visual angle) was displayed for 800 ms at one of the four cardinal points (in random order) at an eccentricity of 6° from the fixation point. The peripheral stimulus could be a target (red circle) or a distracter (green circle).

2.3. Procedure

Subjects were seated in a chair, in a dimly illuminated room, with the head fixed with a chin-rest and a forehead-rest, at a viewing distance of 63 cm. Before collecting the data, the recording was calibrated by the presentation of nine 0.8° boxes, located according to a 3×3 matrix subtending $7 \times 7°$.

2.3.1. Fixation task

Two conditions were used: standard and distracter conditions. In both conditions, subjects were asked to maintain fixation as still as possible on the central point for 1 min. We used this long time interval with the aim of stressing the fixation system. In the distracter condition, 48 stimuli were flashed near the fixation point in the parafovea. Both tasks were performed for 60 s.

2.3.2. Saccadic task

Two conditions were employed: standard and distracter conditions. In the first one, subjects performed visually guided saccades toward the target. Subjects were instructed to maintain fixation on the central point until the target (a red stimulus) appeared unpredictably at one of the four locations; at that moment, the subject had to saccade, as fast as possible, to the target. Overall, 80 targets were displayed. In the distracter task, stimuli could be either targets or distracters. Subjects had to saccade toward the stimulus only if it was red; if the stimulus was green, subjects were instructed to keep fixation on the central fixation mark. Instructions emphasised that the subject should not try to anticipate the target appearance. Twenty targets and 20 distracters were presented in a random sequence at each location.

2.4. Eye-movement recording and data analysis

Horizontal and vertical eye-movements were recorded from the right eye, by means of an infrared pupil reflection system (AMTech ET4 eye tracking system). Filtered (DC-125 Hz) signals were sent to a computer and recorded on a disk. The temporal resolution of the system was 5 ms (sampling rate 200 Hz); spatial resolution was close to 0.03°, similar to that of other studies (Foster, Savage, Mannan, & Ruddock, 2000; Pitzalis & Di Russo, 2001). Signals were analysed off-line after each session. Blinks were automatically detected. In the

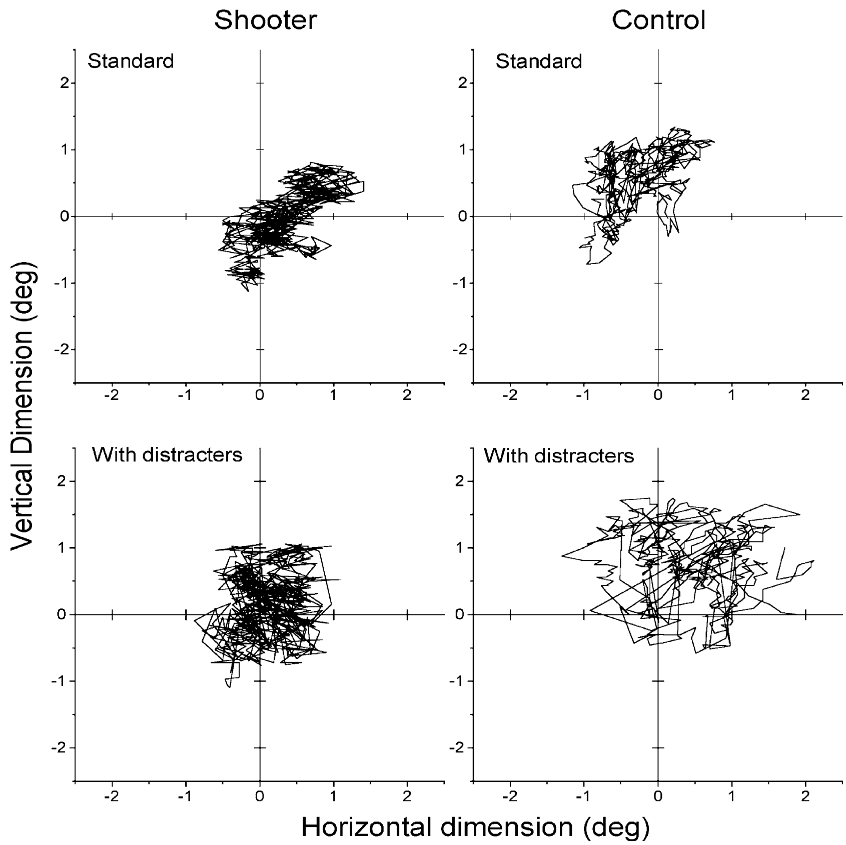

Fig. 1. Eye position during 60-s fixation task in one shooter (left) and in one control subject (right), in the standard condition (top) and when distracters were flashed in the parafovea (bottom).

fixation task, fixation stability (i.e., the position of the right eye in the focal plane) was evaluated by calculating the standard deviation of the eye position averaged along both the horizontal and vertical dimensions (in degrees of visual angle). The whole fixation period (60 s) was divided in two consecutive 30-s fractions. An ANOVA, with Task (standard and distracter condition) and Time intervals (first and second) as the repeated measures factors and Group as the between-subjects factor, was carried out on these data. The number of blinks was compared by the *U* Mann–Whitney test.

In the saccadic tasks, data were rejected for any of the following reasons: (a) recording contaminated by blinking; (b) saccades performed towards distracters; (c) eye-movement before target onset; (d) saccade latency shorter than 80 ms [1] or longer than 800 ms or (e) two saccades performed instead of one. The number of all responses rejected provided a rejection rate, taken as an index of signal reliability. The number of responses rejected for reasons (b) and (e) provided an index of performance accuracy (expressed as percentage of error). Separate ANOVAs were conducted for saccadic latency and saccadic amplitude with Group (shooters and controls) as the between-subjects factor and Task (standard and distracter) and Direction (up, down, left and right) as the within-subjects factors. Post-hoc comparisons were based on the Tukey Honestly significant difference test for non-equivalent samples. Percentage of errors and number of blinks were analysed with the *U* Mann–Whitney test.

3. Results

3.1. Fixation task

Fig. 1 presents representative data for one professional shooter and one control subject. The two top graphs report eye locations during 1 min of fixation on a central mark. The bottom graphs show the same phenomenon when distracters were flashed in the parafovea. The onset of distracters impaired fixation stability in the control subject (as shown by a more sparse distribution of fixation locations); this phenomenon was less marked in the shooter.

[1] According to various authors investigating saccadic latency distribution, eye-movements with latency shorter than 80 ms are "anticipatory saccades" and are not considered express saccades (Fischer, Weber, & Biscaldi, 1993; Weber & Fischer, 1995; Wenban-Smith & Findlay, 1991).

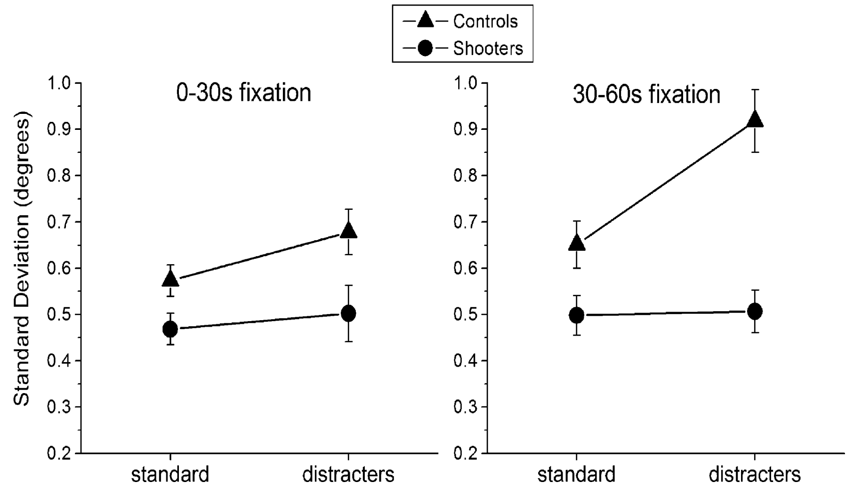

Fig. 2. Data showing eye shift around the fixation point (fixation stability) for both subject groups during the first and second 30-s interval. The vertical bars indicate the standard deviations.

Fig. 2 reports mean data on fixation stability for the two groups averaged during the first and the second 30-s intervals. Results of ANOVA showed that the main effects for Group, Task and Time were not significant. The Group×Task×Time interaction was significant ($F_{(1,13)} = 5.1$; $P < 0.05$). For shooters, fixation stability was comparable in both time intervals, and in both conditions. For the controls, a time related effect was present only in the distracter condition ($P < 0.01$). Shooters showed, in the distracter condition, more stable fixation than controls both during the first ($P < 0.005$) and the second ($P < 0.001$) time intervals.

Blinks, often interpreted as a sign of fatigue, were infrequent in the control group (mean value 9 blinks in 60 s) and nearly absent in shooters (mean value 0.3 blinks in 60 s); the difference between the two groups was statistically significant ($U = 28$; $P < 0.05$).

3.2. Saccadic task

Fig. 3 reports the latency of saccades towards targets displayed at each of the four spatial positions. Inspection of the continuous and dashed lines of each polar plot allows comparison of the latencies obtained in the two conditions (standard vs. distracter). ANOVA results showed significant main effects for the factors Group, Task and Direction. Shooters had shorter saccadic latencies than controls ($F_{(1,13)} = 13.8$, $P < 0.005$). Saccadic reaction times were longer in the distracters condition ($F_{(1,13)} = 336.3$; $P < 0.001$). Further, saccades were generally slower for downward targets ($P < 0.001$) as previously reported (Pitzalis & Di Russo, 2001). The Group×Task interaction was significant ($F_{(1,13)} = 7.1$; $P < 0.05$). The analysis of the interactions showed that shooters had saccadic latencies shorter than controls

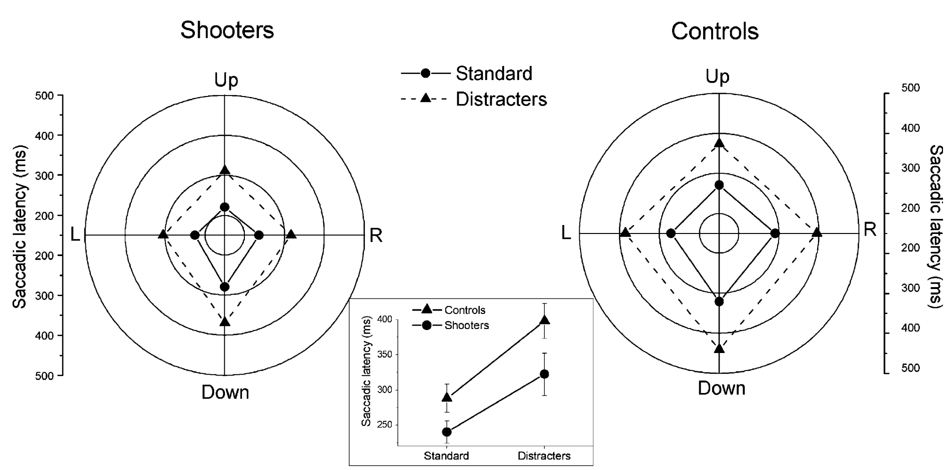

Fig. 3. Polar representation of saccadic latency toward the four spatial positions (up, down, right, left) tested in the two experimental conditions. Concentric circles represent equilatency lines; the inner one indicates 200 ms latency, the outer 500 ms. In the inset, data corresponding to the four positions are collapsed (Group×Task interaction). The vertical bars indicate the standard deviation.

both in the simple reaction to stimuli (45 ms), and when discrimination of target from distracters was required (73 ms). The performance of the control group in the absence of distracters was comparable to that of shooters in the distracters condition (see lower graph in Fig. 3).

Saccades were accurate in both groups and in all conditions. The percentage of errors, defined as the sum of saccades towards non-targets and two-step saccades, was small (13.8% controls, 12% shooters) and comparable in the two groups ($U = 15$; n.s.) The amplitude of correct saccades was similar in the two groups ($F < 1$, n.s.), and the mean number of blinks was not different in the two groups (4.2 in shooters, 5.5 in controls; $U = 25$; n.s.).

4. Control experiment

In order to measure the effect of training on the saccadic latency, one of the control subjects (FDR, one of the authors) was submitted to a saccadic training.

4.1. Methods

Saccadic training consisted of 10 learning sessions, each lasting about 30 min; it was limited to rightward saccades i.e. all stimuli were displayed 6° to the right of the fixation point on the horizontal meridian. During each session, 200 saccades were made: 100 saccades in the standard task and 100 saccades in the distracters task. One pre- and one post-test (identical to the original saccadic task previously described, with stimuli displayed at four spatial locations) were executed before and after the learning period, to measure the degree of transfer to the untrained positions. t-Test analyses were performed on the median saccadic latency between the first and the last training session and between the pre- and the post-test of the original task.

4.2. Results

As already noted, a ceiling effect was found for saccades accuracy; thus, the learning effect was measurable only by saccadic latency.

Fig. 4 shows the median saccadic latency measured in each of the 10 training sessions. With learning, the saccadic reaction time decreased in both the standard and distracter tasks. In both cases, the improvement was clear through seventh–eighth session; then it reached a plateau. In the standard task, the final latency value was 240 ms, representing an advantage of 40 ms ($t_{(99)} = 5.72$; $P < 0.001$). In the distracter task, the latency at the end of training was 320 ms representing an advantage of 100 ms ($t_{(99)} = 9.64$; $P < 0.001$).

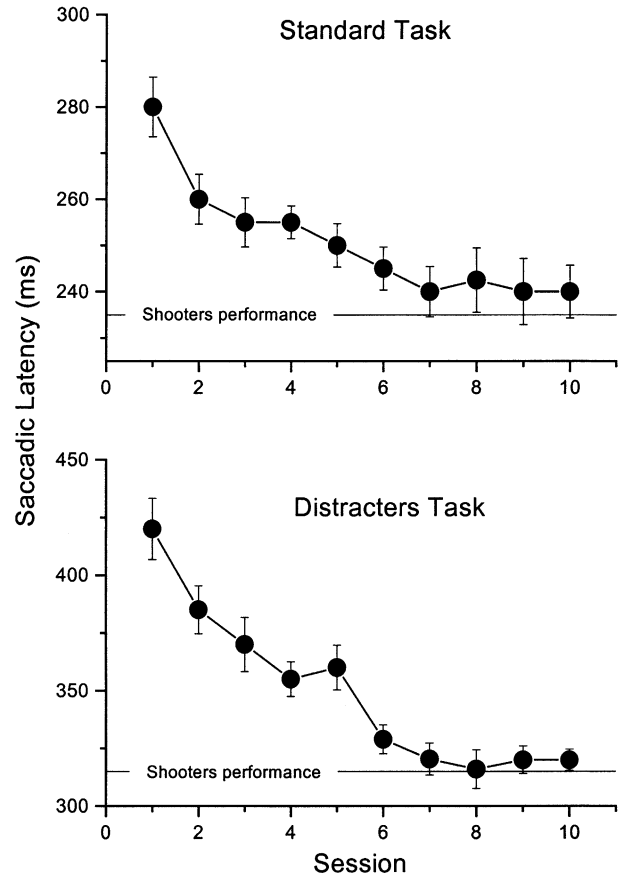

Fig. 4. The effect of practise on saccadic latency for the two tasks. Filled symbols show the median saccadic latencies of the control subject FDR during training, each point is the average of 100 trials; the vertical bars indicate the standard errors. These data refer to rightward trained saccades (i.e., saccades toward a predictable direction). For comparison, shooters' performance is also shown. The lines indicate the mean group latency values obtained in the two conditions of the saccadic tasks; in this case, saccades were performed in four (unpredictable) directions.

As indicated in the figure, the post-training latency of saccades toward a predictable direction was comparable to that of shooters in both the standard (240 ms for control subject vs. 235 ms for shooters) and the distracter (320 ms vs. 315 ms) tasks. However, note that shooters had this performance in the single session they made and that saccadic direction was unpredictable.

Fig. 5 shows the distribution of rightward saccadic latencies for the trained control subject at the beginning (Fig. 5A and B, first session) and at the end (Fig. 5C and D, 10th session) of training. For comparison, the shooters' distribution of rightward saccade latency is reported in the bottom graphs (Fig. 5E and F).

The effect of practise is evident in both tasks. In the standard task, the saccades distribution shifted leftward indicating an overall shortening of the saccadic latencies (medians were 280 and 240 ms before and after training, respectively). Saccadic latencies exhibit at least three main modes (e.g. Fischer et al., 1993): express saccades

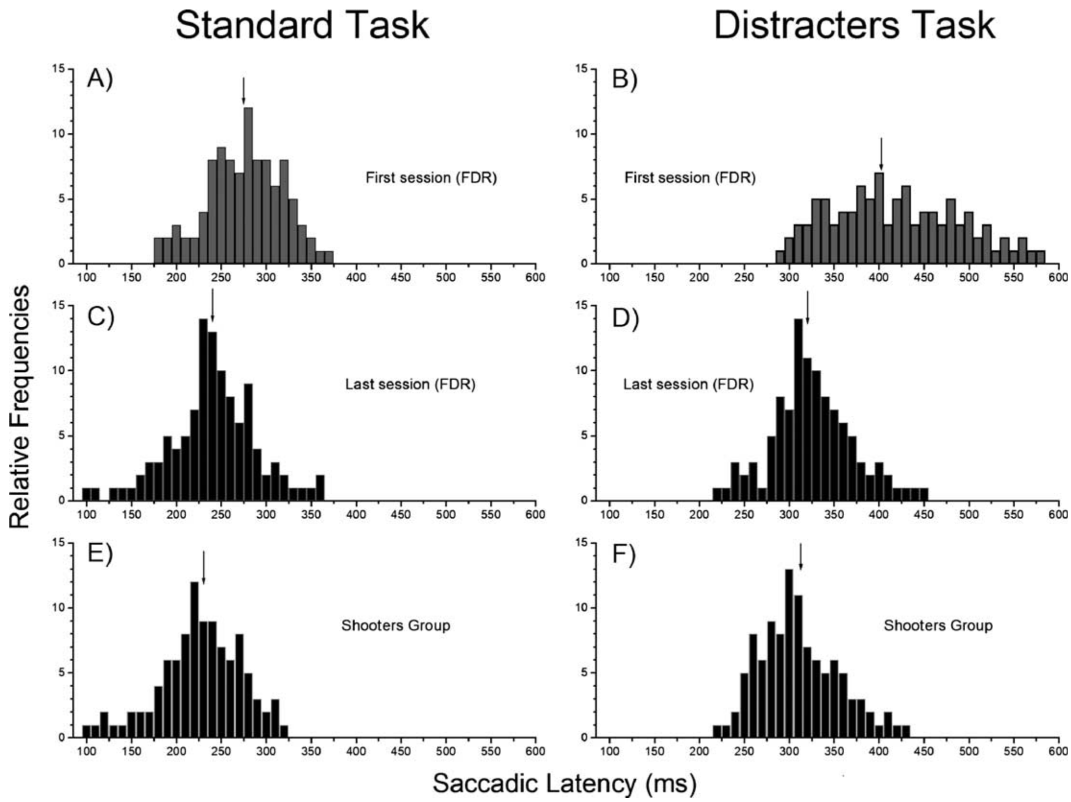

Fig. 5. Distribution of rightward saccadic latencies of the control subject before learning (A, B) and after learning (C, D). In each graph, the distribution is based on 100 saccades. The change in the distribution of saccadic latencies indicates that, after learning, some express saccades were present, and the number of fast-regular saccades increased at the expense of slow-regular saccades. The bottom graphs (E, F) show the distribution of rightward saccades collected in the single session from the shooters. The overall number of saccades was 124. Note that, for shooters, the direction of 2saccades was unpredictable, while for the control subject it was constant. The arrows indicate the median values of each distribution.

(mean latency 100 ms), fast-regular saccades (mean latency 150 ms), and slow-regular saccades (mean latency 200 ms or more). In the control subject, express saccades were totally absent before training, but following the extensive training they were present, although rare (5%). Fast-regular saccades increased from 6% to 15%, and slow-regular saccades decreased from 94% to 80%.

In the distracters task, the subject's latency distribution in the first session was flatter than in the standard task with a median value of 420 ms. The distribution narrowed after the training period, showing a peak around 310 ms (the median value was 320 ms). In this case, the more relevant effect of learning was the shortening of the slow-regular saccades latency.

In both tasks, the distribution of saccadic latencies of the trained subject was close to that of the shooter group. However, note that saccadic direction was predictable for this subject but unpredictable for the shooters.

Fig. 6 shows the results of the control subject in the original saccadic tasks collected before and after training. In these tests, saccade direction was unpredictable. Inspection of the figure shows a clear effect of practise for saccades to the right (trained) side; there was a trend to transfer to other (untrained) space positions; however, this effect was not statistically significant.

An analysis of saccadic latency distribution in the standard condition showed that express saccades were absent in all directions, including the trained one.

5. Discussion

The present data support the view that sport experience may produce a change in elementary visuo-motor tasks related to sport practise. These findings relative to eye-movements are consistent with data on manual reaction time in shooters reported by Czigler et al. (1998).

The superiority of shooters in some of the eye-movement parameters considered in the present study was not immediately predictable; in a way, we are all "experts" in eye-movement, producing about three saccades and three fixations per second during each day of our life. The impressive visuo-motor skills of these athletes, shown when striking the clay target one shot after the other for hours, might have gone undetected in the simple paradigm (fixation and saccadic task) used in our experiment. Indeed, testing athletes with research paradigms that are not typical of sport settings may reduce or remove from the task the advantage gained from sport experience (e.g. Singer, Mark, & Frehlich,

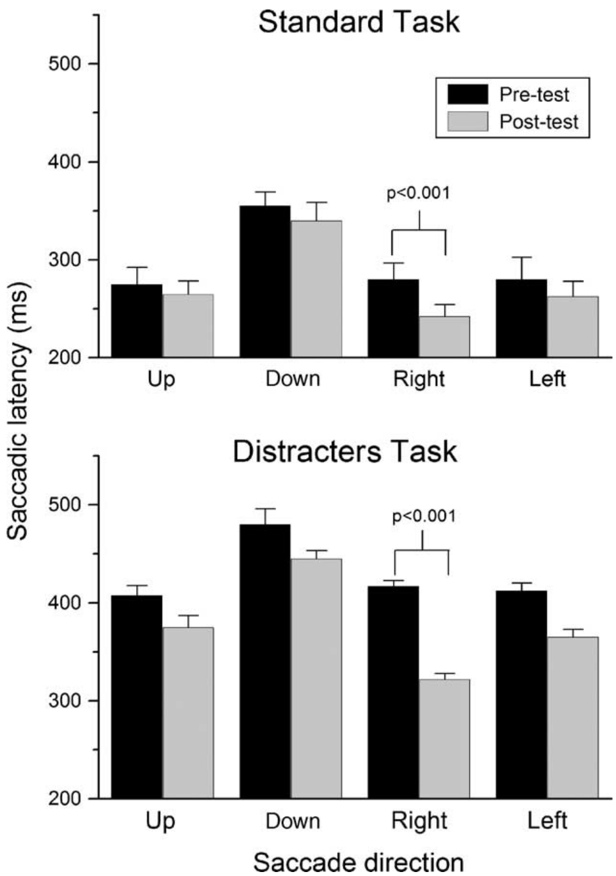

Fig. 6. The effect of rightward saccades learning in both the standard and the distracter condition of the saccadic tasks (unpredictable saccade direction) for the control subject. Data were collected pre- and post-training; each column represents the median saccadic latency of 20 saccades. The vertical bars indicate the standard deviation. The learning effect was significant only for the right trained position in both the standard (280 ms pre-test vs. 243 ms post-test, $t_{(19)} = 5.05$, $P < 0.001$) and the distracter conditions (418 ms pre-test vs. 323 ms post-test, $t_{(19)} = 5.07$, $P < 0.001$). The transfer of learning to other stimuli was not statistically significant.

1998; Williams, Davids, Burwitz, & Williams, 1993). However, we detected a substantial advantage in some parameters describing basic visuo-motor skills. Eye stability during fixation was comparable in the two groups in the standard task, but the skilled performance of the shooters emerged when distracters popped-out in the visual field. This condition requires highly selective attention and can be linked to the shooter's ability to focus on the target and ignore what is going on in the visual scene. Moreover, the shooters did not show any sign of fatigue (as measured by increased instability and/or blinks) in any conditions, while a time-related effect was present for the control subjects in the distracter condition. These observations reveal differences in both the selective aspects (the ability to focus on the target while ignoring distracters) and the intensive aspects of attention (the temporal span of alertness).

The role of attention was evident also in the saccadic latency measurements, where shooters reacted faster than controls to visual stimuli in both the standard and distracter conditions. The shooters' advantage may reflect a generalized "readiness" to respond (Reuter-Lorenz, Oonk, Barnes, & Hughes, 1995; Ross & Ross, 1981) based on the effect of attentional mechanisms working with a higher gain in athletes than in control subjects. Attentional influence may act at various levels. Attention modulates the time course of visual processing (e.g. Carrasco & McElree, 2001; Di Russo & Spinelli, 1999; Hikosaka, Miyauchi, & Shimojo, 1993); moreover, attention may play a specific role on saccadic latency at the level of the disengagement from the fixation point.

According to Fischer and Breitmeyer (1987), when the command to make a saccade occurs while the subject is focusing on the fixation point, attention has to change from an engaged to a disengaged state; this processing takes some time, which adds to saccadic latency. In other words, engaged attention inhibits the saccade system, not allowing a fast saccade (e.g., Mayfrank, Mobashery, Kimmig, & Fischer, 1986). Disengagement from the fixation point becomes faster when the fixation point disappears (the so-called "gap paradigm") or through an extensive training (see Fischer & Ramsperger, 1986 and present FDR data). Thus, it may be proposed that, through daily shooting practise, athletes might learn fast disengagement from the fixation point, thereby shortening saccadic reaction time. This hypothesis can be tested with a gap paradigm. In this way, any surviving differences between shooters and controls would not be explained at the attentional level.

In addition to attentional factors, the advantage measured in athletes in the present study can be due to changes, with respect to control subjects, at the level of motor preparation. The oculomotor preparation hypothesis (Becker, 1989; Kowler, 1990; Paré & Munoz, 1996) contends that the saccadic program toward a predictable direction is partially or completely prepared before target presentation; this early saccade preparation would be marked by the presence of express saccades (Dorris, Pare, & Munoz, 1997; Gagnon, O'Driscoll, Petrides, & Pike, 2002).

Through extensive and specific training, the control was able to produce express saccades toward a predictable direction. The degree of transfer in the saccadic task, requiring saccades in unpredictable directions, showed that learning was spatially selective i.e., only rightward saccades latencies were significantly shortened. Thus, the major portion of learning took place at a retinotopically organised level. This result is in agreement with previous data on humans (Fischer & Ramsperger, 1986) and monkey (Fischer, Boch, & Ramsperger, 1984). After training to one particular location, monkeys made express saccades to this location but mostly regular saccades to untrained locations.

Overall, the saccadic motor preparation may be shorter after training, and this effect is coded at retinotopic level. One may propose that shooting practise imply training of saccadic movements in many directions (often unpredictable), thus producing learning and shortening of saccadic preparation for multiple directions. Along this line, note that shooters exhibited a small percentage of express saccades even when the direction was unpredictable.

The spatial-selective effect of learning on saccadic motor preparation is consistent with the findings (present in both shooters and control subjects) that downward saccades were slower than saccades toward all the other tested directions (up, left and right). Indeed, in free eye-movement search tasks, downward saccades are less frequent than other saccades (e.g., Hall, 1985). Similarly, in shooting practise, downward saccades are less frequent since the target moves upward to the right or to the left, with different orientations. In keeping with this view, shooters express saccades were absent for downward direction.

The use of *prosaccades*, as in the present experiments, leaves open the question about whether shorter reaction times produced by training, in shooters as well as in the trained control subject, depended on the stimulus location (as reviewed by Previc, 1990) or on the direction of the saccades. It is possible that saccadic asymmetries are mediated by a combination of these two factors (see Goldring & Fischer, 1997). Future experiments testing antisaccades (Fischer & Weber, 1992; Goldring & Fischer, 1997) in shooters might help to clarify this issue.

In conclusion, extensive practise can modify elementary visuo-motor functions and athletes may represent a special population for investigating this effect.

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