

Latency of Prosaccades and Antisaccades in Professional Shooters

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ABSTRACT

MORRILLO, M., F. DI RUSSO, S. PITZALIS, and D. SPINELLI. Latency of Prosaccades and Antisaccades in Professional Shooters. *Med. Sci. Sports Exerc.*, Vol. 38, No. 2, pp. 388–394, 2006. **Purpose:** This study evaluated hypothesis that the faster saccadic reaction time in professional clay-target shooters found in a previous study was because of a superiority of athletes arising at the attention level or at level of saccadic motor preparation. **Method:** Ten shooters with at least 6 yr of shooting training in Olympic shotgun disciplines and 10 control subjects participated in the experiments. In the first experiment, prosaccades were studied by comparing the saccadic latencies obtained from the overlap and gap paradigms. In the overlap paradigm, a target was presented randomly at one of four cardinal positions with the fixation point presented throughout the trial duration. In the gap paradigm, the fixation point was removed at the time of target presentation. In the second experiment, subjects were instructed to saccade as quickly as possible in the direction opposite to that of the target location (antisaccades). **Results:** Shooters had shorter saccadic latency than controls, both with gap and overlap conditions in the first experiment and in the antisaccade condition of the second experiment. **Conclusion:** This result indicates that athletes' advantage in saccadic reaction times cannot be attributed to improvement of the attentional mechanism of disengagement. Present results support the hypothesis that shooters develop shorter motor preparation to saccades. **Key Words:** TRS, EYE MOVEMENT, GAP, OVERLAP, ATHLETES, MOTOR EXPERIENCE

Differences in complex visuomotor abilities (e.g., those involved in sport disciplines) are expected between expert athletes and nonexpert subjects. It is more difficult, however, to predict differences in elementary visuomotor skills (e.g., hand or eye movements) in response to a visual stimulus.

In particular, the saccade (i.e., the quick jump of the eye toward a visual target) is an overtrained function; in a way, we are all eye movement "experts," producing about three saccades per second every day of our lives. Thus, the shooters' superiority in this elementary behavior was not predictable. In contrast, in a previous study (8), we showed that shooters' saccadic latency to a stimulus displayed in a random position in the visual field was shorter than that of control subjects.

To explain this superiority, we proposed that the shortening of the saccadic reaction time may be caused a

superiority of athletes arising at the attention level. In general, it is known that attention affects reaction times because is a mechanism that provides priority for perception, consciousness, and action. According to the traditional Posner model (26), orienting attention toward the target requires three mental operations: disengaging from the current focus of attention, moving attention to the location of the target, and engaging the target. Moreover, high-level athletes may develop special attentional skills (3). Specifically, we suggested that through the clay shooting exercise athletes may develop fast disengagement from the actual fixation point to the target (27), thereby shortening their saccadic reaction time. Here we tested this previous hypothesis with the use of overlap and gap paradigms (10,11,13).

In the overlap paradigm, the fixation point is continuously present; in the gap paradigm, the fixation point is offset when the saccadic target appears, or a temporal gap can be introduced between fixation point offset and target onset. Saslow (1967) first noted a great reduction in reaction times when the fixation point was removed just before the target appearance; the presence of a temporal interval further reduced the reaction time (13). It has been argued that, in the gap condition, the saccadic reaction time reflected the actual time required by the reflexive movement; in the overlap condition, an additional mechanism was postulated, named disengagement (27). Disengagement actively moves attention away from the central

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point to the target; it is required to prepare the visually guided saccades (23), and the cost of this mechanism is measured in terms of increasing saccadic reaction time (11). Overall, if saccadic latency difference between shooters and controls was caused by faster disengagement, the gap condition should nullify the athletes' advantage. Conversely, if the difference were not caused by this attentional factor, shooters should perform faster than controls also in the gap paradigm, which does not require disengagement. This latter result supports an alternative explanation of the athletes' shorter saccadic reaction time in terms of motor preparation.

Daily sport practice may train the ocular-motor system to perform over and above the normal level, and this may be reflected in a shortening of eye movement preparation. Saccadic responses can be prepared in advance, before the presentation of the visual target, called early-saccadic preparation theory (1,21). In monkeys, Paré and Munoz (24) recorded faster saccadic latencies with respect to prelearning values following repeated sessions of saccadic movements. The faster saccadic reaction times observed in shooters may derive from a similar learning mechanism. Catching the target implies fast scanning of the visual field; the exercise takes place for many hours each day, many days a week. Such hyperlearning might strengthen the ability to prepare saccades in advance, thus shortening reaction time. Consistently, previous data (8) showed the presence of some express saccades in athletes; these are considered markers of early-saccadic preparation (1,21).

In the second experiment, we tried to evaluate the shooters' early saccadic preparation hypothesis using an antisaccadic task. Whereas prosaccades are in the direction of target location, antisaccades are intentionally guided in the direction opposite to the stimulus. If shorter motor preparation explains the shooters' advantage, it should also be present when an antisaccade is programmed. In contrast, an advantage limited to prosaccades would suggest the enhancement of a specific visual grasp reflex (22) associating stimulus position and eye movement.

MATERIALS AND METHODS

Subjects

A total of 10 professional shooters (all men; mean age 27.9 yr) and 10 control subjects (six men; mean age 27.3 yr) without any shooting experience participated in the experiment; the control group matched the shooters group for age. Shooters had at least 6 yr of training (mean 10 yr) in at least two of the three Olympic shotgun disciplines (Trap, Double Trap, and Skeet). They practiced shooting at least 16 h·wk⁻¹ and participated to national and international championships (as 2000 and 2004 Olympiads). Eye and hand dominance were assessed using a modified version of the Edinburgh inventory (31). All shooters had right hand and right eye dominance; one subject of the control group was left-handed and four subjects had a dominant left eye. Written, informed consent was obtained from all partic-

ipants after the procedures, approved by the local ethical committee, had been completely explained to them.

Stimuli

The stimuli were presented on a 17" SVGA monitor. The screen subtended 27 × 21° of visual angle. A cross inside a 0.3° diameter white circle on a black background, located in the center of the screen, was the fixation point. The target, a 0.6° red circle, was displayed for 300 ms at an eccentricity of 5.5° from the fixation point, at one of the four cardinal positions (left, right, up, down).

Procedure

Subjects were seated on a chair in a dimly illuminated room; their heads were fixed on a chin rest and a forehead rest at a viewing distance of 60 cm. Before data collection, the recording was calibrated by the presentation of nine 0.8° boxes, located according to a 3 × 3 matrix subtending 6 × 6°. The first box appeared in the top-left position, then it jumped to the next position, and so on (from left to right and top to bottom). The subject was instructed to track it. The calibration procedure was repeated three times before the experimental session began. The session included two separate experiments.

In the first experiment—the prosaccadic task—following calibration, subjects were asked to maintain fixation on the central point and then to saccade, as soon as possible, to the target when it appeared in pseudorandom order at one of the four cardinal positions. After saccade, they had to make a saccade back to the fixation point. Two paradigms were compared: overlap and gap. In the overlap paradigm, the fixation point was continuously displayed; with time interval of 1600 ms, the target was presented for 300 ms. In the gap paradigm, the fixation point was removed at the onset of the target (gap = 0 ms), and reappeared only 300 ms later. The time interval between trials and the target duration was the same as in the overlap condition. To control for the effect of the sequence, half of the subjects began the experiment with the overlap paradigm and half with the gap paradigm. For each condition, 80 saccades were made with a pause every 20th stimuli. A total of 160 prosaccades were performed for each subject (four blocks for each paradigm).

In the second experiment—the antisaccadic task—subjects were instructed to saccade as soon as possible in the direction opposite to that of target appearance. Similar to the overlap paradigm, a fixation point was presented continuously for the duration of the trial. Twenty learning trials were allowed before starting the experiment. Overall, 80 antisaccades (four blocks) were recorded for each subject, with a pause every 20 stimuli.

Eye Movement Recording and Data Analysis

Horizontal and vertical eye movements were recorded from the right eye, by 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 to 0.1°. Signals were analyzed offline. Blinks were automatically detected. Data were rejected for any of the following reasons: (a) recordings contaminated by blinking; (b) eye movements occurring before target onset; (c) saccade latency <80 ms or >600 ms; or (d) two saccades performed instead of one. The number of trials rejected provided an index of task accuracy (expressed as percentage of error). Eye movements with latency shorter than 80 ms are classified as anticipatory saccades and are not considered express saccades (14).

A first ANOVA was performed on prosaccadic latency (experiment 1) with group (shooters vs controls) as the between-subjects factor. Paradigm (overlap vs gap) and direction (up, down, left, and right) were the within-subjects factors. A second ANOVA was performed on antisaccadic latency (experiment 2) with group (shooters vs controls) as the between-subjects factor and direction (up, down, left and right) as within-subjects factor.

A third separate ANOVA was performed to compare, for the overlap condition, the latencies of prosaccades (experiment 1) with the latencies of antisaccades (experiment 2). Group (shooters vs controls) was the between-subjects factor, Task (prosaccades vs antisaccade) and direction (up, down, left, and right) were the within-subjects factors. Post hoc comparisons were based on the Tukey Honestly Significant Difference test. The percentage of rejected trials (task accuracy) was analyzed with the U Mann-Whitney test.

Preliminary analysis on the control group showed that the data of the left eye- or hand-dominant control subjects were not specifically different from those of the other

subjects of the group. Thus, this aspect was not further considered in the analyses.

RESULTS

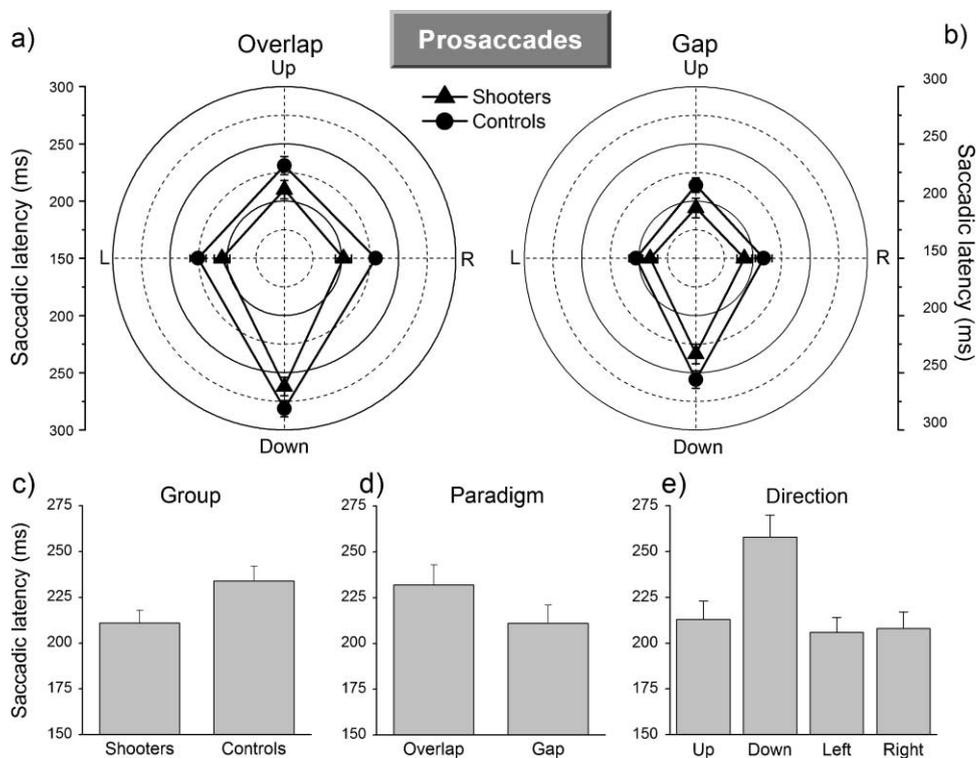
The polar plots of Figure 1 (top) report the mean latency of prosaccades to stimuli occurring at the four cardinal points (experiment 1). Shooters and controls are shown in the overlap (Fig. 1a) and in the gap (Fig. 1b) conditions.

The ANOVA indicated that the main effects of group, paradigm, and direction (reported in the lower part of Fig. 1) were significant. Shooters (mean latency: 211 ms) had shorter ($F_{(1,19)} = 5.2$; $P < 0.05$) saccadic latency than controls (234 ms). Saccadic reaction times were shorter ($F_{(1,19)} = 47.1$; $P < 0.0001$) in the gap (212 ms) compared with the overlap (232 ms) paradigm. Further, post hoc analysis on the main effect of direction ($F_{(3,57)} = 60.5$; $P < 0.0001$) showed that downward saccades (258 ms) were the slowest ($P < 0.0005$). The mean latencies for the three other directions (213, 206, and 208 ms, up, left, and right, respectively) were not different. Interactions were not significant.

Prosaccades were correct in both groups and conditions. The percentage of rejected trials was small (14% controls, 12% shooters) and comparable in the two groups ($U = 199.5$; NS).

Figure 2 shows the distribution of rightward prosaccadic latencies in shooters and controls in the overlap (Fig. 2a) and in the gap (Fig. 2b) paradigm, respectively. Inspection of the figures shows a facilitation effect for the gap condition. In the overlap condition, the shooters saccadic latency distribution showed a peak approximately 190 ms. For controls, the distribution was bimodal, peaking

FIGURE 1—Prosaccades. Polar representation of saccadic latency of shooters and controls toward the four spatial positions (up, down, right, left) tested in the overlap (a) and gap (b) paradigms. Concentric circles represent equi-latency lines; the inner solid circle indicates 200 ms, the outer solid circle indicates 300-ms latency. Vertical and horizontal bars represent the standard errors. The histograms report the main effects of group (c), paradigm (d), and direction (e).



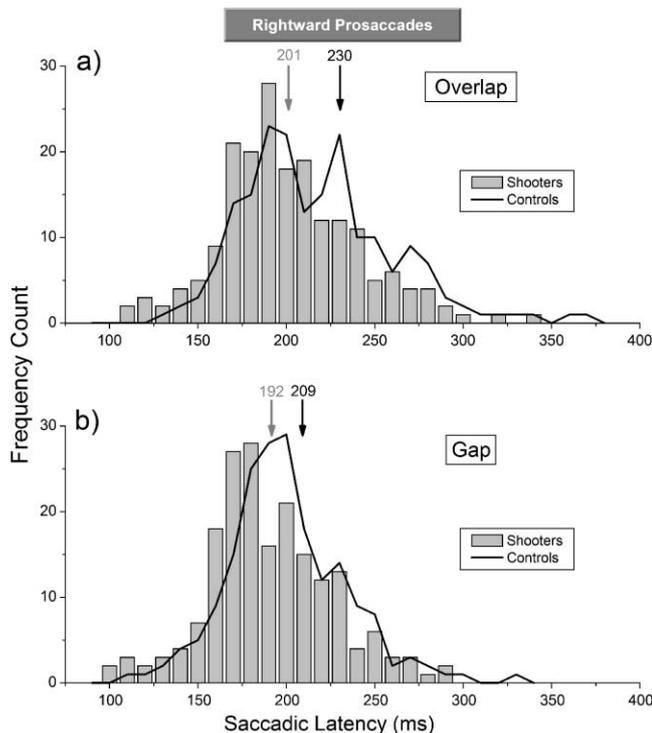


FIGURE 2—Prosaccadic latency distribution for shooters and controls group in the overlap (a) and gap (b) paradigm. To aid comparison, shooters' data are presented as histograms; control subjects data are superimposed, represented by a continuous line. The light and dark gray arrows indicate the mean values of the shooters and controls distributions, respectively. Data are based on approximately 185 rightward saccades. Note: in the gap condition, the presence of some express saccades for shooters but not for controls.

approximately 190 and 230 ms. The mean values of the shooters and controls distributions (indicated in the figure by the light and dark gray respectively) were 201 and 230 ms. In the gap condition, the shooters and controls distributions showed peaks approximately 180 and 200 ms, respectively, whereas the mean values of each distribution were 192 and 209 ms, respectively.

According to Fischer and Weber (13), three main modes of saccadic latencies can be found: slow regular saccades (mean latency ≥ 200 ms), fast-regular saccades (mean latency 150 ms), and express saccades (mean latency 100 ms). In control subjects, express saccades were nearly absent (only 0.6% of latencies being in the range of 100–120 ms) in both the overlap and the gap paradigm. In contrast, shooters showed a small number (5.5%) of express saccades in the gap paradigm.

Intersubjects variability of the gap facilitation effect was pronounced. In particular, two subjects in each group showed no facilitation effect. When present, the effect predominantly resulted from the shortening of the mean latency of the middle- and long-latency saccades (compare Fig. 2a and b).

The polar plot of Figure 3a shows the mean latency for shooters and controls in the antisaccadic task (experiment 2). ANOVA showed that the main effects of group and direction (shown in the lower part of Fig. 3) were significant. Shooters (mean latency: 301 ms) had shorter

($F_{(1,19)} = 4.4$; $P < 0.05$) saccadic latency than controls (336 ms). The effect of direction was significant ($F_{(3,57)} = 15.4$; $P < 0.0001$). The post hoc analysis indicated that saccades to upper (341 ms) and lower (336 ms) targets had longer ($P < 0.0005$) reaction time than leftward (298 ms) and rightward (307 ms) saccades. The interaction between factors was not significant ($F_{(1,19)} = 0.89$ $P = 0.44$).

Figure 4 shows the shooters' and controls' distributions of rightward saccadic latencies in the antisaccadic paradigm. Both distributions show the presence of slow, regular saccadic latencies (>90%). The shooters' saccadic latencies distribution peaks at approximately 280 ms and that of the controls at approximately 300 ms. The mean values of the shooters' and controls' distributions (indicated in the figure by the light and gray, respectively) were 282 and 321 ms. Antisaccadic errors (29.9% controls, 26.5% shooters) were comparable in the two groups ($U = 46.5$; NS). The errors, in most cases, were prosaccadic errors (i.e., eye movements made reflexively toward the target).

The ANOVA comparing latencies recorded in the pro- and antisaccadic task, showed that the effect of group was significant ($F_{(1,19)} = 6.5$; $P < 0.05$, shooters 261 ms, controls 291 ms). The effect of task was significant ($F_{(1,19)} = 120.4$; $P < 0.0001$): prosaccades latency was faster than antisaccades latency (mean difference 88 ms). The main effect of both direction ($F_{(3,57)} = 32.2$; $P < 0.0001$) and the task by direction interaction ($F_{(3,57)} = 14.6$; $P < 0.0001$) were significant. Figure 5 presents the

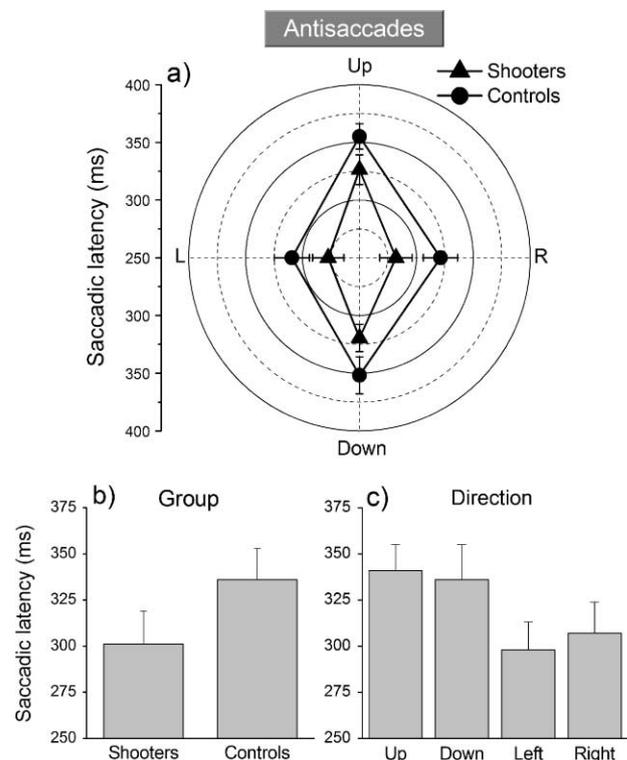


FIGURE 3—Antisaccades. Polar representation of saccadic latency of shooters and controls toward the four spatial positions (a). Vertical and horizontal bars represent the standard errors. Concentric circles represent equilateral lines; the inner solid circle indicates 300 ms, the outer solid circle indicates 400 ms latency. The histograms show the effect of group (b) and direction (c).

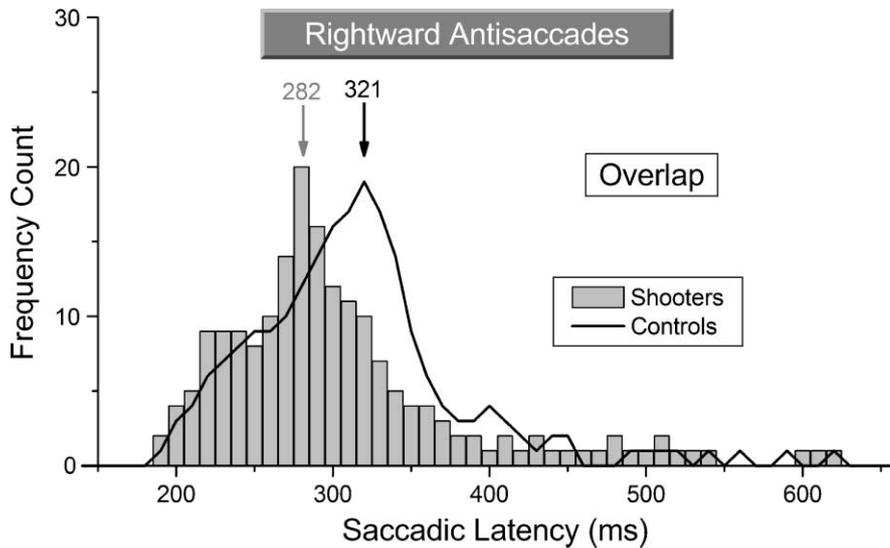


FIGURE 4—Antisaccadic latency distribution for shooters and controls. Data are based on approximately 170 rightward saccades. For other details, see caption of Figure 2.

significant interaction. Prosaccades (see gray histograms) were slower for downward direction (mean value: 273 ms) than for all other directions ($P < 0.0005$), particularly the upward direction (224 ms). This spatial asymmetry was not replicated in the antisaccadic task. Antisaccades (see black histograms) were faster ($P < 0.001$) along the horizontal meridian compared with the vertical meridian, but no difference ($P = 0.98$) was found between upward and downward saccades or between leftward and rightward saccades.

DISCUSSION

Athletes moved the eyes toward a visual target displayed at a random position in the visual space faster than control subjects. This result confirms shooters' advantage previously documented by prosaccades recording (8). In that study, we suggested that the shooters' superiority might result from either a faster disengagement from the central fixation point or to a shorter saccadic motor preparation. The present study reports two new findings to help disentangle between the two hypotheses.

First, athletes' advantage cannot be explained by the attentional mechanism of disengagement. The different performance of the two groups was present also with gap, which facilitates disengagement (11,23). If the advantage measured with overlap paradigm depended on shooters' faster disengagement, then it should vanish with gap. In contrast, shooters preserved their advantage, whereas both groups were faster with gap. These data favor an interpretation of groups' differences in terms of motor preparation rather than attention. Shooters saccades preparation may require less time.

According to various authors (21), express saccades mark early saccadic preparation. The gap effect is characterized by the presence of express saccades, according to some reports (13). In gap condition, we did not find a massive presence of express saccades, possibly for the gap time used (gap = 0). In fact, express saccades frequency is

expected to increase for gap spanning between 0 and 200 ms, both in humans (23) and in monkeys (10). Express saccades, however, were detectable only in the athletes group, a result that supports the hypothesis of an earlier saccade preparation in these subjects.

A faster motor preparation should also produce some advantage on the reaction times of antisaccades; accordingly, the shooters' superiority was detectable also in the second experiment.

In the antisaccadic task, the onset of the stimulus evokes the visual grasp (i.e., the prosaccade); the eye receives an inhibitory message not to execute the reflex, and another motor plan is programmed (a spatial transformation is required). Finally, a movement is executed in the opposite direction. The overall process of planning and replanning movement requires additional time (9,12); consistently, we found longer antisaccadic than prosaccadic latency in both groups. More relevant for the purpose our study, the shooters' advantage was clear both in the prosaccadic (25 ms) and the antisaccadic (35 ms) task, and was proportionally constant (~10%). These data are compatible

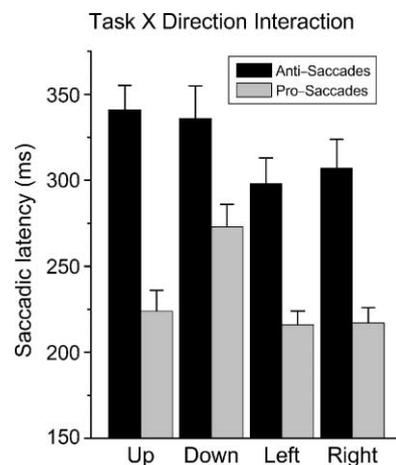


FIGURE 5—Comparison between prosaccades and antisaccades latency for different directions (interaction between task and direction). Shooters' and controls' data are collapsed together.

with an interpretation in terms of faster ocular motor planning. This latter visual motor ability, possibly acquired through extensive visual training of prosaccades involved in shooting practice, may also be detectable in a different visual motor task (e.g., antisaccades), which share the planning phase with prosaccades.

Evidence in favor of the idea that motor planning may be faster in shooters was found recently in an electrophysiological experiment (6). Motor-related cortical potentials were recorded in shooters using a typical paradigm (i.e., the self-paced, alternating finger movement), which has proved useful in evaluating motor preparation and execution both in normal subjects (5) and in patients (7). The analysis indicated that motor preparation for finger movement was shorter and required less neurons activity in athletes than in control subjects. Thus, additional motor experience (e.g., that involved in daily sport training) may modify the brain activity coding for motor preparation of a very simple action, such as finger (6) or eye (present data) movement.

Data indicating a shorter motor (saccadic or manual) preparation are compatible with the general principle that motor exercise involved in sport increases psychomotor efficiency (17). For shooters, the challenge is precise timing and well-coordinated visuospatial actions (saccades and triggering actions). Previous and present data suggest more efficient neural organization of this process. Electrophysiological studies of saccadic motor preparation in shooters are needed, however, to confirm this conclusion. In fact, given that movement reaction times vary across the population, it may be that people who naturally (innately) have shorter movement latencies are more likely to excel in sports such as clay shooting. Although this may not entirely explain the difference in reaction times between athletes and controls, it may explain some of the variance.

A final comment regarding the difference of directional effects for prosaccades and antisaccades: For both gap and overlap conditions, prosaccades downward were slower than upward. This result extends previous findings of professional shooters obtained using the overlap paradigm (8) to the gap condition. Moreover, results agree with earlier studies in normal subjects showing the same vertical saccadic reaction times asymmetry (15,18,19,25,28).

The shorter saccadic latency toward objects located in the visual space above the eye level might fit with the importance of saccades in the exploration of human extrapersonal space (28). In a free eye movement search task, scanning start preferentially in the upper quadrants

(2,4,29,30) and less downward saccades occurs than in all other spatial directions (16,20). This might be true also in shooting practice, where the clay target comes up from center or left or right side and moves toward upper right or upper left fields. Thus, visuomotor experience occurring in shooting practice sums up to normal visual experience, possibly acting at the level of motor preparation.

It is an open question whether shorter reaction times for upward saccades depend more on stimulus location (i.e., the upper portion of the visual field) as reviewed by Previc, (28) or on saccades' direction (i.e., upward). Testing antisaccades is one way of probing the question of stimulus versus response specificity in the visuomotor system. If saccade direction is the dominant aspect, one should expect the same directional pattern for antisaccades and prosaccades, although with longer delay. In contrast, shorter downward latencies in response to upper field stimuli should be expected if saccadic reaction time relies on stimulus location. Neither of these extreme positions was found. In the antisaccadic task, the reaction times increased and the vertical asymmetry observed with prosaccades was cancelled (15). Upward antisaccades had comparable latency to downward antisaccades. Eye movements in the horizontal plain were faster.

Processing asymmetries at visual level, with slowest processing of stimuli in the lower visual field or near space (28) can be invoked to explain these data. Visual asymmetries may add to the longer motor preparation, contributing to prosaccadic longer latency for downward stimuli. In the antisaccade, the same slowest visual processing of lower field stimuli would increase the latency of eye movement in the direction opposite to the stimulus (upward). Thus, the prosaccadic vertical asymmetry would wash out in antisaccades, whereas both horizontal movements (leftward or rightward), having symmetric and fast visual processing, would become significantly faster than movements on the vertical meridian (both upward and downward). In any case, speculation applies to both athletes and controls, because the pattern of saccadic reaction times asymmetry was not different between the two groups. Thus, the directional dimension of saccadic reaction times, indeed, does not reveal any specific feature for athletes group.

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