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Balance of Sharpshooters While Aiming With High Precision

* Károly Bretz	Dept. of Biomechanics, Kinesiology and Informatics, University of Physical Education, Budapest, Hungary * corresponding author
Bohdan Vinohradsky	Dept. of Technical and Shooting Sports, Lviv State University, Lviv, Ukraine
Anatoly Lopatyev	Dept. of Technical and Shooting Sports, Lviv State University, Lviv, Ukraine
Csaba Nyakas	Dept. of Biomechanics, Kinesiology and Informatics, University of Physical Education, Budapest, Hungary, Eszterházy Károly University, Eger, Hungary

ABSTRACT *The aim of this study was to compare the motor control parameters related to shooting which provide postural stability for shooters while aiming and performing the action with high accuracy. Subjects were 66 sharpshooters (air rifle, air pistol and bow) and 22 non-shooter athletes. Postural control was evaluated using a force platform system connected to a HP personal computer. Displacements of center of pressure (COP) were recorded in Romberg position (standstill) as well as in aiming position with opened and closed eyes in both genders. Full-factorial statistical design (ANOVA) demonstrated that sharpshooters stabilize balance better than non-shooters in standstill position. Furthermore, it was proved that holding a weapon while aiming at a target significantly increases postural stability, and the improvement depends on weapon type with an order of rifle>pistol>bow. The results provide data on factors of balance stability in executing a motor action characterized by high accuracy, and rank three shooting sports according to their motor regulation of COP to maintain postural stability. Our findings contribute to understanding and potentially improving top-level performance in sharpshooting.*

KEYWORDS : balance, postural stability, sharpshooter, visual function, aiming, Romberg position.

Introduction

Maintaining balance while performing an action of high accuracy with an upright posture involves complex interactions between visual, vestibular, and somatosensory information, as well as neuromuscular and biomechanical functions [2,3,7,13,15]. These serve to stabilize posture and bring about fine coordination and the co-activation of agonist-antagonist muscles [1,2]. The visual system plays an important role in the control of standing posture [1,7,8]. An excellent model with which to study the stability of balance with high precision is aiming in sport shooting [3,11,12,13]. In this action body sway and firearm swinging are minimized, though they are not reduced to zero. Reaction velocity and sense of tempo make it possible to optimize accuracy by firing the weapon at the right moment by executing this action with high precision [1,3,10].

Methods

Sixty-six athletes participated in this study, with 11 males and 11 females in each group of sharpshooters, namely: rifle, pistol, and bow corps. The control groups were made up of 11 male and 11 female non-shooter athletes. The age range covered 18-24 years in each group. Informed consent was obtained from all participants prior to measurement.

A force platform (Electro-Bionika LTD, Budapest) and a complex computerized system were used to measure the time-varying displacements of COP (center of pressure) [6,7,14,16]. The complex system recorded the COP trajectories and time functions in frontal and sagittal directions. The body sway of sharpshooters in both standstill and aim drill positions was recorded using COP displacements. Representative stabilogram indicating AP (y) and ML (x) excursions of COP is shown in Fig. 1 (panel A). Path length (panel C), as well as the circle containing 95% of the scanned points of the stabilogram trajectories during the test of 20s were also computed automatically (Fig. 1, panel B). In the case of a significant correlation between x_i, y_i, the second kind regression analysis (Equation 1) is the suitable estimation to describe the regression line of the COP displacements (panel B):

$$y = R\frac{\sigma_y}{\sigma_x}(x - m_x) + m_y \qquad (1)$$

The inclination angle (α) showing the direction of regression line was calculated as follows:

$$tg\,\alpha = R\frac{\sigma_y}{\sigma_x} \qquad (2)$$

where R is the correlation coefficient (between x_i and y_i) and σ_x and σ_y are standard deviations; m_x and m_y are the expected values [M(X), M(Y)], computed using coordinates of the scanned points of COP displacements. The α shown on panel B is an illustration of the dominant COP displacements. The radius of the circle is R (panel B), representing the precision of stabilization: the greater R is, the less the stability. From the above presented parameters radius (R) and path length (PL) measurements were selected for the presentation of the results in this study.

The body sway of sharpshooters and control subjects in standstill position was analyzed with their eyes in an either open or closed state (Romberg's test). With eyes open participants were requested to stand on the platform with feet parallel at hip width with arms extended forward horizontally and concentrate on the target located on the wall at eye level. With eyes closed the subjects had to maintain the same position. Recordings were made over a 20s period.

Air rifles, air pistols and bows were employed in the other part of the experiment (aiming position). The target distance was 10m. Circles 10 and 9 were taken into consideration on scorecards; the diameter of the latter was 5.5mm in the case of the rifle, and 27.5mm for that of the pistol. The stance widths were different: 30-70cm in archery; 30-60cm in pistol shooting; 50-70cm in rifle shooting. In this part of the experiment, the subjects were tested with their eyes both open and closed.

Measurement results were analyzed with repeated measures ANOVA and Tukey post hoc *t*-test for pairwise comparisons, using STATISTICA 11 program (StatSoft Inc., Tulsa, OK, USA).

Results

Precision of stabilization (R)

Standstill position

Data obtained regarding R and PL measurements of stabilograms are summarized in Fig. 2. First, the standstill position results obtained regarding R are described based on an analysis of one-way ANOVA with repeated measures (upper row, panels A). An effect of group (weapon) factor was found in men ($F_{3,40}$=6.69, p<0.001) and women ($F_{3,40}$ 3.78, p<0.05). The Romberg test (measurements of subjects with both open and closed eyes) was positive in both genders since the factor of repeated measures was significantly effective to change the R values: $F_{1,40}$=203.1, p<0.001 in men; $F_{1,40}$=12.85, p<0.01 in women. The interaction between the two factors (weapon and eye states) was also significant in both genders: $F_{3,40}$=9.81, p<0.001 in men; $F_{3,40}$=8.54, p<0.001 in women. The statistical results of pairwise comparisons with post hoc *t*-test among the different groups in both the open- and closed-eyes states are shown in Fig. 2. There were differences only in the closed-eyes state in the athlete groups against the control, which means that the athletes could perform better at the balancing function than the non-athletes, but this was only found in the closed-eyes state (see Fig. 2, the asterisks above the columns). It should be mentioned that among the three types of sharpshooting groups there was no difference in the baseline condition regarding both open- and closed-eyes measurements in Romberg positions (ANOVA test including the three athlete groups being selected with the control group being left out substantiated that result (p>0.05)). It should also be mentioned that the overall performance of the male and female participants were comparable in the standstill test position because with the three factor repeated measures ANOVA the gender difference was not significant: (p>0.05); thus, testing both genders only strengthened the results obtained.

Aiming position

The results found in the aiming position for balance control are shown in the B panels (Fig. 2, upper row). Contrary to the radius of stabilogram (R), there was a clear difference between the three weapon-holding groups (in men: $F_{2,30}$=160.7, p<0.001; in women: $F_{2,30}$=305.4, p<0.001). The closed- versus open-eyes states resulted in differences in both genders (in men: $F_{1,30}$=356.0, p<0.001; in women: $F_{1,30}$=12.85, p<0.01). Pairwise comparisons showed that in the men's rifle group, closing the eyes increased radius (p<0.05), while in the two other groups the effects were larger as suggested by a more powerful statistical post hoc *t*-test outcome (p<0.001). In women the pairwise comparisons between open- and closed-eyes states did not reach significance (Tukey post hoc *t*-test). This gender difference was also reflected by the non-significant interaction between the two factors in women, while the interaction was significant in men ($F_{2,30}$=45.81, p<0.001). It should be added that a higher variability was obtained for women in the aiming position.

Comparing the impact of different weapons resulted in marked differences in both genders, that is, in both the open- and closed-eyes states, each group differed markedly from the others (p<0.001, consult symbols • and **x** in Fig. 2). This finding can be considered one of the main findings, that is, the effects of the different weapons are clearly distinct from one another regarding their effect on R of stabilogram, which best reflects the incidence of high amplitude body sway.

Contrasting the two positions, standstill and aiming, may merit further data analysis. Statistical comparisons between the two experimental conditions, that is, standstill versus aiming, regarding both males and females, and also considering the open-eyes condition, there was a marked difference in the performance (three factor ANOVA, $F_{1,62}$=166.2, p<0.001) and, furthermore, in weapon types ($F_{2,62}$=133.5, p<0.001), which means that aiming with weapons markedly enhances stability compared to the baseline condition. There was a significant interaction between the two factors, conditions and weapons ($F_{2,62}$=71.09, p<0.001), which means that aiming with different weapons specifically influences body balancing ability. In the cases of the rifle and pistol groups, R decreased markedly compared to the standstill position (p<0.001); 47% and 32% in men and 52% and 21% in women, respectively. In the case of the bow groups, there was no difference among the two positions.

Path length (PL)

Standstill position

Regarding PL data (Fig. 2, columns in the lower panel) both similarities and differences could be observed as compared to the R data discussed above. In the standstill position (panels A) the similarities are obvious. There was also a difference among the four groups ($F_{3,40}$=6.69, p<0.001 in men and $F_{3,40}$=3.78, p<0.05 in women) and the state of the eyes was also an influencing factor ($F_{1,40}$=203.1, p<0.001 in men and $F_{1,40}$=123.6, p<0.001 in women). Interactions between these factors were also highly significant (men: $F_{3,40}$=11.61; p<0.001; women: $F_{3,40}$=6.21, p<0.01). Comparing weapon groups against controls was significant, but only in the closed eyes condition as it was found also in case of R values (see asterisks above columns in Fig. 2).

Aiming position

Regarding each panel B, however, both differences and similarities between the PL and R data could be found. The difference is obvious if we compare the PL data in the two experimental conditions, A and B. Path length increased while R decreased compared to standstill performances (Fig. 2, compare panels A and B). This statement is based on the following statistics, computing only the three sharpshooter groups from both genders: R: $F_{1,62}$=166.1, p<0.001; PL: $F_{1,62}$=403.1, p<0.001. The similarities could also be observed since both R and PL values increased progressively along the line of the rifle-pistol-bow row. In the case of PL please consult the figure for the paired statistical comparisons regarding how it was proposed in the case of R. Holding and aiming the rifle resulted in the smallest P and PL measures, that is, the most restricted swings in planes and the shortest cumulative movement length values.

Discussion

The present communication attempts to verify a complex biomechanical analytical approach for measuring body balance by employing elite sharpshooters for whom aiming at a target requires controlling body balance. Both genders and three different sharpshooting sport types were compared, that is, rifle, pistol and bow. Besides gender, two other specified conditions were also employed; Romberg's test without the holding of weapons and aiming at target with the holding of weapons. The Romberg test's conditions included an additional group, a non-shooter control group.

The results showed that (1) while being in a standstill position without weapons, the athletes of different groups performed comparably in terms of body balancing in both measures (R and PL), and their performance was better only in the closed-eyes state compared to the non-athlete controls. Thus, within the conditions of Romberg's test, a distinction could be found in favor of the athletes, showing that they possess an advanced proprioceptive capability, which should be a conditioned phenomenon, but comes into surface only in a specified condition in which visual control is switched off (Romberg's test, closed eyes). All the sport groups performed equally, showing that they all reached an optimal proprioceptive condition, independent of gender. (2) Regarding the aiming position, however, sport-type-specific profiles clearly appeared, again in both genders, which points to a better, more restricted body sway function. The following order of performance was found: rifle > pistol > bow. (3) Comparing the two measures employed in this study, R and PL, it can be added that R decreased (precision in stabilization improved), while in comparing the aiming versus standstill positions, PL increased. In general, it can be concluded that the differences in weapon mass, weapon distance from the body, and the magnitude of the athlete's physical effort (among others) may be important factors influencing the amplitude and frequencies of body sway.

The present results were obtained applying an exact, reproducible model situation. The participation of Olympic sharpshooters made it possible to realize a special model to investigate the psychophysiological qualities of human body balance. Our results are in line with

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earlier studies [1,2,8]. In investigating quantitative parameters of balance, the use of the circle (see Fig. 1) for the evaluation of the balance stability of shooters is adequate because its radius indicates the maximum sway amplitudes on the stabilogram. In addition, the scorecard is also circular like the circle of the stabilogram. A negative correlation between the radius and path length of COP displacements, also found here, could be further discussed employing the Fourier spectra of COP displacements [3]. It was observed that the increased sway frequencies were accompanied by reduced amplitudes.

For an accurate interpretation of the excellent Olympic results in shooting, body sway data during aiming, as was exclusively used in this experiment, represent only one of many factors [12]. High-precision shooting actions are closely related to reaction velocity and sense of tempo, as was discussed in a previous paper of ours [3]. Furthermore, the concept of open-loop and closed-loop postural control analysis [6,7,9] and the investigation principle based on the inverted pendulum model [3,7,16] support the explanation of these phenomena. Both of these concepts reflect the existence of relevant time constants influencing parameters of balance control, which has been highlighted already by Collins et al. [6,7].

The quantitative effect of visual and mostly proprioceptive sensory efficiency were clarified by the present finding that the athletes, in the standstill position, showed a better balance ability compared to the non-athletes only in the closed-eyes state [1,2,7]. The positive effect of vision on stance stability might be the consequence of displacement of the weapon relative to the scorecard in the aiming position. Stabilizing the above mentioned "single-line" to the middle of this target, the radius of the circle will be shortened [8]. The higher value of body sway in archery comes from the great effort necessary to shoot a bow. While aiming and observing the target, posture and gun are stabilized through the biomechanical chain composed by the body being in tonus and the gun directed at the target [11,13]. Superimposed vibration while aiming can be controlled simultaneously using a 3D accelerometer fixed to the gun [4]. In accordance with stabilogram-diffusion analysis [6,9], we found that an approximation process exists in stabilization over relatively long-term time intervals for sharpshooters and that COP tends to return to the optimum equilibrium point while they execute an action with high precision; hence, the aiming**.**

We agree with Hawkins [10], who found a relationship between postural stability and shooting performance. In our study, body stability while aiming with three different weapons were tested and evaluated.

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Legendes to Figures
Figure 1.
Evaluation procedures and variables computed automatically. Subject No. 12, archer. Romberg test, opened eyes. Test duration: t = 20s. Panel 'A': time-functions of the COP displacements in frontal (x) and sagittal (y) directions. Panel 'B': stabilogram trajectories with circle, radius: R = 7 mm. Panel 'C': total path lengths .

Figure 2.
Body balance control during Romberg test in sharpshooters. Male and female athletes are compared; data of radius (above) and path length (below) are shown. Two conditions were distinguished: baseline position without carrying weapons (standstill, panels A) and aiming position with the weapons (panels B). In the case of the first condition (A), four groups were used including the non-shooter control group. In B panels only the three shooter groups are presented. Data obtained with athletes in open- and closed-eyes states are also shown (ANOVA statistics in the Results text). Means ± SDs are shown. Statistical differences shown here are based on analyzing differences within appropriate two groups by Tukey post hoc *t*-test: *p<0.05-0.001 vs. Control group (panels A). Furthermore, •p<0.001 vs. all other opened eyes groups, ^{x}p<0.001 vs. all other closed eyes groups, $^{\alpha}$p<0.001 vs. Pistol and Bow groups only, $^{\beta}$p<0.001 vs. Rifle and Pistol groups only (panels B).

Fig. 1

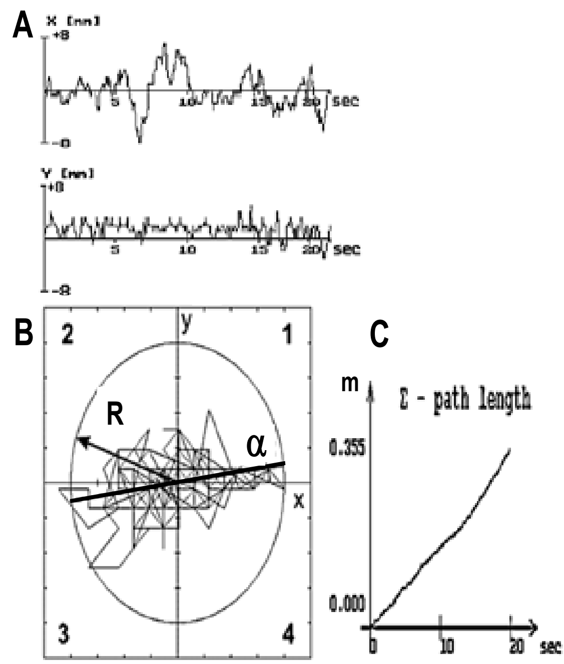
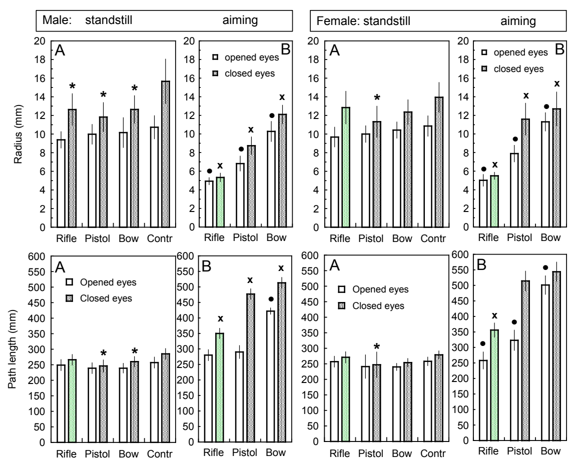


Fig. 2



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