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SHOOTING RANGE IMPROVEMENT BY MONITORING THE DISCRIMINATING FACTORS OF THE JUNIOR BIATHLETES

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Abstract: *The purpose of the research is to identify biomechanical predictors that distinguish between high and low score athletes in biathlon shooting and to determine the relationships among these variables in field testing. Ten biathletes (3 female, 7 male) from CSS Dinamo Râșnov each fired 3 clips of 5 shots in prone and standing shooting positions without physical load, followed by 2 respective series in both disciplines during a simulated 12.5-km pursuit race on roller skis. Referring to the current results, athletes are recommended to focus on vertical rifle sway in prone position and on body sway across the shooting line during standing shooting when fatigued.*

Key words: *Triggering, shooting performance, postural balance.*

1. Introduction

Biathlon is a complex winter sport combining cross-country skiing over distances of 6 to 20 km and precision rifle shooting using 5 shot clips in both the prone and standing positions. Race results are determined by the skiing time and the target shooting performance consisting of accuracy and time at the range [1], [8].

For the standing condition, preceding studies observed strong relationships between body sway [3], [5] as well as rifle movement and shooting performance, which further separates high-level athletes from novices in rifle, pistol, and biathlon shooting [7], [9]. The center-of-pressure (COP) deviation across the shooting line was found to have greater negative effects on the shooting scores [4], [10]. Regarding rifle hold, the horizontal direction was discovered as a main factor [7]. In the prone position, a lack of evidence-based studies and rare considerations on performance-influencing factors such as fine motor control (eye, triggering action) [3] can be observed.

Anaerobic load was reported to impact both disciplines due to increased

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breathing activity and heart rates [8] and to negatively influence postural regulation caused by reduced joint coordination. Physical stress in biathletes was found to negatively affect accuracy [1], shooting times [3], [6], postural control, and rifle stability, with a greater impact on standing than on prone shooting. In addition, exercise was shown to unfavourably influence rifle reaction forces in the back shoulder, which are also considered to determine holding ability, mainly in prone shooting [2].

Biathlon shooting has advanced, becoming more highly developed during the last 2 decades. Improved accuracy and reduced shooting times have led to new requirements for athletes and underlined the need for further research. In earlier studies, a strong focus on single characteristics (e.g., stance stability and rifle sway) is evident, whereas comprehensive biomechanical analyses are lacking. Knowledge of performance predictors in both disciplines (i.e., prone or standing), investigated not only during resting periods, but also in highly stressful situations, is rare and unsystematic. In addition, former studies were mainly accomplished in standardized laboratory conditions, whereas field measurements on biathlon shooting ranges simulating competitions were barely executed.

Consequently, the aims of this study are to identify the relative importance of biomechanical variables in discriminating between high- and low-score performance during rest and a simulated race condition in both prone and standing shooting positions and to discover substantial interrelations between several biomechanical factors and the rifle motion, which is considered to be a central variable for shooting performance.

Based on earlier mentioned studies, it was hypothesized that variables separating high from low score performance change from rest to load situations and differ between prone and standing shooting. In the standing condition, mainly body and rifle sway were expected to be predictors, with a higher contribution of the direction across the shooting line after physical load. In prone shooting, triggering as fine motor control and gun movement due to heavy exercise were assumed to discriminate among performance groups. Furthermore, low shoulder forces, poor triggering behaviour, and high body sway were anticipated to negatively affect rifle movement.

2. Material and Methods

2.1. Subjects

Three female and seven male Romanian biathletes participated in the study.

Because shooting results did not show any gender differences in the past decade, male and female biathletes were not separated. No disabilities or injuries were reported by the athletes. All subjects were informed about the intention of the current study before signing their approval to participate.

2.2. Test protocol

The participants had to fire as follows: (1) 3 clips of 5 shots in the prone position in rest, (2) 3 clips of 5 shots in the standing position in rest, and (3) 4 clips of 5 shots within a simulated 12.5-km race, including shooting order of pursuit competitions (2 clips prone followed by 2 standing series). In the rest situation, the biathletes had a 2-minute break between 5-shot clips. Shooting was accomplished on a 50m outdoor shooting range in Râșnov, Brașov. Subjects performed with their own rifles, in their personal shooting positions, and were instructed to shoot in their individual firing rhythms and speeds. The investigators did not provide feedback about shooting performance. Before starting the test, the biathletes were allowed to zero the rifle for ~10 minutes to adapt to the conditions at the shooting range.

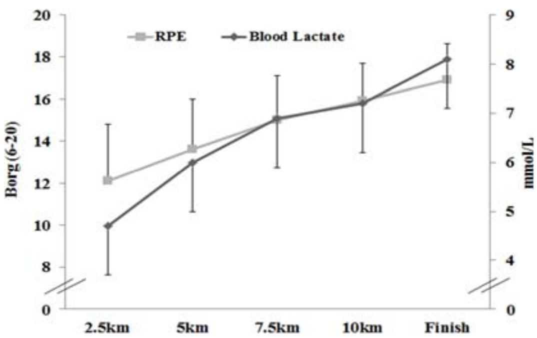

Fig. 1. *Mean values (± SD) of blood lactate concentration and ratings of perceived exertion (RPEs) during and immediately after the simulated race condition (n = 10).*

Note: *Blood samples for determination of lactate concentration were taken instantly after shooting for loops 1 to 4 and right after the final lap. Blood was squeezed from the earlobe, and values of the capillary samples (0.02 mL) were quantified using the lactate analyzer Biosen S. RPE estimation was accomplished after each lap before shooting and immediately at the finish and was determined using the 6-to-20 Borg scale.*

In the simulated competition, the participants had to skate 5 loops of 2.5 km in their individual race speeds with roller skis (Marwe), similar to pursuits in winter competitions. After laps 1 to 4, the subjects had to perform the obligatory 5-shot clip, where biomechanical variables were recorded, followed by a final loop without shooting. Rating of perceived exertion (RPE) scales and blood lactate concentration were chosen for the current study to identify the extent of physiological stress (Figure 1).

2.3. Instruments

Body sway during shooting in the standing position was quantified using a part force platform (University of Transilvania, Brașov, Romania) and calculated as a weighted average of the COP. Triggering behaviour was measured by a strain gauge force transducer (oil sensor) mounted on the trigger. These data were sampled at 100 Hz and captured simultaneously using the IKE Biathlon system (IKE-Software Solutions,). All trigger signals were normalized by the software to the predefined trigger weight of each rifle to retrospectively identify the shot event.

Rifle stability for both the prone and the standing shooting positions was determined by the infrared system, Noptel NOS 4, sampling at 67 Hz. An infrared transmitter was mounted on the frontal part of the barrel, and a signal receiver was placed on the target. Time of shooting was automatically recognized by an integrated microphone.

Shooting scores were recorded by the computer-controlled display system SIUS SA 921.

3. Statistical Analysis

Data in subsequent tables are expressed as mean ± SD. Pearson product–moment correlation coefficients (r) and coefficients of determination (r^2) were calculated to determine relationships between different biomechanical factors.

To identify biomechanical factors distinguishing between high and low performance shooting, linear discriminate analyses (LDAs) were performed separately for each condition. The LDA structure matrix provides R coefficients, which are pooled within-group correlations between discriminating variables and standardized canonical discriminate functions. Only factors that revealed R values higher than .3, and illustrated group differences in mean values, as shown via univariate analyses of variance (ANOVA) calculated by the LDA, were interpreted in this study.

Statistical significance was set at $P < .05$ for all analyses. All statistical tests were processed using SPSS software.

4. Results

The measured blood lactate concentration with a mean value of 8.1 ± 2.0 mmol/L and the mean RPE of 16.9 ± 1.7 at the finish of the simulated 12.5-km race indicated that the subjects were highly stressed, similar to their situation in competitions (Figure 1). The average course time was 33:13 ± 2:14 minutes.

In the prone rest condition (Table 1), the LDA exposed SF_M (R =.71) and $Rifle_{SDx}$ (R = –.41) as substantial discriminators between high and low scoring shooters, but revealed differences in the mean values only for SF_M ($P < .01$; + 28 N).

In prone shooting after physical load (Table 2), all rifle sway variables obtained substantial R values (.49–.82, respectively). However, the mean values of the separated groups differed only for $Rifle_{SDy}$ ($P < .05$), whereas $Rifle_{MVxy}$ was found to be a predictive factor on a tendential-difference basis only ($P = .07$). In both prone conditions, TC did not reveal any discrimination power.

In the standing rest situation (Table 2), all COP variables (COP_{SDx}, COP_{SDy}, COP_{MVxy}), as well as $Rifle_{MVxy}$ were shown to be predictors in distinguishing between high and low score performance (R = .46–.69, P < .01–.05, respectively). $Rifle_{SDx}$ and SF_{SD} exhibited considerable discriminating coefficients (R = .41–.43, respectively) while showing a tendency to differ (P = .06–.07, respectively).

For standing shooting in the race condition, only COP_{SDx} revealed discriminating power (R = .47), but only with a tendency to in-group differences ($P = .07$). $Rifle_{MVxy}$ and $Rifle_{SDy}$ obtained acceptable discriminant coefficients (R = .30–.38, respectively), though they did not differ in their mean values (P = .14–.23, respectively).

For both standing situations, TC was not found to discriminate between high- and low-score biathletes.

Table 1

Descriptive Statistics and Linear Discriminant Analyses (LDA) of Biomechanical Variables Analyzed in the Study for Prone Shooting in High- and Low-Score Athletes

	Descriptive Statics		LDA		
	High score	**Low score**	***R***	***P***	***F***
Rest shooting					
trigger coefficient (a.u.)	0.53 ± 0.26	0.51 ± 0.25	.00	.997	0.00
shoulder_mean (N)	67.03 ± 22.58	39.48 ± 20.95	.71	.014*	7.35
shoulder_SD (N)	0.10 ± 0.04	0.09 ± 0.06	.08	.787	0.08
rifle_SD_X (mm)	0.39 ± 0.26	0.61 ± 0.34	–.41	.133	2.46
rifle_SD_Y (mm)	0.40 ± 0.24	0.39 ± 0.12	.00	.991	0.00
rifle_MV (mm/s)	7.98 ± 4.63	8.41 ± 2.24	–.07	.787	0.08
score (rings)	9.27 ± 0.17	8.81 ± 0.21			
Load shooting					
trigger coefficient (a.u.)	0.49 ± 0.23	0.54 ± 0.26	.06	.848	0.04
shoulder_mean (N)	64.23 ± 21.86	61.39 ± 26.24	–.12	.720	0.13
shoulder_SD (N)	0.16 ± 0.08	0.16 ± 0.06	–.10	.768	0.09
rifle_SD_X (mm)	0.60 ± 0.21	0.75 ± 0.29	.49	.159	2.15
rifle_SD_Y (mm)	0.54 ± 0.13	0.73 ± 0.21	.82	.024*	6.06
rifle_MV (mm/s)	12.56 ± 3.11	16.42 ± 5.66	.63	.072	3.63
score (rings)	8.93 ± 0.25	8.08 ± 0.24			

In prone rest shooting, the mean shoulder forces were 69.8% greater in the top-scoring athletes compared with the low-performance group, which underlines the discrimination suitability and the ability to predict shooting results with this factor. While aiming, qualified shooters were shown to apply fixation strategies [9], supported by an optimal rifle's stock length and a solid gun–shoulder connection [2], which were reported to positively affect marksmanship and rifle hold. The moderate correlation in the current study between shoulder force and rifle sway in the mediolateral direction confirms that substantial butt plate pressure can support the reduction of gun motion. The low-score groups, which consisted of mainly young biathletes, still may not have found a strategy for an optimal gun–shoulder interaction, including appropriate pull with the back hand, adapted rifle length, and an adjusted form of the butt plate [2].

For the standing shooting in rest, all COP variables and the mean velocity of the rifle sway were found to be discriminators between high and low scoring athletes. The strongest predictor in distinguishing one group from the other was the mean velocity of the COP, indicating that the athlete's ability to lower body movements in the last 0.5 second before firing leads to a successful shooting performance. These results are in line with previous studies showing that elite athletes have less body sway and higher scores compared with young biathletes and novices [9], [10] in the rest condition. The current correlations revealed the expected relations between body and rifle sway, demonstrating that less gun instability was related to an improved postural balance control in the tested subjects, which was also reported in biathlon [9] and air rifle studies [7].

Table 2

Descriptive Statistics and Linear Discriminant Analyses (LDA) of Biomechanical Variables Analyzed in the Study for Standing Shooting in High and Low Score Athletes

	Descripive Statics		LDA		
	High score	**Low score**	***R***	***P***	***F***
Rest shooting					
trigger coefficient (a.u.)	0.68 ± 0.45	0.84 ± 0.46	.18	.418	0.69
shoulder_mean (N)	18.77 ± 9.34	26.13 ± 23.72	.21	.350	0.92
shoulder_SD (N)	0.08 ± 0.03	0.13 ± 0.08	.43	.060	3.97
rifle_SD_X (mm)	1.32 ± 0.40	1.66 ± 0.37	.41	.069	3.70
rifle_SD_Y (mm)	1.34 ± 0.35	1.51 ± 0.59	.18	.422	0.67
rifle_MV (mm/s)	17.51 ± 3.80	22.20 ± 6.26	.46	.046*	4.52
COP_SD_X (mm)	0.26 ± 0.11	0.38 ± 0.15	.46	.048*	4.45
COP_SD_Y (mm)	0.44 ± 0.10	0.64 ± 0.22	.61	.010**	7.99
COP_MV (mm/s)	5.40 ± 0.96	7.90 ± 2.43	.69	.005**	10.12
score (rings)	7.23 ± 0.41	5.84 ± 0.75			
Load shooting					
trigger coefficient (a.u.)	1.10 ± 1.30	1.04 ± 0.76	–.03	.910	0.01
shoulder_mean (N)	24.74 ± 15.33	20.82 ± 17.36	–.14	.580	0.32
shoulder_SD (N)	0.15 ± 0.07	0.12 ± 0.07	–.18	.463	0.56
rifle_SD_X (mm)	2.17 ± 0.57	2.31 ± 0.51	–.14	.586	0.31
rifle_SD_Y (mm)	2.05 ± 0.29	2.70 ± 1.75	.30	.234	1.51
rifle_MV (mm/s)	28.52 ± 4.11	34.40 ± 12.00	.38	.140	2.36
COP_SD_X (mm)	0.51 ± 0.14	0.64 ± 0.19	.47	.069	3.71
COP_SD_Y (mm)	0.76 ± 0.24	0.70 ± 0.25	–.15	.550	0.37
COP_MV (mm/s)	11.85 ± 2.44	12.76 ± 2.89	.20	.436	0.63
score (rings)	6.20 ± 0.65	4.40 ± 0.72			

5. Discussion

The main findings of the current study were that vertical rifle sway and shoulder force for prone shooting, as well as body and rifle sway for the standing position, were main discriminators between high- and low-scoring athletes; performance predictors differed from rest to load and from prone to standing shooting; and triggering and shoulder force correlated with the rifle motion in prone shooting, whereas in the standing condition, body sway was related to the rifle movement. In the load situation, which was similar to biathlon competitions, vertical rifle motion (prone) and body sway across the shooting line (standing) were shown to differentiate high from low score performance.

6. Conclusions and Practical Applications

The current investigation illustrated changing factors to discriminate high- from low-scoring athletes depending on discipline (prone, standing) and condition (rest, load). Focusing on these variables in training and competitions should contribute to a successful shooting performance. Control of the vertical movement of the rifle in prone shooting and the COP across the shooting line in the standing situation were key factors in the race simulation. Therefore, we recommend intensifying the shooting under high physical load to strengthen the aforementioned predictors. In addition, task-specific exercise programs during highly variable conditions (e.g., balance training on unstable surfaces) may support the overall performance by increasing perceptual-motor abundance of experience.

The results also obtained several interrelations among various biomechanical factors that confirm the need of a comprehensive view on this complex task.

However, further research on additional kinematic and kinetic aspects and key factors from other disciplines such as sports psychology (i.e., stress management) is required to provide more data on biathlon shooting performance.

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