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Performance-determining factors in biathlon prone shooting without physical stress

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ABSTRACT

This study investigated the most important factors determining biathlon prone shooting performance. 10 female and 16 male biathletes (age 19.9 ± 2.9 years) from the national teams of Finland and Vuokatti-Ruka Sports Academy performed 6x5 biathlon prone shooting shots without physical stress under laboratory conditions. Shooting performance and multiple aiming point trajectory variables were measured together with an analysis of triggering force. Based on the aiming point trajectory data principal component analysis, we identified four technical components in biathlon prone shooting: stability of hold, aiming accuracy, cleanness of triggering and timing of triggering. Multiple regression analysis further determined that cleanness of triggering, aiming accuracy and timing of triggering accounted for 80% of mean shooting performance ($p < 0.001$). Better stability of hold, aiming accuracy and cleanness of triggering were directly associated with better shooting performance ($0.62 \leq |r| \geq 0.79$, all $p < 0.001$). Better stability of hold measures were also associated with better cleanness of triggering, and higher pre-shot trigger force levels were associated with better stability of hold and cleanness of triggering. These results indicate that with both direct and indirect effects on performance, stability of hold seems to be a general prerequisite for successful biathlon shooting. The results also highlight the importance of aiming accuracy, cleanness and timing of triggering, along with a high pre-shot trigger force level. The variables identified in this study could be used to assess biathletes' performance in the most relevant shooting technical aspects to guide the emphasis of their shooting training.

KEYWORDS

biomechanics, optoelectronics, biathlon, rifle shooting, technique, coaching, precision

INTRODUCTION

Biathlon is an Olympic winter sport combining cross-country skiing and rifle shooting, where overall performance is determined by skiing speed, shooting performance and shooting time. A biathlon competition consists of periods of high intensity skiing separated by short recovery intervals (two or four times during the competition depending on the competition type) during which shooting is performed in the prone or standing position.[1] Shooting is performed with small-bore rifles, with targets 50 m away from the shooting lane where the diameter of the hit area for prone and standing shooting targets is 4.5 cm and 11.5 cm, respectively. During each shooting bout in individual competitions, five shots are fired at the targets. Depending on the competition type, shooting performance has been suggested to explain from 30% to 60%[2-5] of overall biathlon performance.

In the standing shooting position, stability of hold[6-8] and cleanness of triggering[7] have been observed to be related to shooting performance. A recent study also suggested that biathletes might use different aiming strategies, hold and timing, and that the strategy used would affect performance-related factors.[9] Regarding postural control, both antero-posterior (cross shooting line)[8] and medio-lateral (in shooting line)[7] sway have been observed to have a negative effect on standing shooting performance. Postural control has an indirect effect on shooting performance as well, as it has been shown to be related to variables relating to movements of the aiming point.[7] Further, when compared to their younger counterparts, national top-level biathletes have demonstrated better shooting performance,[6,7] postural balance[7] and stability of hold[6].

In the prone shooting position, the biathlete has three support points compared to two in the standing position. Hence, rifle sway is assumed to be much smaller in prone shooting. However, to the best of our knowledge, there is only one study in which biathlon prone shooting performance-determining factors have been investigated. In that study by Sattlecker et al.,[8] vertical rifle sway was observed to be related to shooting performance. Furthermore, the authors also found that high pre-shot trigger force values and a flat trigger force curve inclination during triggering increased rifle stability.[8] However, aiming accuracy, cleanness of triggering and timing of triggering, which have been shown to be important factors in biathlon standing shooting[7,9] and air rifle shooting,[10] were not studied. Therefore, the aim of the present study was 1) to study whether aiming accuracy, cleanness of triggering and timing of triggering are also related to biathlon prone shooting performance and 2) to find the most important technical factors explaining biathlon prone shooting performance.

MATERIALS AND METHODS

Participants

A total of 26 biathletes from the national teams of Finland and Vuokatti-Ruka Sports Academy volunteered for the study. Participants were divided into two groups by age, using their International Biathlon Union competition classes.[11] The Senior group (22.1 ± 2.9 years old) consisted of 12 biathletes (4 women, 8 men) who competed in the Senior and Junior (under 22) classes during the previous season. The Youth group (18.1 ± 1.0 years old) consisted of 14 biathletes (6 women, 8 men) who competed in the Youth (under 19) class during the previous season. Because the independent samples *t*-test did not reveal gender differences in shooting performance ($p = 0.545$), women and men were not separated in the analyses.

Before participating in the measurements, all subjects gave their written informed consent, after being informed of the purpose, nature and potential risks of the study. The study was conducted according to the declaration of Helsinki, and ethical approval was granted by the University of Jyväskylä Ethical Committee.

Experimental task

Prior to starting the experimental task, each biathlete performed a preparatory procedure. First, a holding task of 4x45 seconds was performed with a 30-second recovery between sets. One 45-second period consisted of two 10-second holds starting at 10 and 35 seconds during which the biathlete was instructed to approach the target as usual, then focus on holding the aiming point at the center of the target as steadily as possible. After the holding task, zeroing of the rifle was performed. Lastly, each biathlete was instructed to perform 10 separate single shots, as if starting a 5-shot series, and two to four 5-shot series to compensate for the possible differences in the number of zeroing shots. The shooting posture was rebuilt each time. After the preparatory procedure, the biathlete started performing the experimental task.

In the experimental task, the biathlete performed a biathlon prone shooting task of 6x5 shots in a resting state. Each 5-shot series began with the biathlete standing behind the shooting mat, then taking the prone shooting position, shooting five dry shots without ammunition, and ending in the same standing position behind the shooting mat. Participants took a break of approximately 30 seconds between each series. All biathletes used their own biathlon rifles in the shooting tasks and were instructed to shoot using their normal competition rhythm and technique.

Data collection

The measurements were conducted indoors in a laboratory optimized for shooting with minimal external disturbances. An overall schematic of the devices used has been illustrated in figure 1. The shooting tasks were carried out with a 10-meter shooting distance into a scaled target using a Noptel ST 2000 training device (Noptel Inc., Oulu, Finland). The apparatus consisted of an optical transmitter-receiver unit weighting 80 g, which was attached to the barrel of the rifle, and a reflector attached around the targets. The hit point and aiming point trajectory of each shot were recorded at a 67 Hz sampling rate. The pressure on the trigger was measured using a piezoresistive pressure sensor (FSR 402, Interlink Electronics Inc., Irvine, CA, USA). The signals were amplified and collected at 400 Hz using the wireless Coachtech system[12] (University of Jyväskylä, Vuokatti, Finland). The triggering moment was identified using microphone data, which was collected with the same system and synchronized to the triggering moment detected by the Noptel system. The pressure signal values for each shot were also normalized by the Coachtech system to the individual trigger resistance, and the value at the triggering moment was used as 100%. Shots incorrectly detected by the Noptel system (e.g. detected reloads of the rifle) were excluded by including only the shots during which the trigger pressure zero level was exceeded (i.e. the triggering finger was placed on the trigger). Data visualization, analysis and storage were performed using the Coachtech system.

Multiple variables representing shooting performance and different shooting technical components were analyzed (Table 1). Based on the findings of the present study, some of the technical variables and their components presented are slightly different from previous rifle shooting literature, which has been shown and discussed later in the paper.

Statistical methods

All data were controlled for normality using the Shapiro-Wilk test. A parametric test was selected for normally distributed data and a non-parametric test for data that violated the normality assumption.

Principal component analysis (PCA) has been used to classify shooting technical factors in air rifle shooting[10], running target shooting[13] and air pistol shooting[14]. Because substantially more aiming point trajectory variables were included in the present study than were reported by Sattlecker et al.[8] in the previous biathlon prone shooting study, PCA with varimax rotation was used to form orthogonal linear combinations from the measured aiming point trajectory variables. The varimax rotation was selected because most of the variables were not correlated with each other, and because it yielded the simplest structure. However, some of the variables were observed to correlate highly with each other ($r \geq 0.80$), and in such cases, one of the variables was removed from the PCA to avoid the inclusion of two variables that measured the same thing, as was done in the previous study by Hawkins.[14] The variable accounting for a higher proportion of the total variance was preserved. For the final set of variables used in the factor analysis, Bartlett's test of sphericity, which tests the overall significance of all the correlations within the correlation matrix, was significant ($\chi^2(28) = 2088.47$, $p<0.001$), indicating that it was appropriate to use the factor analytic model on this set of data. The Kaiser-Meyer-Olkin measure of Sampling Adequacy indicated that the relationships among variables were strong enough (KMO = 0.59) to proceed with the analysis. The number of components was determined by a minimum eigenvalue of 0.9 and by a minimum of 5% variance accounted for by each component, as was done in the previous study by Ihalainen et al.[10] The weight of 0.4 was set as a substantial amount of loading for each variable and variables with lower weights were therefore not reported. PCA was analyzed over single shots.

Mean values of each variable were calculated for each biathlete. Relationships between shooting performance and aiming point movement and intercorrelations between variables related to aiming point trajectory were computed using the two-tailed Pearson's correlation coefficient or two-tailed Spearman's rank correlation coefficient in cases where the data were not normally distributed.

Furthermore, multiple regression analysis (MRA) with the stepwise selection method was conducted with the mean values of the aiming point trajectory variables as independent variables to study the amount of explained variance in mean shooting performance. Collinearity statistics were undertaken to examine the linear association between the predictive variables in the MRA model.

Differences between the Junior and Senior groups in the mean test values were investigated using the independent samples *t* for the variables that met the normality assumption across both groups. Effect sizes (Hedges' g) were calculated, and values of 0.00 < 0.20, 0.20 < 0.50, 0.50 < 0.80, and ≥ 0.80 were selected to represent the qualitative thresholds for trivial, small, moderate, and large effects, respectively.[15] The Mann-Whitney U test was used for the variables that violated the normality assumption in either group, and Cliff's delta was used to estimate effect sizes, with values of 0.00 < 0.147, 0.147 < 0.33, 0.33 < 0.474, and ≥ 0.474 representing the qualitative thresholds for trivial, small, moderate, and large effects, respectively.[16] The test results are reported as the mean ± standard deviation.

Statistical significance was set at $p < 0.05$. All statistical analyses were conducted with IBM SPSS Statistics 26.0 software (IBM Corp., Armonk, NY, USA).

RESULTS

A total of 769 shots in 26 tests were analyzed. PCA revealed four factors in the aiming point trajectory variables, which accounted for 80.9% of the total variance (Table 2). Factor 1, stability of hold, represented general steadiness of the aiming point. ATV was also identified as a stability of hold variable but removed from the final PCA due to its strong correlation to other stability of hold variables (MV $r = 0.84$, $p < 0.001$; DevY $r = 0.56$, $p < 0.001$) and smaller contribution to the total variance. Factor 2, aiming accuracy, represented preciseness of the aiming point location in relation to the center of the target. Factor 3, cleanness of triggering, represented movement of the aiming point right before triggering. Factor 4, timing of triggering, represented whether the shot occurred while the aiming point was moving towards or away from the center of the target.

The mean values of the aiming point trajectory variables and trigger force variables in the Senior and Youth groups, as well as correlations between mean values of the shooting technical variables and mean shooting performance in the whole sample, are presented in Table 3. The senior group demonstrated statistically tendentially better HIT_{Dist}, and statistically significantly lower COG2Hit, DevX, $Hit_{(1/3)}$ and MV values. Hit_{Dist} correlated significantly to COG_{Dist}, COG2Hit, DevX, $Target_{(1/3)}$, $COG_{(1/3)}$, and ATV, whereas correlations to MV ($r = 0.37$, $p = 0.066$) and DevY ($r = 0.36$, $p = 0.070$) were statistically tendential.

Better horizontal (DevX) and vertical (DevY) stability of hold were associated with better cleanness of triggering (COG2Hit) (Figure 2). Other stability of hold variables also correlated to COG2Hit (MV $r = 0.57$, $p = 0.002$; $COG_{(1/3)}$ $r = -0.78$, $p < 0.001$; ATV $r = 0.61$, $p = 0.001$). Higher pre-shot trigger force values were related to lower MV ($TrigF_{-0.6s}$ $r_s = -0.45$, $p = 0.020$; $TrigF_{-0.2s}$ $r_s = -0.46$, $p = 0.018$), ATV ($TrigF_{-0.6s}$ $r_s = -0.42$, $p = 0.032$; $TrigF_{-0.2s}$ $r_s = -0.43$, $p = 0.028$) and COG2Hit ($TrigF_{-1.0s}$ $r_s = -0.42$, $p = 0.031$; $TrigF_{-0.6s}$ $r_s = -0.45$, $p = 0.022$) but not to other aiming point trajectory variables.

MRA analysis showed that 88% of the variance in mean shooting performance (hit point distance from the target, Hit_{Dist}) was explained by COG2Hit, COG_{Dist}, $TIRE_6$, DevY and ATV (Table 4). Collinearity statistics indicated that multicollinearity was not a concern among the five variables (tolerance = 0.217-0.822, variance inflation factor VIF = 1.216-4.614).

DISCUSSION

The aims of the present study were 1) to identify the most important factors related to biathlon prone shooting performance without physical stress and 2) to find the best variables to describe these factors. Four different components, stability of hold, aiming accuracy, cleanness of triggering and timing of triggering, were identified as the most important factors. The variables describing cleanness of triggering, aiming accuracy and timing of triggering explained a total of 80% of the variance in mean shooting performance. Stability of hold was related to shooting performance both directly and indirectly, as it was also associated to cleanness of triggering.

Principal component analysis has previously identified stability of hold, aiming accuracy and cleanness of triggering as important shooting technical components in air rifle shooting[10] and in running target shooting,[13] both of which were performed using the standing position. Timing of triggering has also been identified as an important component in air rifle shooting.[10] However, the timing of triggering variable TIRE was not studied in that running target shooting study by Mononen et al.[13] Hence, it seems that all three rifle shooting sports, biathlon prone shooting, air rifle shooting and running target shooting, rely on similar basic shooting technical components despite their different formats.

In the present study, stability of hold variables DevX, $COG_{(1/3)}$ and ATV; aiming accuracy variables COG_{Dist} and $Target_{(1/3)}$; and a cleanness of triggering variable COG2Hit were related to biathlon prone shooting performance in resting shooting. Further, senior biathletes demonstrated better stability of hold (MV, DevX, ATV) and cleanness of triggering ($Hit_{(1/3)}$, COG2Hit) than junior biathletes. However, shooting performance was only tendentially better in senior biathletes.

Sattlecker et al.[8] also found that horizontal stability of hold discriminates between high- and low-scoring biathletes in resting shooting, and vertical stability of hold discriminates between these groups in shooting under physical stress. In an air rifle shooting study,[10] in addition to horizontal and vertical stability of hold measures, a stability of hold variable similar to $COG_{(1/3)}$ that was used in the present study was also found to be related to shooting performance. As the results also showed that better stability of hold was associated with better cleanness of triggering, stability of hold seems to be a general prerequisite for successful biathlon prone shooting performance. Further, the most important variables seem to be similar to those that have been identified as important stability of hold measures in air rifle shooting.

In the present study, vertical stability of hold was only tendentially related to shooting performance, which could be due to shooting without physical stress, as heavy breathing and increased heart rate have been observed to affect the aiming phase.[7,17,18] The rifle lies on the left hand (right-handed shooter) and is supported by a special arm sling between the rifle stock and the upper left arm. Therefore, the stronger pulsing of the heart may come through the sling, causing a vertical bouncing movement. Further, because the rifle butt plate is supported against the right shoulder (right-handed shooter), a more pronounced thoracic cage expansion due to heavier breathing could also cause the shoulder and thus the rifle to move more in the vertical direction in shooting under physical stress.

Similar variables to the aiming accuracy variables COG_{Dist} and $Target_{(1/3)}$ that were used in the present study have been observed to be related to shooting performance in biathlon standing shooting[9] and air rifle shooting,[10] yet they have not been studied in biathlon prone shooting. As in air rifle shooting[10], both variables were related to shooting performance in the present study. In the biathlon standing shooting study,[9] both variables were related to shooting performance in biathletes using the hold strategy for aiming. In contrast, neither variable was related to performance in biathletes using the timing strategy.[9] Thus, it could be suggested that biathlon prone shooting could be technically similar to the hold strategy in biathlon standing shooting and precision shooting (e.g. air rifle shooting). This difference in aiming between prone and standing biathlon shooting could also be related to the smaller hit area in the prone position (diameter 4.5 cm) than in standing (11.5 cm), which forces the biathlete to aim more precisely in prone.

Previous studies in biathlon standing shooting[7,9], air rifle shooting[10] and running target shooting[13] have also reported that cleanness of triggering is related to shooting performance. However, the variables representing this aspect of shooting were different. In the present study, $Hit_{(1/3)}$ and COG2Hit were identified as cleanness of triggering variables. In the other biathlon shooting studies referenced,[7,9] ATV was reported to measure cleanness of triggering. However, neither of the two studies performed an analysis to identify the different components but relied on previous studies in precision shooting for the classification of variables. As in the present study, the air rifle shooting[10] and running target shooting[13] studies referenced used principal component analysis over single shots to identify the different components, finding ATV and RTV to represent cleanness of triggering. In the present study, ATV was identified as a stability of hold variable. RTV was omitted from the analyses because the short time-interval between two consecutive shots in biathlon shooting does not always allow for tracking the aiming point movement up to two seconds before triggering, which is needed to perform the calculation. Thus, it could be suggested that $Hit_{(1/3)}$ and COG2Hit better represent cleanness of triggering in biathlon prone shooting, whereas it is likely that ATV could better represent stability of hold.

The timing of triggering variable $TIRE_6$ was not related to shooting performance and did not distinguish between senior and junior biathletes. However, the multiple regression analysis showed that it accounted for 4% of the variation in shooting performance when other components, cleanness of triggering, aiming accuracy and stability of hold, were also considered. A similar result was reported in a previous air rifle shooting study,[10] where timing of triggering accounted for 9% of the variation in shooting performance when other components were also considered, despite its negligible and nonsignificant direct relation to it. A previous study in biathlon standing shooting[9] reported that $TIRE_6$ was directly related to performance in biathletes using the timing strategy for aiming, whereas in biathletes using the hold strategy, it was not. Another biathlon standing shooting study[7] did not observe a relationship between timing of triggering and performance. However, the authors of the study did not distinguish between the different aiming strategies. Thus, it could be suggested that in terms of the timing of triggering component, biathlon prone shooting seems to be similar to air rifle shooting, where it plays a small role in the final level of shooting performance only after other components have been considered. A similar comparison could not be made to the two studies[7,9] on biathlon standing shooting referenced above, as they did not use multiple regression analysis.

Higher pre-shot trigger force values were related to better stability of hold and cleanness of triggering. This is in line with previous findings by Sattlecker et al.[8] who observed that high pre-shot trigger forces and a flat trigger curve inclination during the last 0.5 seconds of shooting were related to better rifle stability. These findings may be related to a cleaner pull of the trigger, which could reduce rifle movements during the final triggering action, or to a stronger grip with the triggering hand, which could increase rifle stability in general. However, the significant correlation coefficients were not strong ($0.42 \leq |r_s| \geq 0.46$), leaving the issue open to various interpretations. It is also possible that using relative, not absolute, trigger forces may cause some controversy, as the resistance threshold needed to trigger the shot may slightly vary between subjects, and it should be carefully taken into account in future studies.

MRA run over test mean values revealed that the cleanness of triggering variable COG2Hit, the aiming accuracy variable COG_{Dist} and the timing of triggering variable $TIRE_6$ accounted for 80% of the of the mean shooting performance. It has been previously reported that in air rifle shooting, the test mean values of the variables describing stability of hold, aiming accuracy, timing of triggering, and cleanness of triggering are the most important, accounting for 81% of shooting performance.[10] Other studies in rifle shooting sports have reported the prediction equation for single shots, but with considerably weaker precision of the prediction.[13,19] It seems that the precision of such predictions is relatively high when test mean values are used for assessing athletes' general shooting technical level.

Complementing the regression equation with the stability of hold variables DevY and ATV further improved the accuracy of the prediction equation by four and three percentage points, respectively. Interestingly, the regression coefficient value of DevY in MRA indicated that increased vertical sway of the rifle improves shooting performance, whereas its correlation coefficient to shooting performance indicated the opposite, although statistically, the correlation was pointing direction only ($p = 0.070$). However, as previously discussed, the results showed that DevY and ATV correlate to each other. The results also showed that the regression coefficients of the two variables (DevY -0.819, ATV 0.094) point in opposing directions causing them to cancel each other out, and their combined effect on mean hit point distance from the center was negligible (-1.1 ± 0.6 mm) in the regression equation. Hence, based on the results of MRA, the most important components of biathlon prone shooting performance were the cleanness of triggering variable COG2Hit, the aiming accuracy variable COG_{Dist} and the timing of triggering variable $TIRE_6$, which accounted for 63%, 14% and 4% of shooting performance, respectively. The influence of the stability of hold component should be interpreted with caution. The controversy might be due to the small number of tests analyzed, probably causing the regression equation with more variables to overfit for the present data.

Despite its moderate correlation to shooting performance, horizontal stability of hold DevX was not included in the regression equation, which is in contrast to the previous air rifle shooting study[10] where it was the most important predictor of shooting performance. This could be related to the nature of biathlon shooting and the time used to calculate the shooting technical variables. Biathlon shooting is performed under time pressure, and most variables used in the present study were calculated over the last 0.6 seconds before triggering. The biathlete might try to aim at the center throughout the last 0.6 seconds and pull the trigger right after reaching a satisfactory hold stability. Thus, it could be that the best hold stability is reached only right before triggering. The fact that ATV, which was calculated over the last 0.2 seconds, was identified as a stability of hold variable, strengthens this suggestion. Aiming on average at the center of the target during the last 0.6 seconds improves the aiming accuracy variable COG_{Dist}, which had the second strongest effect on the regression equation precision. Further, reaching a stable hold right before triggering would explain why the cleanness of triggering variable COG2Hit, that is the distance from the mean aiming location to the hit point, had the largest effect on the regression equation prediction. In that case, if the biathlete aims precisely and can minimize rifle movement right before triggering, having a stable hold throughout the last 0.6 seconds would likely not improve shooting performance further. However, other findings still highlight the importance of general hold stability in biathlon prone shooting, as stability of hold measures calculated over the last 0.6 seconds were associated with cleanness of triggering.

A limitation of the present study is that the shooting was performed as dry firing into a scaled target without physical stress. The biggest differences are the lack of recoil response, the lack of feedback in terms of whether the shot was a hit or a miss, and the previously discussed lack of heavy breathing and high heart rate, which could affect shooting. However, the biathletes were instructed to use their individual competition rhythm and technique, and the standardized laboratory conditions are beneficial for ensuring data quality, follow-up testing for each individual and comparison between athletes. The same technique has been used in previous biathlon shooting[7,9] and rifle precision shooting[10,20] studies. Despite performing the shooting task without physical stress in the present study, a previous study in biathlon standing shooting[7] reported that all the shooting technical variables based on aiming point trajectory movement, which were measured without physical stress, were related to those measured under physical stress. Thus, in light of one of the aims of the present study, which was to find the most relevant parameters, this was considered acceptable.

PERSPECTIVE

The results of the present study support the findings of Sattlecker et al.'s study[8] and provide valuable new information on the technical aspects of biathlon prone shooting. The findings indicate that the key components of biathlon prone shooting performance are stability of hold, aiming accuracy, cleanness of triggering and timing of triggering, which were all related to shooting performance. Stability of hold seems to be a general prerequisite, as better hold was also associated with better cleanness of triggering. Further, a high pre-shot trigger force level should be achieved to improve stability of hold and cleanness of triggering. The parameters measured in the present study can be used to assess the current level and the progression of biathletes' shooting technique in the prone position. In the future, biathlon prone shooting studies should include measures of stability of hold, aiming accuracy, cleanness of triggering and timing of triggering to get a comprehensive understanding of the different aspects of the task. Measurement of trigger force provides additional information about the quality of the triggering action, which could help biathletes improve their shooting performance.

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Table 1. Descriptions of the shooting technical variables.

Variable (unit)	Description
Shooting performance	
Hit_{Dist} (mm)	Distance of the hit point from the center of the target.
Stability of hold	
MV (mm/s)	Mean velocity of the aiming point trajectory during the last 0.6 seconds before triggering (the total distance travelled by the aiming point / time).
DevY (mm)	Vertical standard deviation of the aiming point location during the last 0.6 seconds before triggering.
DevX (mm)	Horizontal standard deviation of the aiming point location during the last 0.6 seconds before triggering.
$COG_{(1/3)}$ (%)	Relative contribution of the last 0.6 seconds before triggering during which the aiming point was within a ring with the radius of $3^{-1} \times 22.5\ mm$ (i.e. one third of the hit area) drawn around the aiming point mean location during (COG) the last 0.6 seconds before triggering.
ATV (mm)	Distance travelled by the aiming point during the last 0.2 seconds before triggering.
Aiming accuracy	
COG_{Dist} (mm)	Distance of the aiming point mean location during the last 0.6 seconds before triggering.
$Target_{(1/3)}$ (%)	Relative contribution of the last 0.6 seconds before triggering during which the aiming point was within a ring with the radius of $3^{-1} \times 22.5\ mm$ (i.e. one third of the hit area) drawn around the center of the target.
Cleanness of triggering	
$Hit_{(1/3)}$ (%)	Relative contribution of the last 0.6 seconds before triggering during which the aiming point was within a ring with the radius of $3^{-1} \times 22.5\ mm$ (i.e. one third of the hit area) drawn around the hit point.
COG2Hit (mm)	Distance between the aiming point mean location (COG) during the last

	0.6 seconds before triggering and the hit point.
Timing of triggering	
$TIRE_6$ (index)	Time sector with the smallest distance of mean location: 1 = -0.6...-0.5 s, 2 = -0.5...-0.4 s, 3 = -0.4...-0.3 s, 4 = -0.3...-0.2 s, 5 = -0.2...-0.1 s, 6 = -0.1...0.0 s.
Trigger force	
$TrigF_{-1.0s}$ (%), $TrigF_{-0.6s}$ (%), $TrigF_{-0.2s}$ (%)	Relative trigger force at 1.0 seconds ($TrigF_{-1.0s}$), 0.6 seconds ($TrigF_{-0.6s}$) and 0.2 seconds ($TrigF_{-0.2s}$) before triggering. Triggering occurred at 100%.

Table 2. Principal component analysis with varimax rotation of the aiming point trajectory variables from all shots (n = 769).

	Factor 1 Stability of hold	Factor 2 Aiming accuracy	Factor 3 Cleanness of triggering	Factor 4 Timing of triggering
Eigenvalue	2.639	1.670	1.173	0.992
% of variance	33.0	20.9	14.7	12.4
Variables				
MV	0.914			
DevY	0.851			
DevX	0.710			
COG_{Dist}		0.955		
$Target_{(1/3)}$		-0.930		
$Hit_{(1/3)}$			-0.879	
COG2Hit			0.734	
$TIRE_6$				0.990

Table 3. Test values (mean ± SD) from Senior (n = 12) and Youth (n = 14) biathletes and two-tailed correlation coefficients between mean values of shooting technical components and shooting performance in the whole sample (n = 26).

Variable (unit)	Senior	Youth	p	ES	Correlation
Shooting performance					
Hit_{Dist} (mm)	9.2 ± 1.4	10.4 ± 2.1	0.086	-0.65	
Stability of hold					
MV (mm/s)	114.4 ± 30.6^	145.5 ± 38.2	0.032	-0.83	0.37
DevY (mm)	3.7 ± 1.0	4.6 ± 1.4	0.074	-0.68	0.36
DevX (mm)	4.7 ± 1.0^	5.8 ± 1.4	0.043	-0.78	0.62***
$COG_{(1/3)}$ (%)	93.4 ± 4.1	89.5 ± 5.6	0.060	0.72	-0.57**
ATV (mm)	20.9 ± 5.2^	28.0 ± 7.7	0.012	-1.00	0.41*
Aiming accuracy					
COG_{Dist} (mm)	7.9 ± 1.3	8.2 ± 1.6	0.640	-0.17	0.67***
$Target_{(1/3)}$ (%)	37.7 ± 8.1	33.3 ± 8.8	0.201	0.48	-0.73***
Cleanness of triggering					
$Hit_{(1/3)}$ (%)	83.5 ± 6.3^	78.4 ± 5.6	0.042	0.79	-0.27
COG2Hit (mm)	6.3 ± 1.1^	7.8 ± 2.0	0.027	-0.83	0.79***
Timing of triggering					
$TIRE_6$ (index)	3.7 ± 0.4	3.6 ± 0.3	0.807	0.09	-0.05
Trigger force					
$TrigF_{-1.0s}$ (%)&	81.7 ± 7.1	76.9 ± 13.5	0.742	0.08	0.25
$TrigF_{-0.6s}$ (%)&	88.3 ± 5.2	84.8 ± 9.7	0.560	0.14	0.34
$TrigF_{-0.2s}$ (%)&	93.9 ± 3.5	92.0 ± 7.2	0.820	0.06	0.33

Statistically significant difference to Youth ^p<0.05

Statistically significant correlation to HitDist *p<0.05, **p<0.01, ***p<0.001

ES effect size of the group difference

&Non-parametric tests used due to violation of normality assumption

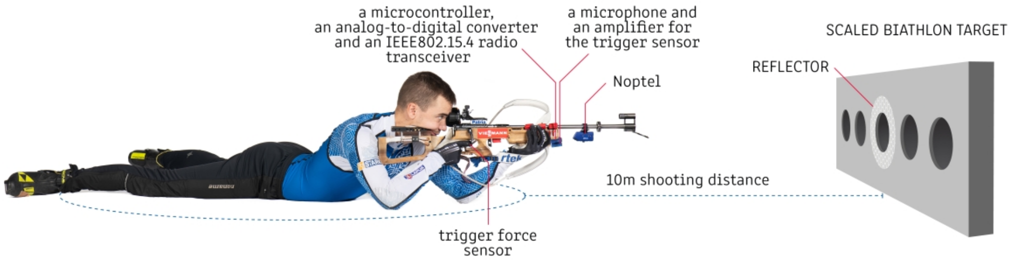
Table 4. Stepwise multiple regression analysis R^2, R^2 change, F change, and regression coefficient B values with mean shooting performance (Hit_{Dist}, hit point distance from the center of the target) as the dependent variable (n = 26).

	R2	R2 change	F change	B
Step 1	0.627	0.627	40.293	
Constant				3.987
COG2Hit				0.828
Step 2	0.762	0.135	13.005	
Constant				1.068
COG2Hit				0.646
COG_{Dist}				0.521
Step 3	0.804	0.042	4.741	
Constant				4.864
COG2Hit				0.632
COG_{Dist}				0.601
$TIRE_6$				-1.191
Step 4	0.843	0.039	5.269	
Constant				6.696
COG2Hit				0.821
COG_{Dist}				0.584
$TIRE_6$				-1.570
DevY				-0.390
Step 5	0.876	0.032	5.201	
Constant				6.572
COG2Hit				0.756
COG_{Dist}				0.652
$TIRE_6$				-1.701
DevY				-0.819
ATV				0.094

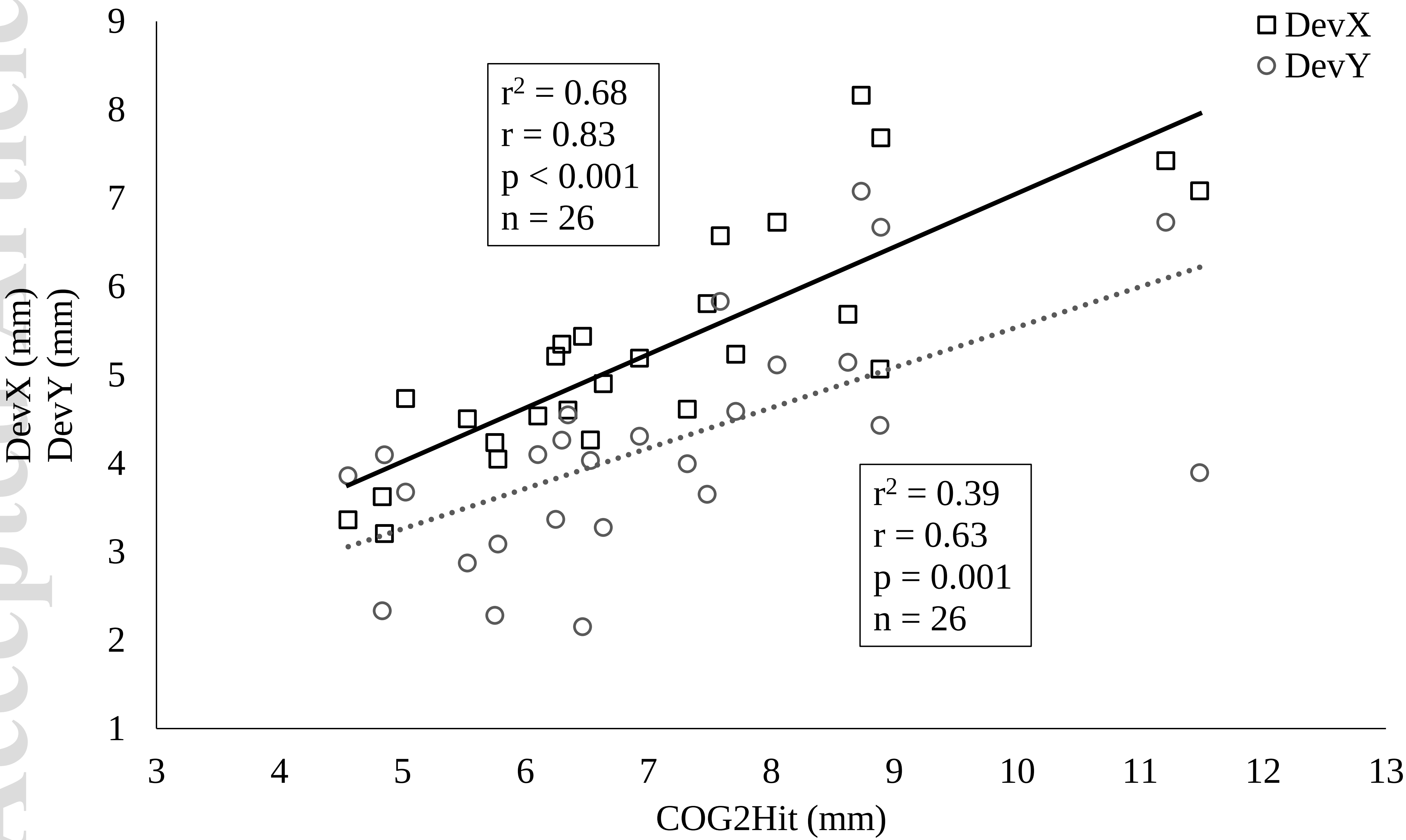
FIGURE LEGENDS

FIGURE 1. An overall schematic of the measurement devices.

FIGURE 2. The relationship between stability of hold (horizontal DevX, vertical DevY) and cleanness of triggering (COG2Hit).



sms_14087_f1.png


DevX
DevY
r2 = 0.68
r = 0.83
p < 0.001
n = 26
r2 = 0.39
r = 0.63
p = 0.001
n = 26
DevX (mm)
DevY (mm)
COG2Hit (mm)
1
2
3
4
5
6
7
8
9
3
4
5
6
7
8
9
10
11
12
13