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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  $19.9 \pm 2.9$  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 ( $0.62 \leq |r| \leq 0.79$ , 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



## 1 INTRODUCTION

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

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

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

30 cleanness of triggering and timing of triggering are also related to biathlon prone shooting  
31 performance and 2) to find the most important technical factors explaining biathlon prone shooting  
32 performance.

## 33 **MATERIALS AND METHODS**

### 34 **Participants**

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

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

### 47 **Experimental task**

48 Prior to starting the experimental task, each biathlete performed a preparatory procedure. First, a  
49 holding task of 4x45 seconds was performed with a 30-second recovery between sets. One 45-  
50 second period consisted of two 10-second holds starting at 10 and 35 seconds during which the  
51 biathlete was instructed to approach the target as usual, then focus on holding the aiming point at  
52 the center of the target as steadily as possible. After the holding task, zeroing of the rifle was  
53 performed. Lastly, each biathlete was instructed to perform 10 separate single shots, as if starting a  
54 5-shot series, and two to four 5-shot series to compensate for the possible differences in the  
55 number of zeroing shots. The shooting posture was rebuilt each time. After the preparatory  
56 procedure, the biathlete started performing the experimental task.

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

### 63 **Data collection**

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

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

## 85 **Statistical methods**

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

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

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

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

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

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

## 129 **RESULTS**

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

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

146 Better horizontal ( $DevX$ ) and vertical ( $DevY$ ) stability of hold were associated with better  
147 cleanness of triggering ( $COG2Hit$ ) (Figure 2). Other stability of hold variables also correlated to  
148  $COG2Hit$  ( $MV$   $r = 0.57$ ,  $p = 0.002$ ;  $COG_{(1/3)}$   $r = -0.78$ ,  $p < 0.001$ ;  $ATV$   $r = 0.61$ ,  $p = 0.001$ ).  
149 Higher pre-shot trigger force values were related to lower  $MV$  ( $TrigF_{-0.6s}$   $r_s = -0.45$ ,  $p = 0.020$ ;  
150  $TrigF_{-0.2s}$   $r_s = -0.46$ ,  $p = 0.018$ ),  $ATV$  ( $TrigF_{-0.6s}$   $r_s = -0.42$ ,  $p = 0.032$ ;  $TrigF_{-0.2s}$   $r_s = -0.43$ ,  $p =$   
151  $0.028$ ) 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  
152 other aiming point trajectory variables.

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

## 157 **DISCUSSION**

158 The aims of the present study were 1) to identify the most important factors related to biathlon  
159 prone shooting performance without physical stress and 2) to find the best variables to describe  
160 these factors. Four different components, stability of hold, aiming accuracy, cleanness of  
161 triggering and timing of triggering, were identified as the most important factors. The variables  
162 describing cleanness of triggering, aiming accuracy and timing of triggering explained a total of  
163 80% of the variance in mean shooting performance. Stability of hold was related to shooting  
164 performance both directly and indirectly, as it was also associated to cleanness of triggering.

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

173 In the present study, stability of hold variables DevX, COG<sub>(1/3)</sub> and ATV; aiming accuracy  
174 variables COG<sub>Dist</sub> and Target<sub>(1/3)</sub>; and a cleanness of triggering variable COG2Hit were related to  
175 biathlon prone shooting performance in resting shooting. Further, senior biathletes demonstrated  
176 better stability of hold (MV, DevX, ATV) and cleanness of triggering (Hit<sub>(1/3)</sub>, COG2Hit) than  
177 junior biathletes. However, shooting performance was only tendentially better in senior biathletes.

178 Sattlecker et al.<sup>8</sup> also found that horizontal stability of hold discriminates between high- and low-  
179 scoring biathletes in resting shooting, and vertical stability of hold discriminates between these  
180 groups in shooting under physical stress. In an air rifle shooting study,<sup>10</sup> in addition to horizontal  
181 and vertical stability of hold measures, a stability of hold variable similar to COG<sub>(1/3)</sub> that was used  
182 in the present study was also found to be related to shooting performance. As the results also  
183 showed that better stability of hold was associated with better cleanness of triggering, stability of  
184 hold seems to be a general prerequisite for successful biathlon prone shooting performance.  
185 Further, the most important variables seem to be similar to those that have been identified as  
186 important stability of hold measures in air rifle shooting.

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

194 breathing could also cause the shoulder and thus the rifle to move more in the vertical direction in  
195 shooting under physical stress.

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

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



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

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

248 MRA run over test mean values revealed that the cleanness of triggering variable  $COG_{2Hit}$ , the  
249 aiming accuracy variable  $COG_{Dist}$  and the timing of triggering variable  $TIRE_6$  accounted for 80%  
250 of the of the mean shooting performance. It has been previously reported that in air rifle shooting,  
251 the test mean values of the variables describing stability of hold, aiming accuracy, timing of

252 triggering, and cleanness of triggering are the most important, accounting for 81% of shooting  
253 performance.<sup>10</sup> Other studies in rifle shooting sports have reported the prediction equation for  
254 single shots, but with considerably weaker precision of the prediction.<sup>13,19</sup> It seems that the  
255 precision of such predictions is relatively high when test mean values are used for assessing  
256 athletes' general shooting technical level.

257 Complementing the regression equation with the stability of hold variables DevY and ATV further  
258 improved the accuracy of the prediction equation by four and three percentage points,  
259 respectively. Interestingly, the regression coefficient value of DevY in MRA indicated that  
260 increased vertical sway of the rifle improves shooting performance, whereas its correlation  
261 coefficient to shooting performance indicated the opposite, although statistically, the correlation  
262 was pointing direction only ( $p = 0.070$ ). However, as previously discussed, the results showed that  
263 DevY and ATV correlate to each other. The results also showed that the regression coefficients of  
264 the two variables (DevY -0.819, ATV 0.094) point in opposing directions causing them to cancel  
265 each other out, and their combined effect on mean hit point distance from the center was  
266 negligible ( $-1.1 \pm 0.6$  mm) in the regression equation. Hence, based on the results of MRA, the  
267 most important components of biathlon prone shooting performance were the cleanness of  
268 triggering variable COG<sub>2Hit</sub>, the aiming accuracy variable COG<sub>Dist</sub> and the timing of triggering  
269 variable TIRE<sub>6</sub>, which accounted for 63%, 14% and 4% of shooting performance, respectively.  
270 The influence of the stability of hold component should be interpreted with caution. The  
271 controversy might be due to the small number of tests analyzed, probably causing the regression  
272 equation with more variables to overfit for the present data.

273 Despite its moderate correlation to shooting performance, horizontal stability of hold DevX was  
274 not included in the regression equation, which is in contrast to the previous air rifle shooting  
275 study<sup>10</sup> where it was the most important predictor of shooting performance. This could be related  
276 to the nature of biathlon shooting and the time used to calculate the shooting technical variables.  
277 Biathlon shooting is performed under time pressure, and most variables used in the present study  
278 were calculated over the last 0.6 seconds before triggering. The biathlete might try to aim at the  
279 center throughout the last 0.6 seconds and pull the trigger right after reaching a satisfactory hold  
280 stability. Thus, it could be that the best hold stability is reached only right before triggering. The  
281 fact that ATV, which was calculated over the last 0.2 seconds, was identified as a stability of hold

282 variable, strengthens this suggestion. Aiming on average at the center of the target during the last  
283 0.6 seconds improves the aiming accuracy variable  $COG_{Dist}$ , which had the second strongest effect  
284 on the regression equation precision. Further, reaching a stable hold right before triggering would  
285 explain why the cleanness of triggering variable  $COG_{2Hit}$ , that is the distance from the mean  
286 aiming location to the hit point, had the largest effect on the regression equation prediction. In that  
287 case, if the biathlete aims precisely and can minimize rifle movement right before triggering,  
288 having a stable hold throughout the last 0.6 seconds would likely not improve shooting  
289 performance further. However, other findings still highlight the importance of general hold  
290 stability in biathlon prone shooting, as stability of hold measures calculated over the last 0.6  
291 seconds were associated with cleanness of triggering.

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

## 305 **PERSPECTIVE**

306 The results of the present study support the findings of Sattlecker et al.'s study<sup>8</sup> and provide  
307 valuable new information on the technical aspects of biathlon prone shooting. The findings  
308 indicate that the key components of biathlon prone shooting performance are stability of hold,  
309 aiming accuracy, cleanness of triggering and timing of triggering, which were all related to  
310 shooting performance. Stability of hold seems to be a general prerequisite, as better hold was also

311 associated with better cleanness of triggering. Further, a high pre-shot trigger force level should be  
312 achieved to improve stability of hold and cleanness of triggering. The parameters measured in the  
313 present study can be used to assess the current level and the progression of biathletes' shooting  
314 technique in the prone position. In the future, biathlon prone shooting studies should include  
315 measures of stability of hold, aiming accuracy, cleanness of triggering and timing of triggering to  
316 get a comprehensive understanding of the different aspects of the task. Measurement of trigger  
317 force provides additional information about the quality of the triggering action, which could help  
318 biathletes improve their shooting performance.

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Table 1. Descriptions of the shooting technical variables.

Variable (unit)	Description
Shooting performance	
Hit <sub>Dist</sub> (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 <sub>(1/3)</sub> (%)	Relative contribution of the last 0.6 seconds before triggering during which the aiming point was within a ring with the radius of $3^{-1} \times 22.5 \text{ mm}$ (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 <sub>Dist</sub> (mm)	Distance of the aiming point mean location during the last 0.6 seconds before triggering.
Target <sub>(1/3)</sub> (%)	Relative contribution of the last 0.6 seconds before triggering during which the aiming point was within a ring with the radius of $3^{-1} \times 22.5 \text{ mm}$ (i.e. one third of the hit area) drawn around the center of the target.
Cleanness of triggering	
Hit <sub>(1/3)</sub> (%)	Relative contribution of the last 0.6 seconds before triggering during which the aiming point was within a ring with the radius of $3^{-1} \times 22.5 \text{ mm}$ (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<sub>6</sub> (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<sub>-1.0s</sub> (%),

TrigF<sub>-0.6s</sub> (%),

TrigF<sub>-0.2s</sub> (%)

Relative trigger force at 1.0 seconds (TrigF<sub>-1.0s</sub>), 0.6 seconds (TrigF<sub>-0.6s</sub>) and 0.2 seconds (TrigF<sub>-0.2s</sub>) before triggering. Triggering occurred at 100%.

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

	Factor 1	Factor 2	Factor 3	Factor 4
	Stability of hold	Aiming accuracy	Cleanness of triggering	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 <sub>Dist</sub>		0.955		
Target <sub>(1/3)</sub>		-0.930		
Hit <sub>(1/3)</sub>			-0.879	
COG2Hit			0.734	
TIRE <sub>6</sub>				0.990

Table 3. Test values (mean  $\pm$  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 <sub>Dist</sub> (mm)	9.2 $\pm$ 1.4	10.4 $\pm$ 2.1	0.086	-0.65	
Stability of hold					
MV (mm/s)	114.4 $\pm$ 30.6 <sup>^</sup>	145.5 $\pm$ 38.2	0.032	-0.83	0.37
DevY (mm)	3.7 $\pm$ 1.0	4.6 $\pm$ 1.4	0.074	-0.68	0.36
DevX (mm)	4.7 $\pm$ 1.0 <sup>^</sup>	5.8 $\pm$ 1.4	0.043	-0.78	0.62 <sup>***</sup>
COG <sub>(1/3)</sub> (%)	93.4 $\pm$ 4.1	89.5 $\pm$ 5.6	0.060	0.72	-0.57 <sup>**</sup>
ATV (mm)	20.9 $\pm$ 5.2 <sup>^</sup>	28.0 $\pm$ 7.7	0.012	-1.00	0.41 <sup>*</sup>
Aiming accuracy					
COG <sub>Dist</sub> (mm)	7.9 $\pm$ 1.3	8.2 $\pm$ 1.6	0.640	-0.17	0.67 <sup>***</sup>
Target <sub>(1/3)</sub> (%)	37.7 $\pm$ 8.1	33.3 $\pm$ 8.8	0.201	0.48	-0.73 <sup>***</sup>
Cleanness of triggering					
Hit <sub>(1/3)</sub> (%)	83.5 $\pm$ 6.3 <sup>^</sup>	78.4 $\pm$ 5.6	0.042	0.79	-0.27
COG2Hit (mm)	6.3 $\pm$ 1.1 <sup>^</sup>	7.8 $\pm$ 2.0	0.027	-0.83	0.79 <sup>***</sup>
Timing of triggering					
TIRE <sub>6</sub> (index)	3.7 $\pm$ 0.4	3.6 $\pm$ 0.3	0.807	0.09	-0.05
Trigger force					
TrigF <sub>-1.0s</sub> (%)&	81.7 $\pm$ 7.1	76.9 $\pm$ 13.5	0.742	0.08	0.25
TrigF <sub>-0.6s</sub> (%)&	88.3 $\pm$ 5.2	84.8 $\pm$ 9.7	0.560	0.14	0.34
TrigF <sub>-0.2s</sub> (%)&	93.9 $\pm$ 3.5	92.0 $\pm$ 7.2	0.820	0.06	0.33

Statistically significant difference to Youth <sup>^</sup>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

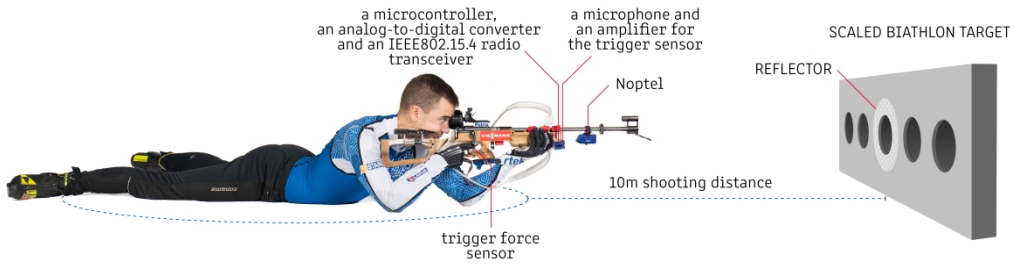
Table 4. Stepwise multiple regression analysis  $R^2$ ,  $R^2$  change, F change, and regression coefficient B values with mean shooting performance ( $Hit_{Dist}$ , hit point distance from the center of the target) as the dependent variable (n = 26).

	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 <sub>Dist</sub>				0.521
Step 3	0.804	0.042	4.741	
Constant				4.864
COG2Hit				0.632
COG <sub>Dist</sub>				0.601
TIRE <sub>6</sub>				-1.191
Step 4	0.843	0.039	5.269	
Constant				6.696
COG2Hit				0.821
COG <sub>Dist</sub>				0.584
TIRE <sub>6</sub>				-1.570
DevY				-0.390
Step 5	0.876	0.032	5.201	
Constant				6.572
COG2Hit				0.756
COG <sub>Dist</sub>				0.652
TIRE <sub>6</sub>				-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).



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