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Rifle and aiming point accelerations do not differ between the most and least accurate shots in biathlon shooting within an athlete

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Abstract

Study aim: As studies from shooting disciplines other than biathlon have observed associations between weapon accelerations and shooting performance, this study investigated whether accelerations of the rifle stock and aiming point (the point on the target where the rifle is aimed at) are associated with shooting performance, and differences in rifle and aiming point accelerations between the most and least accurate shots. Further, associations between rifle and aiming point accelerations were studied.
Materials and methods: Shooting performance (Hit_{Dist}, hit point distance from the center of the target) along with rifle and aiming point accelerations were measured from nine biathletes who performed 6×5 biathlon prone and standing shots.
Results: In the prone posture, rifle or aiming point accelerations were neither associated with shooting performance nor with each other. In the standing posture, vertical rifle accelerations right before triggering were negatively associated with Hit_{Dist} ($r = -0.70$, $p < 0.05$), whereas aiming point accelerations were not associated with Hit_{Dist}. Horizontal rifle accelerations were positively associated with aiming point accelerations in standing ($r = 0.74$, $p = 0.024$), whereas vertical or resultant rifle accelerations did not demonstrate associations with aiming point accelerations. In both postures, rifle accelerations were of the same magnitude in the most and least accurate shots.
Conclusion: Rifle and aiming point accelerations provide limited description of the technical level in biathlon shooting. Moreover, rifle accelerations alone do not appear to provide sufficient information to deduce the aiming point movements. Angular movement would likely be required for aiming point movement estimation.

Keywords: Accelerometer – Wearable – Kinematics – Technique – Rifle shooting

Introduction

Biathlon is an Olympic winter sport combining cross-country skiing and rifle shooting. 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 posture. 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.

Overall performance in biathlon is determined by skiing speed, time spent on the shooting range and number of missed targets [2, 3, 9–11]. In the sprint competition, skiing time explains approximately 60% and shooting performance almost 40% of the performance difference between those finishing in the top-10 and those finishing among ranks 21 to 30 [9]. In the individual competition the corresponding numbers are 50% and 50%, probably caused by the greater penalty for each missed shot [10]. The influence of shooting performance is high also in the pursuit competition, where it explains approximately 40–50% of the race performance, increasing up to 60–70% when excluding start time determined by the preceding sprint race [11]. Accordingly, skiing speed is important for final performance in biathlon, but better shooting perform-

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ance discriminates the podium rank biathletes from their lower ranked counterparts [2, 3].

Biathlon shooting has been extensively studied from the shooting technical perspective. In the prone posture, the biathlete has three support points, both elbows and the lower body. Stability of hold [8, 19], aiming accuracy [8], cleanness of triggering [8] and timing of triggering [8] have been observed to be associated with shooting performance in the prone posture. Furthermore, high pre-shot trigger force values and a flat trigger force curve inclination during triggering has been observed to increase rifle stability [8, 19].

In the standing posture, the base of support forms between the feet. The smaller base of support area and higher center of gravity location of the body-rifle combination makes controlling the sway considerably more difficult compared to the prone posture. In the standing shooting posture, stability of hold [5, 19, 20] and cleanness of triggering [5] have been observed to be associated with 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 [7]. Regarding postural control in the standing posture, both antero-posterior (perpendicular to shooting line) [19] and medio-lateral (parallel to shooting line) [5] 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 associated with variables relating to movements of the aiming point [5]. When compared to their younger counterparts, national top-level biathletes have demonstrated better shooting performance [5, 20], postural balance [5] and stability of hold [20]. A recent study also showed that during an aiming task, biathletes employ more regular and repetitive postural control patterns compared to subjects with three months or no experience in shooting [13]. Notably, only a slight difference was observed between the subjects with three months of shooting training compared to those with no shooting experience at all [13]. Thus, biathlon shooting, especially from the standing posture, is a highly demanding task and mastering it requires extensive sport-specific training.

The optoelectronic system used to measure shooting technical parameters in the aforementioned studies is quite expensive, requires a careful calibration procedure and does not provide information on how the aiming point movement is controlled. In pistol shooting [12, 21] and archery [16], shooting performance has been observed to be associated with acceleration-based parameters measured by a triaxial accelerometer attached on the weapon. On the other hand, Zak et al. observed no significant differences in rifle accelerations in biathlon standing shooting when performance was assessed after skiing bouts of varying intensities [22], suggesting that there may be a difference on the association of weapon accelerations to shooting performance between precision shooting and biathlon shooting. However, Zak et al. did not report whether shooting performance was affected by the skiing intensity.

Since a wireless calibration-free accelerometer could be easily used by coaches and athletes to provide feedback of rifle kinematics, the main purpose of the present study was to investigate the associations between shooting performance and rifle accelerations. To further understand how rifle motion is controlled in moving the aiming point, the secondary purpose was to assess whether there is a direct association between rifle and aiming point accelerations. It was hypothesized that higher rifle accelerations are associated with worse shooting performance, and that rifle accelerations are associated with aiming point accelerations.

Materials and methods

Participants

Nine competitive biathletes (5 males, 4 females) from the Finnish national development team were invited and volunteered to participate in the study. Participants were 22 ± 3 years old (min 19 – max 29 years old) and had been actively involved in competitive biathlon for 9 ± 3 years (min 6 – max 15 years). All athletes had represented Finland at international competitions, either at senior (IBU world cup, IBU cup) or junior/youth level (IBU junior cup, IBU youth/junior world championships).

The study was conducted according to the guidelines of the Declaration of Helsinki and approved by the Ethics Committee of the University of Jyväskylä (26 April 2019). All subjects were informed of the purpose, nature and potential risks of the study. They also gave their written informed consent before participating in the measurements.

Experimental overview

All participants were asked to repeat the following procedure twice: once from the prone and once from the standing posture. The participants used their personal biathlon rifles at all stages of the study.

Prior to starting the experimental task, the participants were requested to complete a preparatory procedure consisting of four 45-second holding tasks with a 30-second recovery in between. One 45-second period consisted of two 10-second holds starting at 10 and 35 seconds. During each holding period, the biathlete was instructed to first approach the target as usual, and 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 set, and two to four 5-shot sets to compensate for the possible differences in the number of zeroing shots. After the

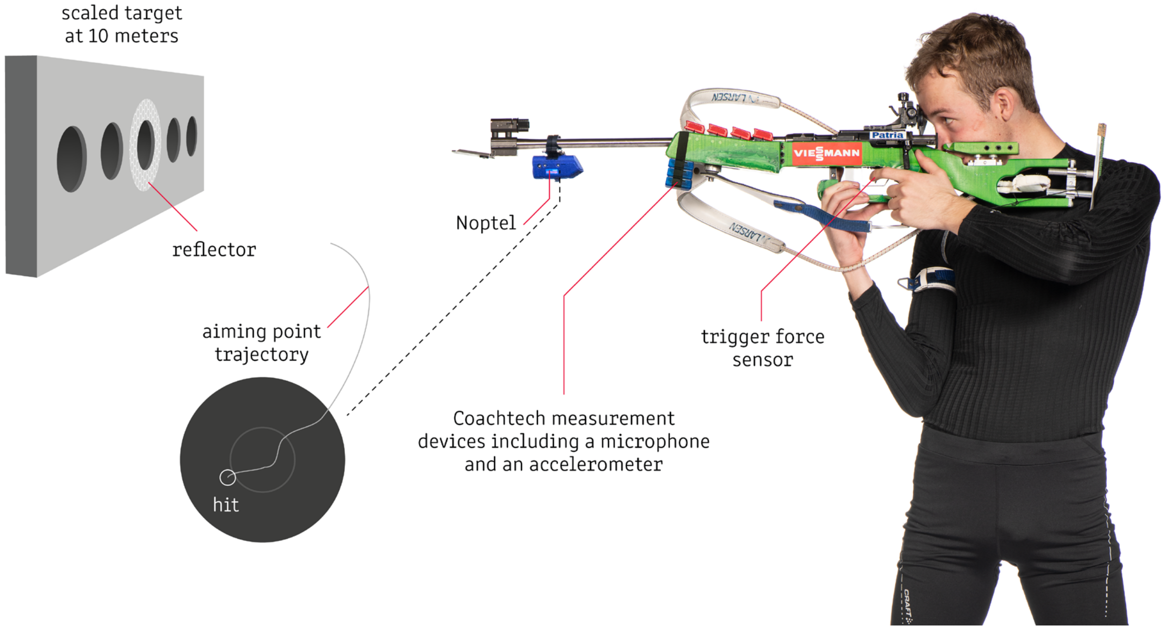

Figure 1. An overall schematic of the measurement devices

preparatory procedure, the biathlete started performing the experimental task.

In the experimental task, the biathlete was instructed to perform a biathlon shooting task of 6 × 5 shots in a resting state from the prone and standing postures using their normal competition rhythm and technique. Each 5-shot set began with the biathlete standing behind the shooting mat, then taking the shooting posture (prone or standing), shooting five dry shots without ammunition, and ending in the same standing posture behind the shooting mat. Participants took a break of approximately 30 seconds between each set.

Data collection

The shooting tasks were carried out indoors in a laboratory optimized for shooting, using dry firing into a scaled target at 10 meters. An overall schematic of the measurement set-up used has been illustrated in Figure 1.

Shooting performance and movement of the aiming point were measured at 67 Hz using a Noptel ST 2000 training device (Noptel Inc., Oulu, Finland) with the NOS 4 software version 4.5.3. 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.

Rifle kinematics were simultaneously measured with a triaxial accelerometer (MPU-9250; InvenSense, CA, USA), attached at the distal end of the rifle stock. The sensor possesses a dynamic measurement range of ±16 g and a measurement resolution of 0.488 milligravity.

Microphone data was used to identify the triggering moment and for data synchronization. A piezoresistive pressure sensor (FSR 402, Interlink Electronics Inc., Irvine, CA, USA) was taped on the rifle trigger and used to automatically filter out shots incorrectly detected by the Noptel system (e.g., detected reloads of the rifle). The method has been described in a previous study [8].

Data from the accelerometer, microphone and pressure sensor were synchronously collected using Coachtech measurement nodes (weight 68 g) at 400 Hz, and further processed and stored using the Coachtech system [17] (University of Jyväskylä, Vuokatti, Finland). Aiming point coordinate data was synchronized to other sensors' data by matching the triggering moment automatically detected by the Noptel software to the microphone pulse caused by triggering. The software for signal processing and filtering out incorrect shots was created using the LabView programming environment (National Instruments, Austin, TX, USA).

Variables

Shooting performance and aiming point accelerations were analyzed from Noptel data. Hit point distance from the center of the target (Hit_{Dist}) was used as the variable for shooting performance. Two-dimensional (2D) aiming point (AP) acceleration variables were calculated from the aiming point trajectory coordinate data. Highest mean 2D resultant acceleration magnitude during a consecutive 50-millisecond period ($MAXacc_{AP}$), and standard deviation of the 2D resultant acceleration magnitude ($SDaccR_{AP}$) were calculated and reported for the time intervals 0.6 to 0.2 seconds and 0.2 to 0.0 seconds prior to each triggering.

The three-dimensional (3D) rifle accelerometer data were analyzed and the dynamic resultant, vertical and horizontal acceleration magnitudes in the global coordinate system were calculated applying the methods described by Mizell [14]: let a be the vector made up of the measurement axes values obtained from the accelerometer. The vertical acceleration vector corresponding to gravity g was estimated by low-pass filtering a using the 2nd order Butterworth filter with 0.2 Hz cut-off frequency. The dynamic component d of a, caused by the rifle's motion, was calculated with vector subtraction:

$$d = a - g.$$

Sensor raw accelerations, the estimated gravity component, and the resulting dynamic accelerations in the three sensor axes 0.6 to 0.0 seconds before triggering for one example shot are illustrated in Figure 2. The vertical component of the dynamic acceleration was calculated as the vector projection p of d upon the global vertical axis (direction of gravity):

$$p = \left(\frac{d \cdot g}{g \cdot g}\right).$$

The horizontal component of the dynamic acceleration was calculated with vector subtraction:

$$h = d - p.$$

Finally, the dynamic resultant (accR), vertical (accV, including the up-down direction) and horizontal (accH, including the left-right and forward-backwards directions) acceleration magnitudes were calculated as follows:

$$\text{accR}_{\text{rifle}} = \|d\| = \sqrt{d_x^2 + d_y^2 + d_z^2},$$

$$\text{accV}_{\text{rifle}} = \|p\| = \sqrt{p_x^2 + p_y^2 + p_z^2} \quad \text{and}$$

$$\text{accH}_{\text{rifle}} = \|h\| = \sqrt{h_x^2 + h_y^2 + h_z^2}.$$

Highest mean 3D dynamic resultant acceleration magnitude during a consecutive 50-millisecond period ($\text{MAXacc}_{\text{rifle}}$), and standard deviations of the dynamic 3D resultant ($\text{SDaccR}_{\text{rifle}}$), vertical ($\text{SDaccV}_{\text{rifle}}$) and horizontal ($\text{SDaccH}_{\text{rifle}}$) acceleration magnitudes were calculated and reported for the time intervals 0.6 to 0.2 seconds and 0.2 to 0.0 seconds prior to each triggering.

Statistical analysis

For each participant, mean ± standard deviation values of all shots (test means), and of ten most (high accuracy means) and least accurate (low accuracy means) shots were calculated. Data were controlled for normality using the Shapiro-Wilk test in IBM SPSS Statistics 26.0 software (SPSS; IBM Corp., Armonk, NY, USA).

To assess the associations of rifle and aiming point accelerations with shooting performance, and the associations of rifle accelerations with aiming point accelerations, the two-tailed Pearson's correlation coefficient was used when the normality assumption was met. When the normality assumption was violated, both two-tailed Pearson's correlation coefficient and Spearman's rank correlation coefficient were used to avoid misinterpretations. Pearson correlation coefficients are reported since the Pearson and Spearman tests produced congruent on each occasion. Correlation analyses were conducted in SPSS. Rank-based non-parametric methods for analyzing longitudinal data in factorial experiments (nparLD) from the nparLR R-package [15] in R (64-bit version 4.1.2, https://www.r-project.org/) were used to evaluate posture (two within-subject categories; prone, standing) and shooting accuracy (two within-subject categories; high, low) main and interaction effects on shooting performance, and rifle and aiming point accelerations. Where significant main effects were observed, specific categories were compared to each other

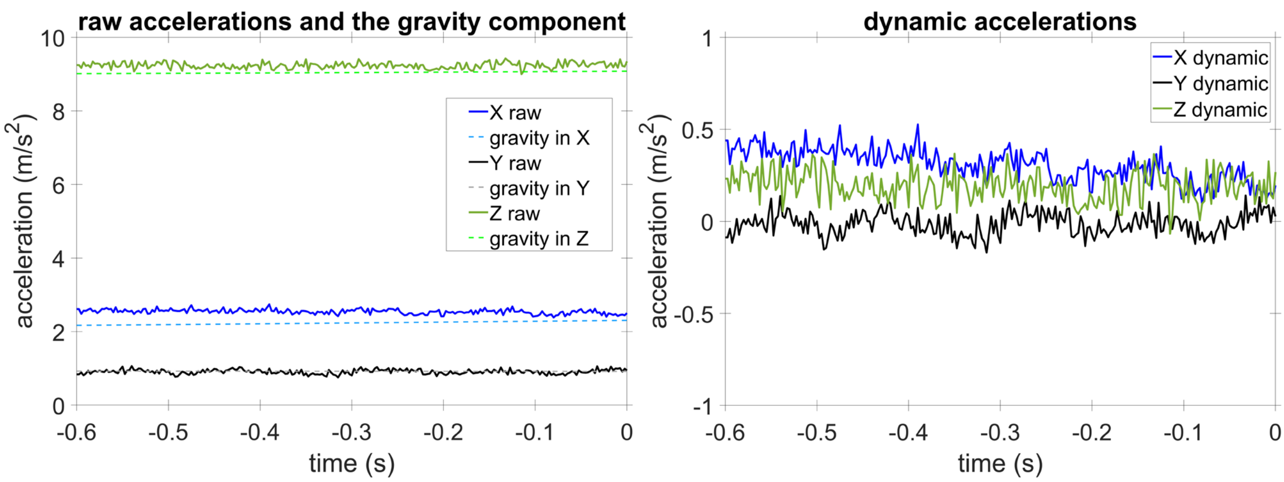

Figure 2. Left: Raw accelerations and the estimated gravity component in the three sensor axes. Right: Dynamic accelerations in the three sensor axes

in post-hoc testing using the Wilcoxon signed-rank test in SPSS. Statistical significance was set at $p < 0.05$.

Results

Statistically significant effects of posture (ANOVA-type Statistic ATS = 73.8; degrees of freedom df = 1; $p < 0.001$) and accuracy (ATS = 173.3; df = 1; $p < 0.001$) on shooting performance were observed with nparLD. Rifle (ATS 38.6 to 344.5; df = 1; all $p < 0.001$) and aiming point accelerations (ATS 42.0 to 150.0; df = 1; all $p < 0.001$) showed statistically significant effects of posture. The effects of accuracy on rifle accelerations were not statistically significant, whereas on standard deviation of the aiming point acceleration magnitude ($SDaccR_{AP}$) the effect of accuracy was nearing significance (ATS = 3.0; df = 1; $p = 0.082$). A significant interaction effect between posture and accuracy on $SDaccR_{AP}$ (ATS = 5.8; df = 1; $p = 0.016$) was observed but not on any other variable.

The biathletes hit 24.5 mm further away from the center of the target in the standing (Hit_{Dist} 33.6 ± 4.1 mm) than in the prone (9.1 ± 1.5 mm) posture. A Wilcoxon signed-rank test indicated that this difference was statistically significant (T = 45, z = –2.666, $p = 0.008$). In the standing posture, rifle accelerations were 20–39% higher and aiming point accelerations 35–70% higher than in the prone posture (for all T = 45, z = –2.666, $p = 0.008$). The less accurate shots were 11.1 mm and 35.6 mm further away from the center of the target in the prone (3.9 ± 0.8 mm vs 15.0 ± 2.7 mm) and the standing posture (16.3 ± 3.2 mm vs 51.9 ± 6.4 mm), respectively (both T = 45, z = –2.666, $p = 0.008$). However, differences between high and low accuracy test means in rifle and aiming point accelerations were negligible and did not reach statistical significance in either posture (Table 1).

In the prone posture, none of the rifle or aiming point acceleration variables were associated with Hit_{Dist}. In the standing posture, vertical rifle acceleration magnitude ($SDaccV_{rifle}$) showed a significant negative association with Hit_{Dist} 0.2 to 0.0 s before triggering (Figure 3), and 0.6 to 0.2 s before triggering the association was nearing significance ($r = –0.65$, $p = 0.061$). Other acceleration variables were not associated with Hit_{Dist} in the standing posture.

Table 1. Descriptive statistics (mean ± standard deviation) and comparisons of aiming point (AP) and rifle accelerations between prone and standing, and between high and low accuracy shots in each posture

	Prone			Standing		
	High accuracy	Low accuracy	All	High accuracy	Low accuracy	All
	(m/s^2)	(m/s^2)	(m/s^2)	(m/s^2)	(m/s^2)	(m/s^2)
0.6 to 0.2 s before triggering						
$MAXacc_{AP}$	4.4640 ± 0.6513	4.5041 ± 0.7779	4.4461 ± 0.6570	6.7797 ± 1.2624$^{\#\#\wedge\wedge}$	6.7091 ± 1.4174$^{\#\#\wedge\wedge}$	6.7724 ± 1.3512**
$SDaccR_{AP}$	1.6086 ± 0.1996	1.6338 ± 0.1952	1.6175 ± 0.1884	2.1911 ± 0.3966$^{\#\#\wedge\wedge}$	2.1728 ± 0.4154$^{\#\#\wedge\wedge}$	2.1890 ± 0.4023**
$MAXacc_{rifle}$	0.1413 ± 0.0139	0.1376 ± 0.0120	0.1401 ± 0.0135	0.2002 ± 0.0493$^{\#\#\wedge\wedge}$	0.1889 ± 0.0281$^{\#\#\wedge\wedge}$	0.1919 ± 0.0347**
$SDaccR_{rifle}$	0.0468 ± 0.0023	0.0473 ± 0.0020	0.0472 ± 0.0019	0.0577 ± 0.0058$^{\#\#\wedge\wedge}$	0.0562 ± 0.0036$^{\#\#\wedge\wedge}$	0.0567 ± 0.0044**
$SDaccH_{rifle}$	0.0426 ± 0.0061	0.0434 ± 0.0068	0.0431 ± 0.0065	0.0530 ± 0.0072$^{\#\#\wedge\wedge}$	0.0511 ± 0.0062$^{\#\#\wedge\wedge}$	0.0519 ± 0.0055**
$SDaccV_{rifle}$	0.0432 ± 0.0081	0.0421 ± 0.0080	0.0425 ± 0.0084	0.0530 ± 0.0099$^{\#\#\wedge\wedge}$	0.0517 ± 0.0076$^{\#\#\wedge\wedge}$	0.0523 ± 0.0086**
0.2 to 0.0 s before triggering						
$MAXacc_{AP}$	3.7780 ± 0.6945	3.7793 ± 0.6290	3.8205 ± 0.5783	6.3103 ± 1.0156$^{\#\#\wedge\wedge}$	6.6958 ± 1.3639$^{\#\#\wedge\wedge}$	6.4798 ± 1.1657**
$SDaccR_{AP}$	1.5689 ± 0.2460	1.5528 ± 0.1940	1.5769 ± 0.1948	2.4784 ± 0.3348$^{\#\#\wedge\wedge}$	2.8033 ± 0.5409$^{\#\#\wedge\wedge}$	2.6087 ± 0.4153**
$MAXacc_{rifle}$	0.1198 ± 0.0089	0.1199 ± 0.0073	0.1215 ± 0.0074	0.1717 ± 0.0352$^{\#\#\wedge\wedge}$	0.1693 ± 0.0253$^{\#\#\wedge\wedge}$	0.1691 ± 0.0277**
$SDaccR_{rifle}$	0.0445 ± 0.0024	0.0450 ± 0.0020	0.0452 ± 0.0018	0.0553 ± 0.0051$^{\#\#\wedge\wedge}$	0.0580 ± 0.0101$^{\#\#\wedge\wedge}$	0.0559 ± 0.0050**
$SDaccH_{rifle}$	0.0406 ± 0.0061	0.0409 ± 0.0063	0.0412 ± 0.0060	0.0505 ± 0.0066$^{\#\#\wedge\wedge}$	0.0535 ± 0.0123$^{\#\#\wedge\wedge}$	0.0516 ± 0.0066**
$SDaccV_{rifle}$	0.0391 ± 0.0083	0.0395 ± 0.0080	0.0397 ± 0.0087	0.0506 ± 0.0099$^{\#\#\wedge\wedge}$	0.0509 ± 0.0077$^{\#\#\wedge\wedge}$	0.0504 ± 0.0081**

SDacc standard deviation of dynamic acceleration magnitude; MAXacc highest mean acceleration magnitude of the dynamic resultant acceleration during a consecutive 50-millisecond period (2D for aiming point, 3D for rifle); R resultant; H horizontal; V vertical; ** $p < 0.01$ for difference to prone all; $^{\#\#}$ $p < 0.01$ for difference to the corresponding accuracy in prone (high vs high, low vs low); $^{\wedge\wedge}$ $p < 0.01$ for difference to the opposite accuracy in prone (high vs low, low vs high).

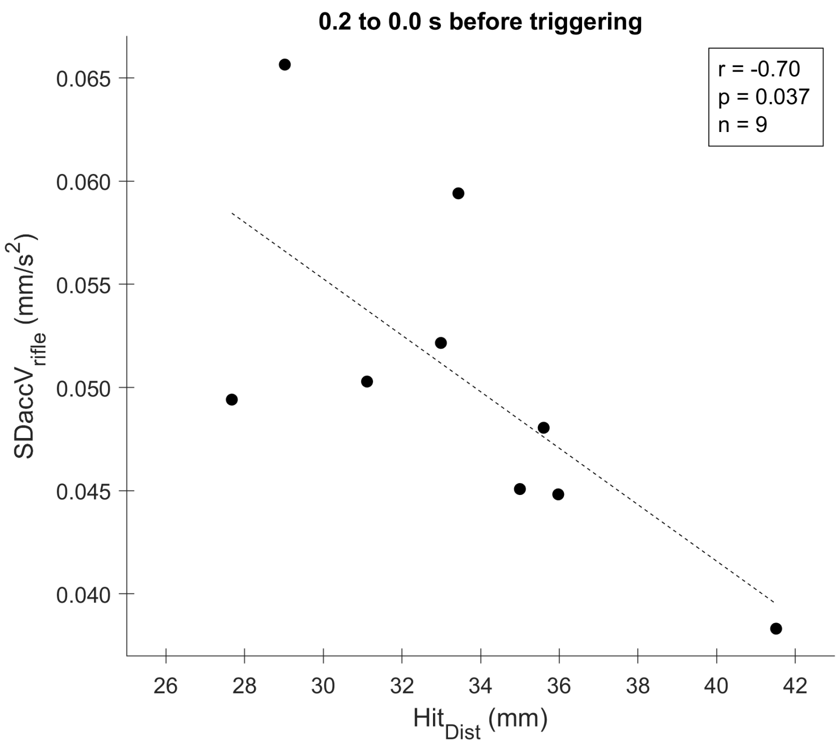

Figure 3. Association between standard deviation of dynamic vertical rifle acceleration magnitude ($SDaccV_{rifle}$) and hit point distance from the center of the target (Hit_{Dist}) in the standing posture 0.2 to 0.0 seconds before triggering

In the prone posture, rifle accelerations were not associated with aiming point accelerations. In the standing posture, the associations between horizontal rifle acceleration magnitude ($SDaccH_{rifle}$) and aiming point accelerations were significant 0.6 to 0.2 seconds before triggering ($MAXacc_{AP}$ r = 0.73, p = 0.025, $SDaccR_{AP}$ r = 0.74, p = 0.024) and nearing significance 0.2 to 0.0 seconds before triggering ($MAXacc_{AP}$ r = 0.66, p = 0.055, $SDaccR_{AP}$ r = 0.64, p = 0.065). Other rifle and aiming point acceleration variables in the standing posture were not associated with each other.

Discussion

The main findings of the study were that rifle and aiming point accelerations provide very limited information on the technical level in biathlon shooting. In the prone posture, rifle or aiming point accelerations were neither associated with shooting performance nor with each other. In the standing posture, higher vertical rifle accelerations right before triggering were associated with more accurate shooting, whereas aiming point accelerations were not associated with shooting performance. Furthermore, horizontal rifle accelerations were positively associated with aiming point accelerations in standing, but neither vertical nor resultant rifle accelerations demonstrated associations with aiming point accelerations. Rifle and aiming point accelerations were higher in the standing posture than in the prone posture, but in both postures, they were of the same magnitude in the most and least accurate shots.

In the prone posture, no associations were observed between shooting performance and rifle accelerations. In the standing posture, vertical rifle accelerations right before triggering showed a negative correlation to hit point distance, indicating that higher accelerations led to more accurate shooting. These findings are in contrast to previous studies in pistol shooting [12, 21] and archery [16]. Each of those studies found positive associations between shooting performance and acceleration magnitudes before triggering, indicating that lower accelerations led to more accurate shooting. Further, a study using marker-based motion capture in biathlon standing shooting reported that lower mean sway velocity of the rifle in cross-shooting line indicated better shooting performance [20]. Based on the present study, it can only be speculated that the negative correlation between vertical rifle accelerations and hit point distance in the standing posture can be either due to increases or decreases in rifle velocity. Especially considering the spread in acceleration values shown in Figure 3, it is possible that in some subjects, rifle velocity might tend to increase, whereas in some, it might tend to decrease. Both would show increased acceleration magnitudes.

Further, rifle accelerations did not differ between the most and least accurate shots in either posture. Regarding standing shooting, this finding is in line with a previous study that did not find differences in rifle accelerations in biathlon standing shooting after skiing bouts of different intensities [22]. These findings might indicate that decreases in shooting performance or increases in exercise intensity do not affect rifle acceleration metrics measured with an accelerometer in biathlon shooting.

Based on these findings, it could be suggested that rifle kinematics in biathlon shooting should be assessed using velocity-based metrics, not accelerations. The major difference of biathlon shooting and pistol shooting or archery is its nature, which might partly explain these incongruent results. In biathlon shooting, the biathlete performs under time pressure because the shooting time can explain up to 7% of the total performance difference between the top-10 and those achieving ranks 21 to 30 in the world cup [9, 10, 11]. Furthermore, in biathlon one does not need to hit the center of the target, as only hits and misses are counted, not points as in pistol and archery. Therefore, biathletes are able to pull the trigger quite quickly after achieving a satisfactory aiming picture inside the hit area. Therefore, in some shots the rifle could be actually decelerating during the phases used in the analyses (0.6 to 0.2 seconds and 0.2 to 0.0 seconds before triggering). In pistol and archery, it is more likely that the weapon is being held still before triggering, and the attached accelerometer senses microaccelerations caused by trembling of the weapon, which have been found to be associated with shooting performance [12, 16, 21].

Aiming point accelerations right before triggering did not differ between high and low accuracy shots in either posture. Correspondingly, they were not directly associated with shooting performance. This is partly in line with a previous study by Sattlecker et al. [19]. They did not find differences between high and low performers in the test mean values for aiming point movement in the prone posture. In contrast, in the standing posture the horizontal movement of the aiming point tended to differ between the groups. However, the statistical set-up is different between these studies, as Sattlecker et al. compared test mean values between subjects, and the present study compared the most and least accurate shots from the same subjects. Moreover, the difference in the standing posture was not statistically significant in their study either.

Rifle accelerations before triggering were not associated with aiming point accelerations in the prone posture. In the standing posture, only horizontal rifle accelerations demonstrated associations with aiming point accelerations. The reason for why other rifle acceleration variables did not show associations with aiming point accelerations could be the lack of measuring the rotational component of the rifle's motion. It might be that the biathlete moves the aiming point predominantly by rotating the rifle. However, also postural sway directly affects rifle's motion in the standing posture [18], which could explain why horizontal rifle accelerations were associated with aiming point movement. This could be supported indirectly too, as previous studies in biathlon [5, 19, 20] and air rifle shooting [1, 4, 6] have observed associations between postural sway and aiming point movement. Therefore, future research should also measure the rotational component e.g., by using motion capture [18, 20] or a miniature gyroscope attached on the weapon [12]. This would allow for a more comprehensive description of how rifle motion is controlled to move the aiming point. Furthermore, the method used for sensor orientation estimation does not allow for distinguishing between left-right and forward-backwards directions from the dynamic horizontal acceleration component. Rifle movements in these directions could be assessed e.g., using motion capture. However, the aim of the present study was to use a wireless calibration-free sensor.

Sample size was small in the present study which may cause uncertainties in the interpretation of the results, and thereby future research is advised to use a greater sample size to confirm the results. Also, having the subjects perform the shooting as dry firing, with additional devices attached to their rifles, and without physical stress, may limit the generalizability of the findings to biathlon practice. The loss of recoil response, heavy breathing, high heart rate, the lack of a natural biathlon training environment, as well as the weight of the measuring devices could affect both shooting technique and performance. However, rifle movement was assessed before triggering, whereas the recoil causes movement after it. Furthermore, previous biathlon shooting studies have also used the same technique [5, 7, 8], and shooting technical parameters at rest and under physical exertion have been found to be highly related [5]. Thereafter, considering the aims of the present study and the benefits of standardized laboratory conditions for data quality, these delimitations were considered reasonable. However, the authors suggest future research to search and develop new measurement methods that allow assessing biathlon shooting technique with higher ecological validity and without interfering with their natural way of performance.

Conclusion

No associations between rifle or aiming point accelerations and shooting performance were observed. Further, rifle accelerations were not associated with aiming point accelerations in the prone posture. In the standing posture, horizontal rifle accelerations demonstrated associations with aiming point accelerations. Consequently, the results suggest that rifle and aiming point accelerations provide only very limited description of the technical level in biathlon shooting, and that accelerations of the rifle alone do not provide sufficient information for aiming point movement estimation.

Conflict of interest: Authors state no conflict of interest.

References

1. Ball K., Best R., Wrigley T. (2003) Body Sway, Aim Point Fluctuation and Performance in Rifle Shooters: Inter – and Intra-Individual Analysis. *J. Sports Sci.*, 21(7): 559–566. DOI: 10.1080/0264041031000101881.
2. Björklund G., Dzhilkibaeva N., Gallagher C., Laaksonen M.S. (2022) The Balancing Act between Skiing and Shooting–the Determinants of Success in Biathlon Pursuit and Mass Start Events. *J. Sports Sci.*, 40(1): 96–103. DOI: 10.1080/02640414.2021.1976493.
3. Björklund G., Laaksonen M.S. (2022) The Determinants of Performance in Biathlon World Cup Sprint and Individual Competitions. *Front. Sports Act. Living*, 4: 841619. DOI: 10.3389/fspor.2022.841619.
4. Ihalainen S., Kuitunen S., Mononen K., Linnamo V. (2016) Determinants of Elite-Level Air Rifle Shooting Performance. *Scand. J. Med. Sci. Sports*, 26(3): 266–274. DOI: 10.1111/sms.12440.
5. Ihalainen S., Laaksonen M.S., Kuitunen S., Leppävuori A., Mikkola J., Lindinger S.J., Linnamo V. Technical Determinants of Biathlon Standing Shooting Performance before and after Race Simulation. (2018) *Scand. J. Med. Sci. Sports*, 28(6): 1700–1707. DOI: 10.1111/sms.13072.
6. Ihalainen S., Linnamo V., Mononen K., Kuitunen S. (2016) Relation of Elite Rifle Shooters' Technique-Test Measures to Competition Performance. *Int. J. Sports Physiol. Perform.*, 11(5): 671–677. DOI: 10.1123/ijspp.2015-0211.
7. Köykkä M., Ihalainen S., Linnamo V., Ruotsalainen K., Häkkinen K., Laaksonen M.S. (2021) Aiming Strategy Affects Performance-Related Factors in Biathlon Standing Shooting. *Scand. J. Med. Sci. Sports*, 31(3): 573–585. DOI: 10.1111/sms.13864.
8. Köykkä M., Laaksonen M.S., Ihalainen S., Ruotsalainen K., Linnamo V. (2022) Performance-Determining Factors in Biathlon Prone Shooting without Physical Stress. *Scand. J. Med. Sci. Sports*, 32(2): 414–423. DOI: 10.1111/sms.14087.
9. Luchsinger H., Kocbach J., Ettema G., Sandbakk Ø. (2018) Comparison of the Effects of Performance Level and Sex on Sprint Performance in the Biathlon World Cup. *Int. J. Sports Physiol. Perform.*, 13(3): 360–366. DOI: 10.1123/ijspp.2017-0112.
10. Luchsinger H., Kocbach J., Ettema G., Sandbakk Ø. (2019) The Contribution from Cross-Country Skiing and Shooting Variables on Performance-Level and Sex Differences in Biathlon World Cup Individual Races. *Int. J. Sports Physiol. Perform.*, 14(2): 190–195. DOI: 10.1123/ijspp.2018-0134.
11. Luchsinger H., Kocbach J., Ettema G., Sandbakk Ø. (2020) Contribution from Cross-Country Skiing, Start Time and Shooting Components to the Overall and Isolated Biathlon Pursuit Race Performance. *PLoS One*, 15(9): e0239057. DOI: 10.1371/journal.pone.0239057.
12. Marković S., Dopsaj M., Umek A., Prebeg G., Kos A. (2020) The Relationship of Pistol Movement Measured by a Kinematic Sensor, Shooting Performance and Handgrip Strength. *Int. J. Perform. Anal. Sport*, 20(6): 1107–1119. DOI: 10.1080/24748668.2020.1833624.
13. Michalska J., Zając R., Szydło K., Gerasimuk D., Słomka K.J., Juras G. (2022) Biathletes Present Repeating Patterns of Postural Control to Maintain Their Balance While Shooting. *PLoS One*, 17(5): e0267105. DOI: 10.1371/journal.pone.0267105.
14. Mizell D. (2003) Using Gravity to Estimate Accelerometer Orientation. In: Azada D. (ed.) Proceedings of the Seventh IEEE International Symposium on Wearable Computers. IEEE, White Plains, New York, pp. 252–253. DOI: 10.1109/ISWC.2003.1241424.
15. Noguchi K., Gel Y.R., Brunner E., Konietschke F. (2012) NparLD: An R Software Package for the Nonparametric Analysis of Longitudinal Data in Factorial Experiments. *J. Stat. Softw.*, 50(12): 1–23. DOI: 10.18637/jss.v050.i12.
16. Ogasawara T., Fukamachi H., Aoyagi K., Kumano S., Togo H., Oka K. (2021) Archery Skill Assessment Using an Acceleration Sensor. *IEEE Trans. Hum. Mach. Syst.*, 51(3): 221–228. DOI: 10.1109/THMS.2020.3046435.
17. Ohtonen O., Heikkinen T., Hakkarainen A., Leppävuori A., Linnamo V. (2016) Online Feedback System for Athletes and Coaches. In: Hakkarainen A., Linnamo V. and Lindinger S. (eds.) Science and Nordic Skiing III. University of Jyväskylä, Jyväskylä, pp. 53–60.
18. Sadowska D., Krzepota J., Klusiewicz A. (2019) Postural Balance and Rifle Stability in a Standing Shooting Position after Specific Physical Effort in Biathletes. *J. Sports Sci.*, 37(16): 1892–1898. DOI: 10.1080/02640414.2019.1603136.
19. Sattlecker G., Buchecker M., Gressenbauer C., Müller E., Lindinger S.J. (2017) Factors Discriminating High From Low Score Performance in Biathlon Shooting. *Int. J. Sports Physiol. Perform.*, 12(3): 377–384. DOI: 10.1123/ijspp.2016-0195.

20. Sattlecker G., Buchecker M., Müller E., Lindinger S.J. (2014) Postural Balance and Rifle Stability during Standing Shooting on an Indoor Gun Range without Physical Stress in Different Groups of Biathletes. *Int. J. Sports Sci. Coach.*, 9(1): 171–184. DOI: 10.1260/1747-9541.9.1.171.
21. Tang W-T., Zhang W-Y., Huang C-C., Young M-S., Hwang I-S. (2008) Postural Tremor and Control of the Upper Limb in Air Pistol Shooters. *J. Sports Sci.*, 26(14): 1579–1587. DOI: 10.1080/02640410802287063.
22. Žák M., Struhár I., Janoušek D., Ondráček J. (2019) Dynamic Rifle Stability Is Not Influenced by Exercise Intensity in Young Biathletes. *J. Hum. Sport Exerc.*, 15(4): 762–771. DOI: 10.14198/jhse.2020.154.04.

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