**Author(s):** Ihalainen, Simo; Laaksonen, Marko S.; Kuitunen, Sami; Leppävuori, Antti; Mikkola, Jussi; Lindinger, Stefan Josef; Linnamo, Vesa

**Title:** Technical determinants of biathlon standing shooting performance before and after race simulation

**Year:** 2018

**Version:** Accepted version (Final draft)



**Please cite the original version:**

Ihalainen, S., Laaksonen, M. S., Kuitunen, S., Leppävuori, A., Mikkola, J., Lindinger, S. J., & Linnamo, V. (2018). Technical determinants of biathlon standing shooting performance before and after race simulation. Scandinavian Journal of Medicine and Science in Sports, 28(6), 1700-1707. https://doi.org/10.1111/sms.13072

MR SIMO IHALAINEN (Orcid ID : 0000-0001-8246-0526)

DR MARKO S LAAKSONEN (Orcid ID : 0000-0002-5574-8679)

Article type : Original Article

**Technical determinants of biathlon standing shooting performance before and after race simulation**

Simo Ihalainen[1,2], Marko S. Laaksonen[3], Sami Kuitunen[1], Antti Leppävuori[2,4], Jussi Mikkola[1], Stefan Josef Lindinger[5] and Vesa Linnamo[2]

[1] KIHU – Research Institute for Olympic Sports, Jyväskylä, Finland

[2] Biology of Physical Activity, Faculty of Sport and Health Sciences, University of Jyväskylä, Jyväskylä, Finland

[3] Department of Health Sciences, Swedish Winter Sports Research Centre, Mid Sweden University, Östersund, Sweden

[4] Finnish Biathlon Association, Finland

[5] Department of Sport Science and Kinesiology, University of Salzburg, Salzburg, Austria

**Running title:** Biathlon standing shooting performance

This article has been accepted for publication and undergone full peer review but has not been through the copyediting, typesetting, pagination and proofreading process, which may lead to differences between this version and the Version of Record. Please cite this article as doi: 10.1111/sms.13072

**Corresponding author:**

Simo Ihalainen, M.Sc.

KIHU - Research Institute for Olympic Sports

Address: Rautpohjankatu 6, 40700 Jyväskylä, Finland

Telephone: +358 50 338 9519

Fax: +358 20 781 1501

E-mail: simo.ihalainen@kihu.fi

**Abstract**

The aim of this study was to identify performance determining factors in biathlon standing shooting in rest and after intense exercise. Eight Finnish national and nine junior team biathletes participated in the study. Participants fired 40 resting shots (REST) and 2*5 competition simulation shots (LOAD) after 5 min of roller skiing at 95% of peak heart rate. Hit percentage, aiming point trajectory and postural balance were measured from each shot. Cleanness of triggering (ATV, movement of the aiming point 0-0.2 s before the shot) and vertical stability of hold (DevY) were the most important components affecting shooting performance both in REST (DevY, $R=-0.61$, $p<0.01$; ATV, $R=-0.65$, $p<0.01$) and in LOAD (DevY, $R=-0.50$, $p<0.05$; ATV, $R=-0.77$, $p<0.001$). Postural balance, especially in shooting direction, was related to DevY and ATV. Stability of hold in horizontal ($F(1,15)=7.025$, $p<0.05$) and vertical ($F(1,15)=21.285$, $p<0.001$) directions, aiming accuracy ($F(1,15)=9.060$, $p<0.01$), and cleanness of triggering ($F(1,15)=59.584$, $p<0.001$) decreased from REST to LOAD, accompanied by a decrease in postural balance. National and junior team biathletes differed only in hit percentage in REST (92±8 % vs. 81±8 %, $p<0.05$) and left leg postural balance in shooting direction in LOAD (0.31±0.18 mm vs. 0.52±0.20 mm, $p<0.05$), and the intense exercise affected the shooting technical components similarly in both national and junior groups. Biathletes should focus on cleanness of triggering and vertical stability of hold in order to improve biathlon standing shooting performance. More stable postural balance in shooting direction could help to improve these shooting technical components.

**Key Words**: performance, biomechanics, technique, optoelectronic measures, postural balance

## Introduction

Stability of hold and postural balance have been identified as performance determining factors in biathlon standing shooting. Stability of hold affects biathlon standing shooting performance both in rest[1] and after intense exercise[2] so that the smaller the movement of the rifle is, the better the shooting performance is. It has been shown that increasing exercise intensity decreases both stability of hold and shooting performance[2]. On the other hand, a constant exercise intensity at 90 % of maximal heart rate did not decrease shooting results in junior level biathletes[3]. Elite level biathletes have shown better stability of hold compared to youth level biathletes in standing shooting without physical stress, which contributed to the observed shooting performance difference between the different age groups[1]. Two training intervention studies in biathlon shooting have also shown that specific shooting training can improve stability of hold[4] and biathlon standing shooting performance both in rest and after intense exercise[5].

In order to achieve a stable hold in biathlon standing shooting, good postural balance is required. The stability of hold in biathlon standing shooting has been related to postural balance both in rest and after intense exercise[1,6]. The same link between stability of hold and postural balance has also been reported in air rifle shooting[7-10]. Elite and junior level athletes have been shown to differ in postural balance in standing shooting without physical stress, which as in the case of stability of hold, contributed to the observed shooting performance difference between the groups[1]. Fatigue has been demonstrated to decrease postural balance in shooting posture[11] and in normal quiet standing[12]. Both aerobic, anaerobic[13], as well as local muscular fatigue decrease postural balance[14]. All these factors are likely to influence and decrease postural balance in biathlon shooting.

Even though the previously published studies show a link between biathlon shooting performance, stability of hold and postural balance, the correlations reported have been low or moderate at best. This suggests that other factors contribute to the biathlon standing shooting performance. Aiming accuracy, cleanness of triggering (the cumulative distance travelled by the aiming point during the last 0.2 s before the shot), and timing of triggering have been shown to affect shooting performance in air rifle[7,8], running target[15] and air pistol[16] shooting. To the best of our knowledge, these shooting technical components have not been studied in biathlon as possible shooting performance determining factors. Therefore, the aim of this study was to identify performance determining factors in biathlon standing shooting. Based on the results in previous studies in biathlon, air rifle, running target, and air pistol shooting[1,6-8,10,15,16], the first hypothesis was that in addition to stability of hold and postural balance, aiming accuracy, cleanness of triggering, and timing of triggering would be important performance determining factors in biathlon standing shooting technique. The second objective was to analyze, how the technical skill level in these factors changes from rest to intense exercise. Based on the previous studies on the effect of fatigue on postural balance[11-14], it was hypothesized that postural balance and stability of hold would be compromised by the intense exercise. The third objective was to investigate how the high-level biathletes differ from lower level athletes in these shooting technical components, and whether the intense exercise affects the groups differently. Based on the results in biathlon standing shooting without physical stress[1], it was hypothesized that the high-level biathletes would demonstrate more stable hold and postural balance also after intense exercise.

## Materials and methods

### *Participants*

Eight Finnish national team (NAT, age 25.5 ± 2.7 years, race simulation velocity 14.5 ± 1.5 km/h) and 9 junior team (JUN, age 17.9 ± 1.6 years, race simulation velocity 13.9 ± 1.7 km/h) biathletes participated in the study. NAT group consisted of 4 males and 4 females, and JUN group consisted of 7 males and 2 females. All participants were right-handed and shot from the same side. The subjects were informed about the possible risks of all study procedures before providing a written informed consent. The study was conducted according to the declaration of Helsinki, and ethical approval was granted by the University of Jyväskylä Ethical Committee.

### *Experimental task*

Testing protocol is illustrated in figure 1. Participants fired 4 standing shooting series of 5 shots at rest. After the shooting task, a 10-minute roller skiing warm-up was performed on a large motor-driven treadmill OJK-2 (Telineyhtymä, Kotka, Finland), followed by a maximal incremental roller skiing test using V2 skating technique. In this test protocol inclination was maintained constant at 3 degrees, whereas velocity increased 1.5 km/h with every three-minute stage from the initial velocities of 6.5 km/h for junior women, 8 km/h for junior men and senior women and 9.5 km/h for senior men until exhaustion. At the end of every stage, the treadmill was stopped for 15 to 20 seconds for blood lactate sample collection. This small timeframe was included in the three-minute stage. The maximal test was followed by a 5-minute passive recovery period and a 10-minute active skiing recovery period. Both the warm-up and active recovery were performed at maximal incremental test starting velocity.

After the recovery period, a second resting shooting set consisting of 4 standing shooting series of 5 shots was performed. After the second shooting set a competition simulation was performed. Competition simulation consisted of 5 minutes of roller skiing at the velocity of 95 % of peak heart rate, followed by one standing shooting series of five shots. The 5-minute skiing followed by the shooting task was performed for two times. The skiing velocity at 95 % of peak heart rate was determined from the heart rate versus velocity curve of the incremental test by linear interpolation from the two consecutive stage velocities which were above and below the 95% of the peak heart rate value. Shooting task started 30-60 s after the cessation of the 5-minute skiing task.

Heart rate monitor Polar V800 (Polar Electro Oy, Kempele, Finland) was used for heart rate monitoring during the entire test protocol. Time point markers were manually added to the heart rate data in order to recognize all shooting series and maximal and competition simulation skiing tasks. In maximal incremental test peak heart rate (HRpeak) was determined as the highest mean value of a continuous 30 s time period. In addition, submaximal heart rate values used for analysis were means from the last 30 s at each stage. Blood samples were collected and lactate concentration was analyzed with Biosen C-Line (EKF-diagnostic GmbH, Barleben/Magdeburg, Germany) at rest, after each load in the incremental test, one minute after the cessation of the incremental test, before the second resting shooting series, and after the both competition simulation shooting tasks.

Shooting score and aiming point trajectory variables were measured with Noptel ST 2000 (Noptel Inc., Oulu, Finland) shooting system. An optical measuring unit weighting 80 g was attached to the rifle barrel. All participants used their own competition rifles in the shooting tasks, and the participants kept the skies on during the shooting task. Shooting was carried out indoors with 10 m shooting distance into a scaled biathlon target, equipped with a reflective surface. Aiming point location on the target was measured and stored at 100 Hz. Before the first measured shooting series, gun zeroing was performed in a seated position with stable support under the rifle stock. Participants were allowed to shoot 3-5 standing warm-up series of 5 shots before starting the measurements. The gun zeroing was checked and adjusted during the warm-up series. The athletes were also instructed to shoot at their normal competition rhythm and technique. Hit point location and 5 shooting technical aiming point trajectory variables were analyzed from each shot (table 1).

Postural balance during the shooting task was measured with two AMTI (Advanced Mechanical Technology Inc., Watertown, USA) force plates (one force plate under each ski). The force plate data was collected at 1000 Hz synchronously with a shot moment trigger signal from a microphone into a custom-made software. Center of pressure (COP) location under both feet was calculated from both force plates separately, and also a combined whole-body COP location based on the both force plate data was calculated. COP coordinates were filtered with a 4-order zero-phase lag low pass filter at 10 Hz cut-off frequency, as recommended by Ruhe et al.[17]. Postural balance variables analyzed from the force and COP data are described in table 1.

*Statistical methods*

Repeated measures T-test was used to compare the first 20 resting shots to the 20 resting shots fired after the incremental maximal roller skiing test. Repeated measures T-test was also used to compare the first LOAD series to the second LOAD series. As no statistically significant differences were found in the Hit%, the mean values of all 40 resting shots (REST) and mean values of all 10 shots fired after the competition simulation (LOAD) were used for subsequent analysis. Independent samples Mann-Whitney U test showed that in NAT and JUN groups, there were no statistically significant differences between the genders in Hit% either in REST or in LOAD, so the test results for men and women were pooled in NAT group and the test results for boys and girls were pooled in JUN group. Shapiro-Wilk's test was used to test the normality of the data. Only one stability of hold variable (DevY) violated the normality assumption, and a natural logarithm transformation was used for this variable to meet the requirements of normal distribution.

Independent samples t-test was used to investigate group differences between NAT and JUN level athletes in relative heart rates during the competition simulation roller skiing, in relative heart rates before and after the LOAD shooting, and in blood lactate after the LOAD shooting. A two-way repeated measures ANOVA (shooting condition REST vs. LOAD, expertise level NAT vs. JUN) with Huynh-Feldt correction was used to analyze the effect of intense exercise and expertise level on shooting performance and shooting technical variables. Post hoc analysis was performed with Bonferroni correction. Two-tailed Pearson correlation coefficients were computed to examine the relationship between the Hit% and all aiming point trajectory and postural balance variables in REST and LOAD. Pearson correlation coefficients were calculated in the whole subject group and in NAT and JUN groups. Pearson correlation coefficients were also calculated between the absolute change in Hit% from REST to LOAD and the absolute change in all aiming point trajectory and postural balance variables from REST to LOAD. Level of statistical significance was set at 0.05. Statistical analysis was conducted with IBM SPSS statistics software (IBM Co., Armonk, New York, USA) (version 22.0).

**Results**

The NAT and JUN groups demonstrated similar physiological loadings during the competition simulation and LOAD shooting. There were no differences between NAT and JUN groups in relative heart rates during the competition simulation roller skiing (96 ± 2 % vs. 97 ± 1 %), in relative heart rates before LOAD shooting (87 ± 5 % vs. 90 ± 2 %), in relative heart rates after LOAD shooting (79 ± 5 % vs. 83 ± 6 %), or blood lactate after LOAD shooting (5.2 ± 1.9 mmol/l vs. 6.7 ± 1.1 mmol/l).

The group means ± SD are presented in table 2. A significant main effect of shooting condition was observed for Hit% $F(1,15)=8.557$, $p<0.01$, shooting time $F(1,15)=5.177$, $p<0.05$), horizontal stability of hold DevX $F(1,15)=7.025$, $p<0.05$, vertical stability of hold DevY $F(1,15)=21.285$, $p<0.001$, aiming accuracy $COG_{hit}$ $F(1,15)=9.060$, $p<0.01$, cleanness of triggering ATV $F(1,15)=59.584$, $p<0.001$, timing of triggering TIRE $F(1,15)=7.304$, $p<0.05$), postural balance variables sdY $F(1,15)=47.470$, $p<0.001$, sdX_L $F(1,15)=7.235$, $p<0.05$, sdX_R $F(1,15)=7.806$, $p<0.05$, sdY_L $F(1,15)=6.401$, $p<0.05$ and sdY_R $F(1,15)=17.275$, $p<0.001$, vertical force variable F_R $F(1,15)=11.683$, $p<0.01$ and force distribution $F(1,15)=8.389$, $p<0.05$. A significant main effect of expertise level was observed for Hit% $F(1,15)=5.478$, $p<0.05$ and sdY_L $F(1,15)=4.924$, $p<0.05$. An interaction effect of shooting condition and expertise level was found only in shooting direction postural balance sdY $F(1,15)=6.100$, $p<0.05$.

*Relations between hit percentage and shooting technical components*

In the whole subject group, vertical holding ability and cleanness of triggering correlated with the Hit% both in REST (DevY, R=-0.61, p<0.01; ATV, R=-0.65, p<0.01) and in LOAD (DevY, R=-0.50, p<0.05; ATV, R=-0.77, p<0.001). The absolute change in ATV from REST to LOAD also correlated with the absolute change in Hit% (R=-0.49, p<0.05). Shooting direction postural balance of the right leg (sdY_R) was related to the Hit% in REST (R=-0.54, p<0.05) and in LOAD (R=-0.70, p<0.01).

When analyzing the NAT and JUN groups separately, ATV correlated with Hit% in LOAD both in NAT and JUN groups (Fig. 2). In REST, ATV correlated with the Hit% in JUN (R=-0.91, p<0.001) but not in the NAT group. The absolute change in Hit% from REST to LOAD correlated with the absolute change in ATV (R=-0.77, p<0.05) and absolute change in DevY (R=-0.72, p<0.05) in the NAT group but not in the JUN group.

*Inter-relations between shooting technical components*

All variables measured in REST correlated with the corresponding variable measured in LOAD except Hit%, sdX and sdX_R. Statistically significant correlations between shooting technical components are presented in table 3.

**Discussion**

The purpose of this study was to identify performance determining factors in standing biathlon shooting. The second objective was to analyze, how the technical skill level in these factors changes from rest to intense exercise. The third objective was to investigate how the high-level biathletes differ from lower level athletes in these shooting technical components. The results of this study showed that cleanness of triggering, vertical holding ability and postural balance were related to shooting performance in rest and after intense exercise. Contrary to the hypotheses, aiming accuracy and timing of triggering did not show a relation to shooting performance. Shooting performance, postural balance and all shooting technical components except timing of triggering decreased from rest to load shooting condition. Cleanness of triggering decreased from rest to load shooting condition in both national and junior level biathletes, and this decrease was related to the decrease in shooting performance. Postural balance was related to shooting performance both directly, and indirectly through more stable hold and cleaner triggering. National and junior level athletes differed only in hit percentage in rest and left leg postural balance in shooting direction after intense exercise. The intense exercise affected the shooting technical components similarly in both national and junior level groups.

The results of the present study confirm the results of the previous studies[1,2,6] and the first study hypothesis regarding stability of hold and postural balance as important shooting technical components in biathlon standing shooting. Stability of hold in vertical direction and postural balance in shooting direction were related to the hit percentage both in rest and after intense exercise.

Sattlecker et al.[1] found similar relations between the stability of hold, postural balance, and shooting accuracy in rest. In a race simulation study where the standing shooting task was measured after strenuous exercise, stability of hold was shown to be related to postural balance, but not to the shooting performance[6]. The results of the present study showed a relation between the stability of hold and shooting performance in biathlon standing shooting also after intense exercise. The differences in the results of these two studies could be related to the exercise protocol (constant 3° uphill vs. normal biathlon competition track) or the shooting conditions (simulated shooting into a biathlon target vs. live shooting into a single target) used in the studies. The constant 3° uphill at 95% HRpeak differs from the normal biathlon competition with varying terrain, heart rate profile, and the pressure of competing against other athletes. Although fatigue aspect was achieved, these can be considered as limitations of the present study and thus further studies should focus on making the race simulation even more realistic.

The important stability of hold and postural balance components identified in the present study differed from the previous studies in biathlon standing shooting[1,6]. In the present study the stability of hold in vertical direction was related to biathlon standing shooting performance both in rest and after intense exercise, whereas previously the stability of hold in horizontal direction has been related to standing shooting performance in rest[1]. This difference could be related to the used measuring devices or chosen stability of hold variables. Sattlecker et al.[1] used motion analysis and range of motion to measure and quantify stability of hold, whereas the actual aiming point trajectory on the target was measured in the present study and standard deviation was used as a measure of the stability of hold. In the biathlon standing shooting after intense exercise Sattlecker et al.[6] found a tendency in the postural balance in cross shooting direction to discriminate between groups of high and low performing biathletes. In the present study the postural balance in shooting direction was related to the shooting performance. This difference could be related to the different exercise protocols preceding the shooting task, which in the previous study was about 15 minutes longer compared to the present study. The longer exercise task could have increased the influence of local muscular fatigue on postural balance especially in the antero-posterior direction[18], which might have been missed in the present study.

The results of the present study supported the hypothesis that cleanness of triggering is an important aspect of biathlon standing shooting technique. Cleanness of triggering was related to the hit percentage both in the whole subject group and in the national and junior team biathletes. Out of all the measured variables, cleanness of triggering had the strongest relation to shooting performance. The decrease in cleanness of triggering from resting shooting to intense exercise was also related to the decrease in hit percentage from rest to exercise. Cleanness of triggering has been shown to be related to air rifle[7,8] and running target[15] shooting performance, but has not been studied previously as a performance determining factor in biathlon standing shooting. One possible explanatory reason for the technical skill level of the biathletes' cleanness of triggering is the postural balance in shooting direction in the back (right) leg, since this variable was related to cleanness of triggering. Based on the measurements in this study, it cannot be assessed whether the postural stability affects cleanness of triggering, or whether the movement of the aiming point during the triggering phase affects the right leg postural balance. Furthermore, the cleanness of triggering variable used in the present study is an indirect measure of the triggering action, and more direct trigger force measurements could further explain the underlying reasons behind the technical skill level in cleanness of triggering.

Contrary to our first study hypothesis, aiming accuracy and timing of triggering did not show statistically significant correlations to the hit percentage. Based on visual inspection of the aiming point trajectory data, the biathletes seemed to use two different shooting strategies, holding (hold the aiming point steady in the center of target before firing the shot) or timing of triggering (fire the gun as soon as the aiming point reaches the target) strategy. These different shooting strategies have been discussed previously in air rifle[19] but not in biathlon shooting. For the athletes using the timing of triggering shooting strategy, the 0.6 s time period used in the present study to calculate aiming accuracy did not reflect the actual aiming accuracy, since these shooters were moving towards the center of target for the 0.6 s period and did not even try to aim at the center of target for the whole time period. Aiming accuracy variable used in the present study could be an important variable for the shooters using the holding strategy as in air rifle[7,8,10] and air pistol[16] shooting, but this aspect of the biathlon shooting technique is a topic for future studies.

Timing of triggering variable showed no significant relation to the hit percentage. The same result was shown previously in air rifle shooting, where timing of triggering did not correlate with the shooting scores. However, in air rifle shooting multiple regression analysis showed that timing of triggering accounted for 9 % of the variation in shooting score, when the technical skill level in stability of hold, aiming accuracy and cleanness of triggering were taken in to account.[7] The number of tests conducted in this study do not provide the possibility to use multiple regression analysis reliably and test whether timing of triggering affects shooting performance in biathlon similarly to air rifle shooting. On the other hand, both the timing of triggering and aiming accuracy measures have been identified as performance determining factors in shooting events, where unlike in biathlon shooting, the shooting time is not a limiting factor. The differences in the important shooting technical components between biathlon and other shooting disciplines could just as well be related to the different nature of these shooting tasks and the time constraints present in biathlon shooting.

The results of the present study support the second study hypothesis and showed that hit percentage, postural balance and the technical skill level of all aiming point trajectory variables except timing of triggering decreased from rest to intense exercise. This finding is in line with the study by Hoffman et al.[2], who showed that increasing exercise intensity decreased hit percentage and stability of hold. Contrary to all other shooting technical measures, timing of triggering improved from rest to intense exercise. Timing of triggering was related to the technical skill level in holding ability and aiming accuracy, and the improvement in timing of triggering from rest to load was likely caused by the decrease in holding ability and aiming accuracy. In air rifle shooting a similar non-significant increase was seen in timing of triggering in competition situation compared to training situation, when the stability of hold and aiming accuracy decreased from training to competition[10].

The athletes have to rely more on the timing of triggering when holding ability and aiming accuracy decreases, and the timing of triggering is easier to time correctly when the movement of the aiming point is larger. All other shooting technical components (stability of hold, aiming accuracy and cleanness of triggering) were related to postural balance. Especially postural balance in shooting direction was related to these shooting technical components. It is likely that the decrease observed in stability of hold, aiming accuracy and cleanness of triggering from rest to intense exercise was caused by the decrease in postural balance. In air rifle shooting, a similar relation between the change in shooting direction postural balance and the change in stability of hold was reported[10].

Previously the effect of fatigue on postural balance has been related to increased cardiac and respiratory movements, decreased muscle coordination and force, and compromised sensory information[12,14,20,21]. From a practical point of view, the biathletes usually hold their breath during the aiming and triggering phase, which means that the observed decrease in postural balance from rest to intense exercise is likely caused by other mechanisms, such as higher cardiovascular load, than the increased breathing activity. The microvibrations caused by the heart rate manifest more strongly in the vertical force component[20], so this could explain why the effect of intense exercise was more evident in the shooting direction (medio-lateral) postural balance as well as the importance of vertical stability of hold.

The results of the present study did not support the third study hypothesis that the high-level biathletes would demonstrate more stable hold and postural balance after intense exercise compared to lower level athletes. National team athletes demonstrated better test results only in hit percentage in rest and left leg postural balance in shooting direction in exercise compared to junior team athletes. Intense exercise affected only shooting direction postural balance differently between the groups, so that the postural balance declined more in the national team. Previously Sattlecker et al.[1] showed that in shooting without physical stress, national level athletes had more stable hold and postural balance compared to junior athletes. The differences in the results of these studies could be related to the smaller sample size measured in the present study, the smaller age difference between the national and junior teams in the present study, and/or different performance level in the national or junior groups measured in these studies (Finnish vs. Austrian biathlon teams). The small number of significant differences between the national and junior team athletes can also be explained partly by the wide variation in the test results, and partly by the group division used in the present study. The division between the national and junior team is not based on shooting performance alone so much as on the combined performance level in shooting and cross-country skiing.

**Perspective**

The results of the present study have practical significance to the athletes and coaches as well as sports scientists. Firstly, cleanness of triggering and vertical holding ability seem to be key factors in biathlon standing shooting performance, and athletes should focus on minimizing the movement of the aiming point in these phases. In addition to stability of hold and postural balance measures, cleanness of triggering should be included in biathlon shooting studies in order to acquire more comprehensive description about the shooting task. Secondly, the postural balance especially in shooting direction was related to these shooting technical components, and the athletes might be able to reduce the movement of the aiming point in triggering phase and in the holding phase by improving their postural stability. And lastly, the correlation between the measured variables in resting and exercised states implies that the biathlon standing shooting skill level can be improved by training in both resting and exercised states, at least when the resting situation training is carried out in the same technique and rhythm as in the exercised state.

**Acknowledgements:** The authors would like to acknowledge Keijo Ruotsalainen, Miika Köykkä, Olli Ohtonen, Christoph Gressenbauer and Janina Edfelder for their valuable assistance in data collection and Finnish biathlon team coaches and athletes for their participation in the measurements.

**Disclosures:**

No conflicts of interest were declared by the authors. This work was funded by International Biathlon Union (IBU) developmental grant to Finnish Biathlon Association.

**References**

1. Sattlecker G, Buchecker M, Müller E, Lindinger SJ. Postural balance and rifle stability during standing shooting on an indoor gun range without physical stress in different groups of biathletes. *International journal of Sports Science & Coaching*. 2014;9(1):171-184.

2. Hoffman MD, Gilson PM, Westenburg TM, Spencer WA. Biathlon shooting performance after exercise of different intensities. *Int J Sports Med*. 1992;13(3):270-273.

3. Gallicchio G, Finkenzeller T, Sattlecker G, Lindinger S, Hoedlmoser K. Shooting under cardiovascular load: Electroencephalographic activity in preparation for biathlon shooting. *International Journal of Psychophysiology*. 2016;109(Supplement C):92-99. doi: https://doi.org/10.1016/j.ijpsycho.2016.09.004.

4. Groslambert A, Candau R, Grappe F, Dugue B, Rouillon JD. Effects of autogenic and imagery training on the shooting performance in biathlon. *Res Q Exerc Sport*. 2003;74(3):337-341.

5. Laaksonen MS, Ainegren M, Lisspers J. Evidence of improved shooting precision in biathlon after 10 weeks of combined relaxation and specific shooting training. *Cogn Behav Ther*. 2011;40(4):237-250.

6. Sattlecker G, Buchecker M, Gressenbauer C, Müller E, Lindinger SJ. Factors discriminating high from low score performance in biathlon shooting. *International Journal of Sports Physiology and Performance*. 2016:1-23.

7. Ihalainen S, Kuitunen S, Mononen K, Linnamo V. Determinants of elite-level air rifle shooting performance. *Scand J Med Sci Sports*. 2016;26(3):266-274.

8. Ihalainen S, Linnamo V, Mononen K, Kuitunen S. Relation of elite rifle shooters' technique-test measures to competition performance. *Int J Sports Physiol Perform.* 2016;11(5):671-677.

9. Ball KA, Best RJ, Wrigley TV. Body sway, aim point fluctuation and performance in rifle shooters: Inter- and intra-individual analysis. *J Sports Sci*. 2003;21(7):559-566.

10. Ihalainen S, Mononen K, Linnamo V, Kuitunen S. Which technical factors explain competition performance in air rifle shooting? *International journal of Sports Science & Coaching*. 2017(Epub ahead of print).

11. Bermejo JL, García-Massó X, Paillard T, Noé F. Fatigue does not conjointly alter postural and cognitive performance when standing in a shooting position under dual-task conditions. *J Sports Sci*. 2017:1-7.

12. Paillard T. Effects of general and local fatigue on postural control: A review. *Neuroscience & Biobehavioral Reviews*. 2012;36(1):162-176. doi: http://dx.doi.org/10.1016/j.neubiorev.2011.05.009.

13. Fox ZG, Mihalik JP, Blackburn JT, Battaglini CL, Guskiewicz KM. Return of postural control to baseline after anaerobic and aerobic exercise protocols. *J Athl Train*. 2008;43(5):456-463.

14. Madigan ML, Davidson BS, Nussbaum MA. Postural sway and joint kinematics during quiet standing are affected by lumbar extensor fatigue. *Human Movement Science*. 2006;25(6):788-799.

15. Mononen K, Viitasalo JT, Era P, Konttinen N. Optoelectronic measures in the analysis of running target shooting. *Scand J Med Sci Sports*. 2003;13(3):200-207.

16. Hawkins R. Identifying mechanic measures that best predict air-pistol shooting performance. *International Journal of Performance Analysis in Sport*. 2011;11(3):499-509.

17. Ruhe A, Fejer R, Walker B. The test-retest reliability of centre of pressure measures in bipedal static task conditions--a systematic review of the literature. *Gait Posture*. 2010;32(4):436-445.

18. Vuillerme N, Burdet C, Isableu B, Demetz S. The magnitude of the effect of calf muscles fatigue on postural control during bipedal quiet standing with vision depends on the eye–visual target distance. *Gait & Posture*. 2006;24(2):169-172. doi: https://doi.org/10.1016/j.gaitpost.2005.07.011.

19. Zatsiorsky VM, Aktov AV. Biomechanics of highly precise movements: The aiming process in air rifle shooting. *J Biomech*. 1990;23 Suppl 1:35-41.

20. Conforto S, Schmid M, Camomilla V, D'Alessio T, Cappozzo A. Hemodynamics as a possible internal mechanical disturbance to balance. *Gait Posture*. 2001;14(1):28-35.

21. Sturm R, Nigg B, Koller EA. The impact of cardiac activity on triaxially recorded endogenous microvibrations of the body. *Eur J Appl Physiol Occup Physiol*. 1980;44(1):83-96.

**Tables**

Table 1. Variables describing shooting performance, shooting technique and postural balance.

| Component | Variable (unit) | Description |
|---|---|---|
| Overall performance | Hit% (%) | Percentage of hit targets |
| Shooting time | Shooting time (s) | Total shooting time from first to last shot in a five-shot series |
| Stability of hold | DevX (mm)<br>DevY (mm) | Horizontal (DevX) and vertical (DevY) standard deviations of the location of the aiming point during the last 0.6 s before the shot. Smaller DevX and DevY values indicate better holding ability. |
| Aiming accuracy | $COG_{hit}$ (mm) | Mean distance of the aiming point from the center of target during the last 0.6 s. Smaller $COG_{hit}$ values indicate better aiming accuracy. |
| Cleanness of triggering | ATV (mm) | Cumulative distance travelled by the aiming point during the last 0.2 s. Smaller ATV values indicate better triggering. |
| Timing of triggering | TIRE (index) | Time period when the mean location of the aiming point is closest to the centre of target: 0-0.2 s before the shot TIRE = 3, 0.2-0.4 s before the shot TIRE = 2, 0.4-0.6 s before the shot TIRE = 1. Greater TIRE values indicate better timing of triggering. |
| Postural balance | sdX (mm)<br>sdY (mm) | Standard deviation of the whole-body COP location perpendicular to shooting direction (sdX) and in shooting direction (sdY) during the last 0.6 s before the shot. Smaller values indicate more stable postural balance. |
| | sdX_L (mm)<br>sdX_R (mm) | Standard deviation of the left (sdX_L) and right (sdX_R) leg COP location perpendicular to shooting direction during the last 0.6 s. |
| | sdY_L (mm)<br>sdY_R (mm) | Standard deviation of the left (sdY_L) and right (sdY_R) leg COP location in shooting direction during the last 0.6 s. |
| Force | F_L (N)<br>F_R (N) | Mean vertical left (F_L) and right (F_R) leg force during the last 0.6 s. |
| | Force distribution (%) | Percentage of force on the left leg, F_L/(F_L + F_R)*100 |

Table 2. Hit percentage, aiming point trajectory variables and postural balance in REST and LOAD conditions.

| | NAT | | JUN | |
|---|---|---|---|---|
| | REST | LOAD | REST | LOAD |
| Hit% | 92 ± 8† | 80 ± 13 | 81 ± 8* | 68 ± 20 |
| Shooting time | 12.0 ± 2.1 | 13.2 ± 3.3 | 12.9 ± 3.4 | 14.5 ± 4.0 |
| DevX | 23.2 ± 8.0* | 26.7 ± 4.8 | 24.2 ± 5.6 | 26.4 ± 5.1 |
| DevY | 18.5 ± 5.1* | 21.5 ± 4.7 | 22.6 ± 7.2** | 28.1 ± 8.7 |
| $COG_{hit}$ | 37.1 ± 17.3 | 44.0 ± 19.7 | 42.1 ± 13.1* | 49.5 ± 16.7 |
| ATV | 53.9 ± 6.5*** | 70.7 ± 7.2 | 60.5 ± 11.5*** | 77.4 ± 13.0 |
| TIRE | 2.5 ± 0.3 | 2.6 ± 0.3 | 2.5 ± 0.1** | 2.7 ± 0.2 |
| sdX | 0.70 ± 0.13 | 0.73 ± 0.15 | 0.74 ± 0.20* | 0.82 ± 0.18 |
| sdY | 0.65 ± 0.14*** | 0.91 ± 0.21 | 0.74 ± 0.20** | 0.86 ± 0.24 |
| sdX_L | 0.73 ± 0.18 | 0.78 ± 0.25 | 0.73 ± 0.22** | 0.92 ± 0.21 |
| sdX_R | 0.73 ± 0.19 | 0.89 ± 0.33 | 0.69 ± 0.20* | 0.9 ± 0.24 |
| sdY_L | 0.27 ± 0.17 | 0.31 ± 0.18† | 0.43 ± 0.17* | 0.52 ± 0.20 |
| sdY_R | 0.21 ± 0.08 | 0.26 ± 0.05 | 0.24 ± 0.10** | 0.34 ± 0.12 |
| F_L | 425 ± 68 | 429 ± 68 | 454 ± 64 | 457 ± 67 |
| F_R | 297 ± 42* | 290 ± 40 | 321 ± 54* | 314 ± 49 |
| Force distribution | 59 ± 5* | 60 ± 5 | 59 ± 5 | 59 ± 5 |

Statistically significant difference between REST and LOAD, *$p<0.05$, **$p<0.01$, ***$p<0.001$

Statistically significant difference between NAT and JUN, †<0.05

Table 3. Two-tailed Pearson's correlation coefficient R values between shooting technical components in REST and LOAD.

| | REST | | LOAD | |
|---|---|---|---|---|
| Component 1 | Component 2 | R | Component 2 | R |
| DevY | sdY_R | 0.63** | sdY_R | 0.58* |
| ATV | sdY_R | 0.77*** | sdY_R | 0.67** |
| $COG_{hit}$ | DevY | 0.52* | DevY | 0.69** |
| | DevX | 0.70** | sdX | 0.50* |
| | sdY | 0.66** | sdY | 0.54* |
| TIRE | DevX | 0.54* | DevY | 0.55* |
| | $COG_{hit}$ | 0.84*** | $COG_{hit}$ | 0.75*** |
| ΔTIRE | | | ΔDevY | 0.53* |
| | | | $\Delta COG_{hit}$ | 0.55* |

*p<0.05, **p<0.01, ***p<0.001, statistically significant correlation

Δ, correlation between the absolute change from REST to LOAD

**Figure legends**

Figure 1. Test protocol.

Figure 2. Relation between hit percentage and cleanness of triggering (ATV) in shooting after intense exercise (LOAD).

**Figures**

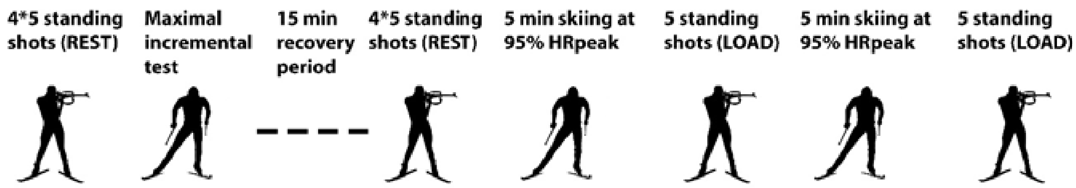


Figure 1. Test protocol.

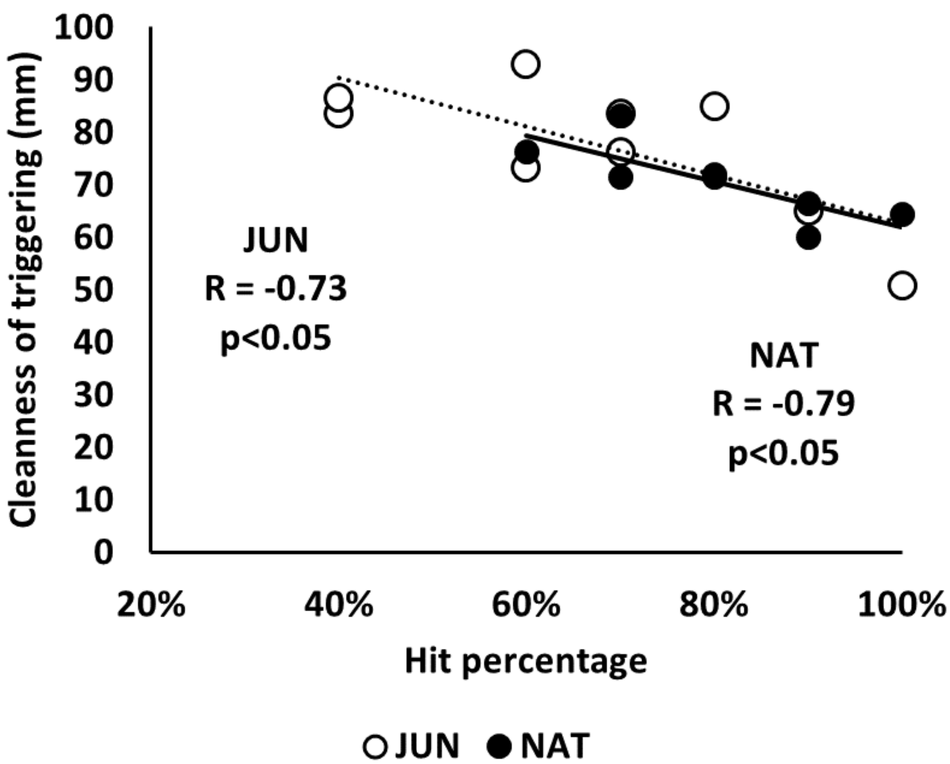


Figure 2. Relation between hit percentage and cleanness of triggering (ATV) in shooting after intense exercise (LOAD).