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270

TECHNICAL DETERMINANTS OF COMPETITIVE RIFLE SHOOTING PERFORMANCE

SIMO IHALAINEN

UNIVERSITY OF JYVÄSKYLÄ

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Editors
Taija Juutinen
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ABSTRACT

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The purpose of this thesis was to identify technical determinants of elite level air rifle and biathlon standing shooting performance and investigate how these technical determinants are affected by training, competition situation, or intense exercise. Forty international and national level air rifle shooters and 17 biathletes participated in the studies. In air rifle shooting, shooting performance, aiming point trajectory, and postural balance were measured from each shot in a simulated competition series in the training situation and in the actual competition situation. The shooters' competition results were collected from each measured season. In biathlon, the same shooting technical variables were measured in rest and in shooting after competition simulation roller skiing task. Horizontal stability of hold, aiming accuracy, timing of triggering, and cleanness of triggering were the most important technical determinants of elite level air rifle shooting performance, explaining 81% of the variance in shooting score. Postural balance was related to air rifle shooting performance directly, and indirectly through more stable hold and cleaner triggering. Shooting technique test measures were related to the competition results achieved during the season. Long term shooting training improved stability of hold, aiming accuracy, cleanness of triggering, and postural balance. All these aspects of shooting technique deteriorated in competition compared to training situation. In biathlon standing shooting, vertical stability of hold and cleanness of triggering were related to shooting performance, and postural balance affected both of these components. Intense exercise decreased biathlon standing shooting performance and all shooting technical components except timing of triggering. The decrease in shooting technical components was related to the decrease in postural balance. The elite level shooters' reference values presented in the thesis can be used by athletes and coaches in pursuing superior rifle shooting technique and in assessing shooters' technical strengths and weaknesses. The results also demonstrated the importance of psychological skills, since all the progress made through technique training could be lost in the competition situation. Postural balance is one clear aspect which affects the important shooting technical components both in air rifle and biathlon shooting.

Keywords: shooting technique, postural balance, stability of hold, aiming accuracy, cleanness of triggering, timing of triggering, competition performance

Author's address Simo Ihalainen
KIHU – Research Institute for Olympic Sports
Rautpohjankatu 6, 40700 Jyväskylä, Finland
simo.ihalainen@kihu.fi

Supervisors Professor Vesa Linnamo, PhD
Biology of Physical Activity
Faculty of Sport and Health Sciences
University of Jyväskylä, Finland

Dr. Sami Kuitunen, PhD
Football Performance & Science Department
Aspire Academy, Qatar

Reviewers Professor Joan Vickers, PhD
Faculty of Kinesiology
University of Calgary, Canada

Dr. Joe Causer, PhD
Research Institute for Sport and Exercise Sciences
Liverpool John Moores University, United Kingdom

Opponent Professor Øyvind Sandbakk, PhD
Department of Neuromedicine and Movement Science
Faculty of Medicine and Health Sciences
Norwegian University of Science and Technology, Norway

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Jyväskylä 23.5.2018
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LIST OF ORIGINAL PUBLICATIONS

This thesis is based on the following original articles, which are referred to in the text by Roman numerals:

I Ihalainen, S., Kuitunen, S., Mononen, K. & Linnamo, V. 2016. Determinants of elite-level air rifle shooting performance. Scandinavian Journal of Medicine & Science in Sports 26 (3), 266-274.

II Ihalainen, S., Linnamo, V., Mononen, K. & Kuitunen, S. 2016. Relation of Elite Rifle Shooters' Technique-Test Measures to Competition Performance. International Journal of Sports Physiology and Performance 11 (5), 671-677.

III Ihalainen, S., Mononen, K., Linnamo, V. & Kuitunen, S. 2018. Which technical factors explain competition performance in air rifle shooting? International Journal of Sports Science & Coaching 13 (1), 78-85.

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

Additionally, some previously unpublished results are included in this thesis.

ABBREVIATIONS

ANOVA	analysis of variance
ATV	cleanness of triggering
COG_{hit}	aiming accuracy
COM	center of mass
COP	center of pressure
DevX	horizontal stability of hold
DevY	vertical stability of hold
F_L	left leg vertical force
F_R	right leg vertical force
Hit%	percentage of hit targets
INT	international level athletes
MRA	multiple regression analysis
NAT	national level athletes
PCA	principal component analysis
sdX	postural balance in cross shooting direction
sdX_L	postural balance of the left leg in cross shooting direction
sdX_R	postural balance of the right leg in cross shooting direction
sdY	postural balance in shooting direction
sdY_L	postural balance of the left leg in shooting direction
sdY_R	postural balance of the right leg in shooting direction
TIRE	timing of triggering

CONTENTS

1 INTRODUCTION

Shooting sports have been a part of the Olympic Games since the first modern games held in Athens in 1896. Rifle shooting was part of the first Winter Olympic Games held in Chamonix in 1924 as military patrol. Later, biahlon was introduced as a permanent Winter Olympics event in 1960. Nowadays, shooting has grown into a global sport with 158 national shooting sport federations and worldwide public intrest. In the London 2012 Olympic Games, the total maximum television audience in the shooting events was 73 million people, and the total number of viewer hours during the London 2012 Olympic Games was 215 million. During the 2010-2011 season, the biathlon world cups and world championships reached a total television audience of 960 million. One of the intriguing aspects of shooting sports is the combination of high technical skill level and the psychological demands of being able to perform at the high technical skill level even in stressful competition situations.

Shooting performance has been shown to be related to both technical and psychological aspects, and the differences between successful and unsuccessful performances are extremely small. The shooting technique studies in rifle and biathlon shooting have mainly concentrated on stability of hold and postural balance (Ball, Best & Wrigley 2003a; Era et al. 1996; Hoffman et al. 1992; Konttinen, Lyytinen & Era 1999; Sattlecker et al. 2014; Sattlecker et al. 2017; Zatsiorsky & Aktov 1990). The differences in these shooting technical components between elite and pre-elite shooters have been clearly established (Era et al. 1996; Konttinen, Lyytinen & Viitasalo 1998b; Konttinen, Landers & Lyytinen 2000; Sattlecker et al. 2014), and these shooting technical components have been related to shooting performance among novice shooters (Mononen et al. 2007). At the elite level, no such relation was evident in rifle (Ball, Best & Wrigley 2003a) or biathlon (Sattlecker et al. 2017) shooting. All in all, the studies in elite level shooting have not been able to demonstrate the factors related to shooting performance. The shooting technical components widely known among the shooters to affect shooting performance have been omitted in many of the studies, or the previous studies have failed to incorporate all the relevant components in the measurements. For example, aiming accuracy and trigger control are often discussed and trained by the elite shooters, but have been left largely unnoticed in the scientific studies.

Therefore, the aim of the present study was to identify technical determinants of elite level air rifle and biathlon standing shooting performance, and to further investigate how these technical determinants are affected by long-term shooting training, competition situation, or intense exercise. The similarities in rifle and biathlon standing shooting offer the possibility to assess whether the same shooting technical components affect performance in these two different shooting tasks, when rifle shooting is performed in rest and biathlon shooting is carried out after strenuous fatiguing exercise.

2 REVIEW OF THE LITERATURE

2.1 Air rifle shooting

Air rifle shooting is an Olympic event, in which the athletes try to hit a stationary target from 10-meter distance in a standing shooting position (International Shooting Sport Federation 2017). The diameter of the 10-ring is 0.5 mm, and the best shooters are able to hit the 10-ring with every shot in a competition series. The competition consists of a qualification round and a final. In the qualification round, men shoot 60 shots in 75 minutes and women shoot 40 shots in 50 minutes. The eight best shooters in the qualification round proceed to the final. In the final, the shooter with the lowest score after 12 shots is eliminated from the competition. After the first elimination, all remaining athletes shoot two additional shots, and again the shooter with the lowest score is eliminated from the competition. This same system is continued until only the winner remains. The winner and the second athlete shoot a total of 24 shots in the final.

Men's current qualification round world record is 633.5 points (10.56 points/shot) and final world record is 250.9 points (10.45 points/shot). Women's current qualification round world record is 422.9 points (10.57 points/shot) and final world record is 252.1 points (10.50 points/shot). Elite level air rifle shooting requires both good and stable technique as well as psychological coping skills in order to be able to shoot over 10.4 points per shot in a competition. For example, in Rio Olympic Games 2016, Olympic finalists' shooting performance decreased by 0.28 points per shot (2.7%) in men's and 0.21 points per shot (2.0%) in women's competition from qualification to final round (Figure 1). Even in the absolute elite level, the high-pressure situation can affect shooting performance.

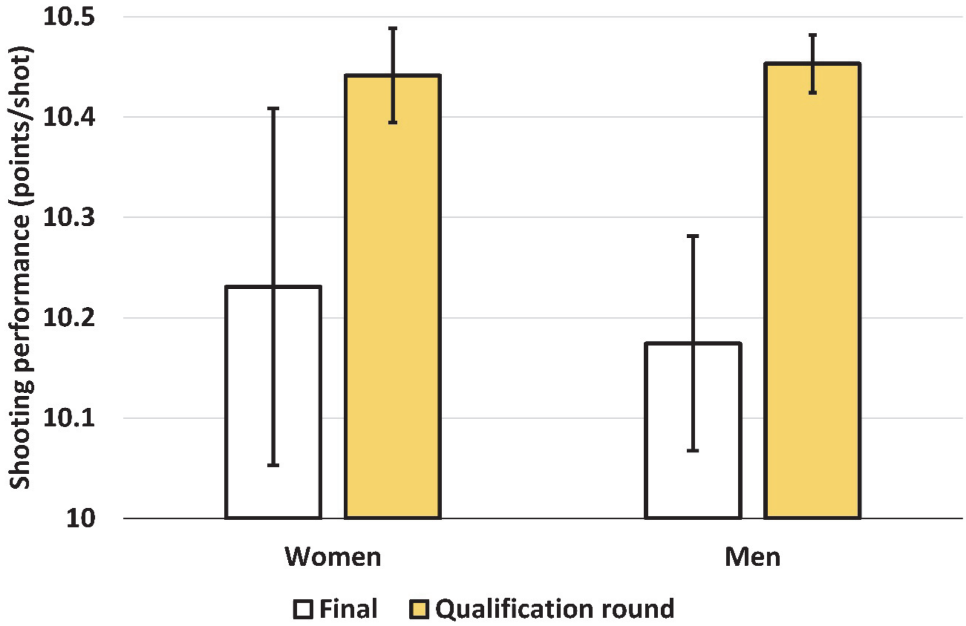

FIGURE 1 Olympic finalists' mean shooting performance in Rio Olympic Games 2016 in the final and qualification rounds.

Air rifle competitions are psychologically stressful situations for the shooters, and state anxiety has been related to shooting performance in competition situation (Sade et al. 1990). Anticipation of performance has been shown to increase anxiety, heart rate, and blood pressure in professional musicians (Abel & Larkin 1990). Relationships between state anxiety, heart rate, blood pressure and postural balance (Abel & Larkin 1990; Conforto et al. 2001) are possible reasons why the shooting performance can decrease in competition compared to the training situation. This psychological effect of competition situation on shooting performance has been demonstrated by Solberg et al. (1996) who showed that a relaxation meditation training program was able to increase performance level in shooting competitions, even without concurrent increase in training situation shooting performance. Furthermore, a single subject case study was able to show that a cognitive–behavioral intervention reduced state anxiety and increased competition shooting performance (Prapavessis et al. 1992).

Although the psychological aspect is clearly an important part of air rifle shooting, the majority of air rifle shooting studies have concentrated on shooting technique. Technical aspects in air rifle shooting include stability of hold (Ball, Best & Wrigley 2003a; Konttinen, Lyytinen & Viitasalo 1998a; Konttinen, Lyytinen & Viitasalo 1998b; Mononen et al. 2007; Zatsiorsky & Aktov 1990), postural balance (Ball, Best & Wrigley 2003a; Era et al. 1996; Mononen et al. 2007), aiming accuracy (Zatsiorsky & Aktov 1990), and trigger control (Helin, Sihvonen & Hanninen 1987; Konttinen, Landers & Lyytinen 2000; Konttinen et al. 2003). However, these studies have not been able to demonstrate the relation of these technical components to elite level shooting performance. Furthermore, the scientific literature is missing longitudinal studies quantifying the development of these shooting technical components in the long term. In addition to the psychological and technical aspects of rifle shooting, the shooting task has been studied from motor control, motor learning and focus of attention point of views (Gallicchio et al. 2016; Hillman et al. 2000; Janelle et al. 2000; Konttinen, Landers & Lyytinen 2000; Raisbeck & Diekfuss 2017). However, this thesis was designed to address the technical aspects of elite rifle shooting performance.

2.1.1 Technical factors affecting air rifle shooting performance

2.1.1.1 Stability of hold

One of the most studied aspect of air rifle shooting technique is the stability of hold, i.e. the ability to control and minimize the movement of the gun during the aiming phase. During the aiming phase, the stability of hold improves towards the shot moment (Konttinen, Lyytinen & Viitasalo 1998b; Zatsiorsky & Aktov 1990). This improvement in the stability of hold towards the shot moment has been shown to be related to decreasing heart rate during the aiming phase (Konttinen, Lyytinen & Viitasalo 1998a). Stability of hold has been shown to be better in elite level rifle shooters compared to athletes of lower shooting performance level (Konttinen, Lyytinen & Viitasalo 1998a; Konttinen, Lyytinen & Viitasalo 1998b; Konttinen, Landers & Lyytinen 2000; Zatsiorsky & Aktov 1990). Stability of hold also discriminates between low and high scoring shots in groups of elite, pre-elite (Konttinen, Lyytinen & Viitasalo 1998b), and novice shooters (Mononen et al. 2007), so that the high scoring shots have more stable hold than the low scoring shots.

Stability of hold has been shown to be related to shooting performance in a group of novice rifle shooters (Mononen et al. 2007), but no study so far has shown the same correlation in a group of elite level rifle shooters. It has been suggested that both the small variation in shooting scores and the individual shooting strategies in elite level rifle shooting confound the relationship between technique measures, such as stability of hold, and shooting performance (Ball, Best & Wrigley 2003a). It was also suggested that intra-individual analysis should be preferred in elite level sports in order to take into account the differences in individual shooting techniques. (Ball, Best & Wrigley 2003a). The importance of stability of hold in elite level air rifle shooting remains unclear.

Stability of hold has been measured in horizontal and vertical directions as aiming point trace length (Ball, Best & Wrigley 2003a), fluctuation amplitude and variance (Zatsiorsky & Aktov 1990), and standard deviation (Figure 2) of the aiming point location (Mononen et al. 2007) during discrete time intervals before the shot. In elite level air rifle shooting, stability of hold in vertical direction has been reported to be better than the stability of hold in horizontal direction (Ball, Best & Wrigley 2003a; Zatsiorsky & Aktov 1990). Zatsiorsky and Aktov (1990) also reported that the vertical stability of hold improves more than the horizontal stability of hold with increasing shooting performance level. The authors also stated that the vertical stability of hold was more closely related to shooting performance than the horizontal stability of hold, even though this was not assessed with statistical methods due to the small number of participants.

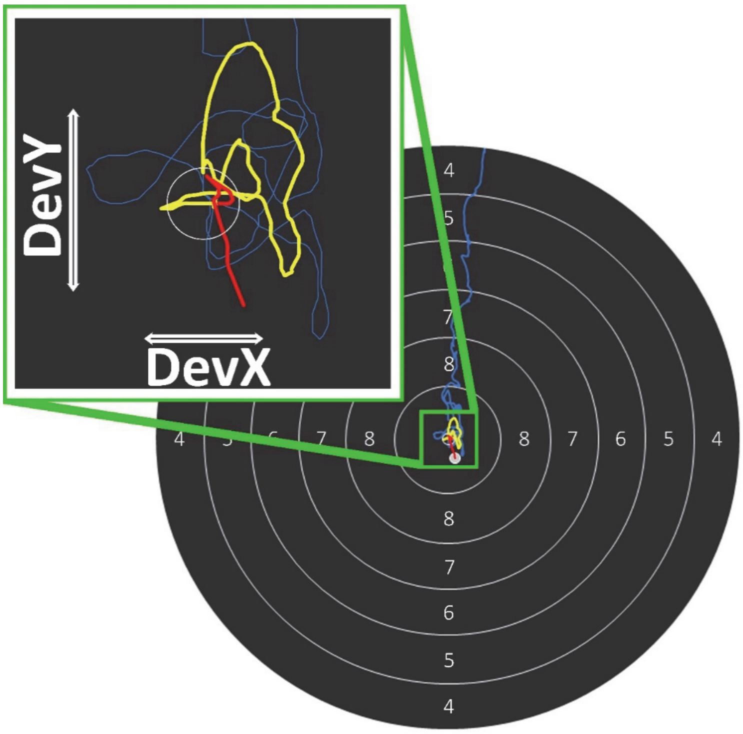

FIGURE 2 Aiming point trajectory of an elite level air rifle shooter. Yellow line indicates the movement of the aiming point during 1-0.2 s before the shot. Red line indicates the movement of the aiming point during 0.2-0 s before the shot. Stability of hold can be measured as standard deviation of the aiming point location in horizontal (DevX) and vertical (DevY) directions during a discrete time interval (for example 1-0 s before the shot) (Mononen et al. 2003).

2.1.1.2 Postural balance

Postural balance is another performance determining factor in rifle shooting and it is connected to stability of hold. Elite level shooters have more stable postural balance compared to untrained controls (Aalto et al. 1990). Postural balance also differentiates between athletes of elite and pre-elite performance levels (Era et al. 1996; Konttinen, Lyytinen & Era 1999; Mon et al. 2014). Elite level shooters have also been shown to be able to decrease the amount of body sway prior to the shot moment. This same reduction in body sway was not evident in lower level shooters. (Era et al. 1996).

In a group of novice shooters, postural balance has been shown to be related to shooting performance both directly, as well as indirectly through more stable hold (Mononen et al. 2007). In elite level rifle shooters, no statistically significant relations between postural balance, stability of hold, and shooting performance could be found in an inter-individual analysis. However, intra-individual analysis showed various correlations between postural balance, stability of hold, and shooting performance. (Ball, Best & Wrigley 2003a).

Postural balance has been traditionally measured in antero-posterior and medio-lateral directions (Ball, Best & Wrigley 2003a; Era et al. 1996; Konttinen, Lyytinen & Era 1999; Mononen et al. 2007). In rifle shooting posture, medio-lateral direction coincides with the shooting direction, and antero-posterior direction coincides with the cross-shooting direction. The studies reporting elite level rifle shooters' postural balance have shown that the balance in shooting direction (medio-lateral) is more stable than the balance in cross-shooting (antero-posterior) direction (Era et al. 1996; Konttinen, Lyytinen & Era 1999).

Measures of postural balance include the motion of the center of mass (COM) and the center of pressure (COP). These two measures of postural balance are closely related to each other, as the COP oscillates around the COM trajectory, and the horizontal acceleration of the COM is proportional to the COM-COP difference. This relation allows the calculation of COM position from COP position data, which is easily measured with force plates. (Benda, Riley & Krebs 1994; Caron, Faure & Brenière 1997; Morasso, Spada & Capra 1999). A wide variety of parameters calculated from the COP or COM data exist, which have been used to assess postural balance. These parameters include range, path length, mean velocity, standard deviation, and area (Ruhe, Fejer & Walker 2010).

2.1.1.3 Trigger control

Trigger control can be assessed both as cleanness and timing of triggering. Cleanness of triggering refers to the motion of the aiming point during the last 0.2 s before the shot (Figure 3), i.e. does the triggering motion cause a jerk in the motion of the aiming point. It has been shown that on average, the aiming point is closest to the center of target 0.2 s before the shot and moves further away from the center of target during the triggering phase both in groups of novice and elite rifle shooters (Goodman et al. 2009). This result could be interpreted as a sign of unclean triggering in the studied shooter groups. Surprisingly there are no studies reporting the actual cleanness of triggering values in air rifle shooting. Mononen et al. (2003) identified cleanness of triggering as an important technical component in running target shooting and cleanness of triggering correlated with the shooting scores both in running target and stationary shooting conditions investigated in the study. In addition to running target shooting, cleanness of triggering was shown to be related to shooting performance also in air pistol shooting (Hawkins 2011). However, the effect of cleanness of triggering on air rifle shooting performance remains unclear.

In addition to cleanness of triggering, trigger control can be assessed as timing of triggering. Timing of triggering refers to the shooters' ability to fire the shot when the aiming point is moving towards the center of target, instead of moving away from the center of target. Konttinen, Landers and Lyytinen (2000) showed that high scoring shots differed from moderate and low scoring shots so that the aiming point was moving towards the center of target until the shot moment. The shooting result started to deteriorate in low and moderate scoring shots 300-400 ms before the shot, so that the aiming point was moving away from the center of target. (Konttinen, Landers & Lyytinen 2000). Unfortunately, the shooting technique parameters used in their study do not differentiate between the effects of cleanness of triggering and timing of triggering on shooting performance and trigger control. Several studies have investigated timing of triggering in relation to the cardiac cycle, and mixed results have been presented both about the shooters' ability to time the triggering action in distinct cardiac cycle phases (i.e. during diastole or systole) and about the benefits of timing the triggering during diastole or systole (Bothwell, Donne & Andrews 1997; Helin, Sihvonen & Hanninen 1987; Konttinen et al. 2003; Mets, Konttinen & Lyytinen 2007).

FIGURE 3 Cleanness of triggering measured as the cumulative distance travelled by the aiming point during the last 0.2 s before the shot (red line) (Mononen et al. 2003).

2.1.1.4 Aiming accuracy

Rifle shooting aiming accuracy measures have been reported in only one study. Zatsiorsky and Aktov (1990) measured aiming accuracy as the mean distance of the aiming point from the center of target during different time periods before the shot. The authors reported that aiming accuracy increased towards the shot moment, but the authors did not investigate the differences in aiming accuracy between shooters of different performance levels, nor the relation of aiming accuracy to shooting performance. (Zatsiorsky & Aktov 1990). The same aiming accuracy measure has been used previously in running target (Mononen et al. 2003) and pistol (Hawkins 2011) shooting events (Figure 4) and the aiming accuracy was identified as an important shooting technical component in these shooting events. In pistol shooting, aiming accuracy was related to shooting performance in groups of national (Hawkins 2011) and elite (Ball, Best & Wrigley 2003b) level shooters. However, the importance of aiming accuracy on air rifle shooting performance remains unclear.

In addition to aiming accuracy, the aiming process has been studied as aiming time and the quiet eye duration. Quiet eye duration refers to the final fixation time to target before the initiation of a motor response. Both aiming time and quiet eye duration have been shown to be longer in expert compared to nonexpert rifle shooters (Janelle et al. 2000).

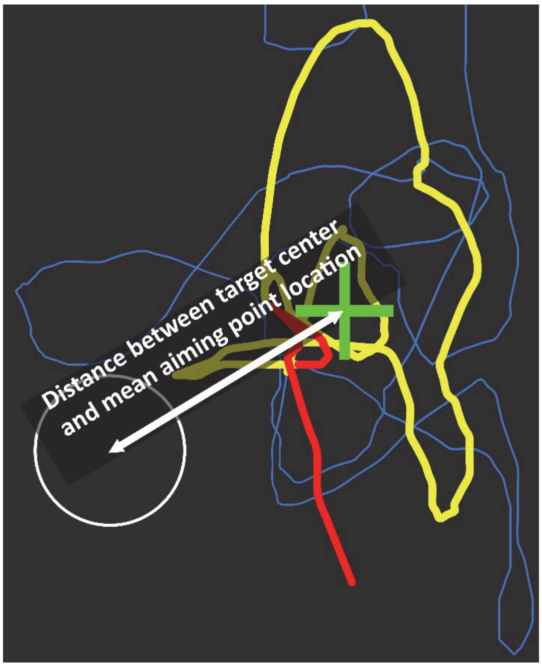

FIGURE 4 Aiming accuracy measured as the distance between target center and mean location of the aiming point (green cross) during a discrete time interval (for example 1-0 s before the shot, depicted here as yellow and red line) (Mononen et al. 2003).

2.2 Biathlon

Biathlon is an Olympic event combining cross country skiing and rifle shooting. The skiing distance in biathlon competitions varies between 6 and 20 km. The skiing distance is covered in 3 or 5 loops, and a prone or standing shooting task is performed between each loop. Shooting task is carried out into five parallel targets at 50 m shooting distance. The target diameter is 115 mm in standing and 45 mm in prone shooting position. Biathletes have to use a .22 caliber small bore rifle weighing at least 3.5 kg. Each missed target in the shooting task adds a penalty skiing loop of 150 m or a penalty time, dependent on the competition type. (International Biathlon Union 2016). The total race time consists of course time (the time spent in the skiing loops), range time (approach and preparation for the shooting task, the actual shooting task, exit from the shooting range), and penalty time (time added due to missed targets) (Luchsinger et al. 2017).

The exercise intensity during skiing in biathlon competition is approximately 90% of maximal heart rate. Heart rate decreases 10-12 beats per minute during the approach to the firing line and heart rates are 85-87% of maximal heart rate at the start of the shooting task. The heart rate decreases to 61-73% of maximal heart rate during the shooting task. (Hoffman & Street 1992). Carrying the rifle during the skiing task has been shown to affect the energy expenditure. The energy cost of rifle carriage during the skiing task has been estimated to increase the oxygen consumption by 0.20 l/min and 0.19 l/min in women and men, respectively (Rundell & Szmedra 1998). Rifle carriage has also been shown to increase ventilation by 8.1%, heart rate by 1.7% and blood lactate by 15.1%. The effect of rifle carriage on ventilation was also shown to be greater in women compared to men. The changes in the energy cost were accompanied by changes in the skiing technique. Carrying a rifle was shown to reduce cycle time and length, poling and arm swing times, and leg ground contact time, whereas an increase was seen in peak leg force and the impulse of leg force, average cycle force, and impulse of forefoot force. (Stoggl et al. 2015).

2.2.1 Biathlon standing shooting technique

The two shooting positions in biathlon, prone and standing, differ from each other. The stability of hold in prone shooting is much more stable compared to standing shooting. This difference in the stability of hold in these shooting positions can be seen as smaller shot group diameters and higher shot scores achieved in prone compared to standing shooting. Even though the prone shooting position is more accurate, the smaller target size in prone position leads to similar hit percentages observed in prone and standing shooting positions. (Hoffman et al. 1992).

Biathlon standing shooting shares some similar aspects with air rifle shooting. Both disciplines are shot with a rifle, the successful performance requires accurate and consistent shooting technique, and the standing shooting posture is similar in both disciplines. There are also obvious differences between air rifle and biathlon shooting. The biathlon shooting is carried out without any supportive clothing, whereas heavily supportive shooting jackets, trousers, and shoes are used in air rifle shooting. Also, the time requirements for shooting are a lot shorter for biathlon compared to air rifle shooting. In air rifle competitions, the shooter is required to shoot at a pace of one shot per 75 seconds in order to complete the competition shots during the competition time limit. In biathlon shooting, the interval between the shots is only a few seconds.

The whole biathlon standing shooting series was reported to last approximately 25-30 s in biathlon world cup sprint races and most of this time (~15 s) was spent in preparation for the first shot. The time interval between the shots after the first shot was approximately 2-4 s. (Luchsinger et al. 2017).

Despite these obvious differences between the two shooting events, stability of hold and postural balance have been identified as performance determining factors in both biathlon standing shooting and air rifle shooting. Stability of hold affects biathlon standing shooting performance both in rest (Sattlecker et al. 2014) and after intense exercise (Hoffman et al. 1992) so that the smaller the movement of the gun is, the better the shooting performance is. Elite level biathletes have also demonstrated 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 (Sattlecker et al. 2014). Also, a training intervention study by Groslambert et al. (2003) showed that a specific training program was able to enhance holding ability, which was accompanied by a non-significant increase in shooting performance. Laaksonen, Ainegren and Lisspers (2011) did not measure stability of hold, but they reported that a combined relaxation and holding training intervention was able to improve biathlon standing shooting performance both in rest and after intense exercise.

Good postural balance is required in order to achieve a stable hold in biathlon standing shooting. The stability of hold in biathlon standing shooting has been shown to be related to postural balance both in rest and after intense exercise (Sattlecker et al. 2014; Sattlecker et al. 2017). Elite and junior level athletes have been shown to differ in postural balance in standing shooting without physical stress. Similar to results regarding the stability of hold, the difference in postural balance contributed to the observed shooting performance difference between the elite and junior level biathletes (Sattlecker et al. 2014).

2.2.2 Effect of fatigue on shooting performance

Cross country skiing has been shown to cause upper and lower body fatigue. This fatigue is manifested as lower skiing speeds, lower force production levels of the lower and upper body, decreased cycle rates, and decreased muscle activation. The effects of fatigue on lower and upper body differed, since in the upper body the force production levels decreased while the force production time remained at constant level. The opposite finding was shown for lower body force production characteristics. (Ohtonen et al. 2018).

The skiing task precedes shooting in biathlon competitions, and this skiing task and the resulting fatigue influences the shooting task. In biathlon, it has been shown that increasing exercise intensity decreases both stability of hold and shooting performance (Hoffman et al. 1992; Vickers & Williams 2007). To the best of the author's knowledge, there are no studies reporting the changes in biathlon shooting postural balance due to increasing exercise intensity. In a military shooting study, exercise-induced fatigue was shown to decrease postural balance in shooting posture (Bermejo et al. 2018). Fatigue has also been shown to decrease postural balance in normal quiet standing (Paillard 2012). Both aerobic, anaerobic (Fox et al. 2008), as well as local muscular exercise (Gosselin, Rassoulian & Brown 2004; Madigan, Davidson & Nussbaum 2006; Vuillerme, Forestier & Nougier 2002; Vuillerme, Pinsault & Vaillant 2005; Vuillerme et al. 2008; Vuillerme & Pinsault 2007) have been shown to impair postural balance.

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 (Conforto et al. 2001; Paillard 2012; Sturm, Nigg & Koller 1980). All these factors are likely to decrease postural balance in biathlon shooting, where the shooting task is carried out after strenuous exercise. The observed relationships between postural balance, stability of hold and shooting performance in biathlon standing shooting (Sattlecker et al. 2014; Sattlecker et al. 2017) could imply that the effect of fatigue on shooting performance is mediated through the declining postural balance.

3 PURPOSE OF THE THESIS

The present thesis was designed to investigate the technical determinants of elite level air rifle and biathlon shooting performance and to examine how these determinants are affected by long-term shooting training, competition situation psychological pressure and intense exercise. The thesis is based on four original articles, and the specific aims and hypotheses of the studies were:

1) To identify the most important performance-determining factors in elite level air rifle shooting technique (Original papers I and II).

   It was hypothesized that in addition to stability of hold and postural balance, aiming accuracy and trigger control would affect elite level shooting performance.

2) To examine the long-term changes in shooting technique and their relationship to changes in shooting performance (Original paper II).

   The hypothesis was that stability of hold, aiming accuracy, trigger control, and postural balance would improve and result in enhanced shooting performance.

3) To investigate the effect of competition situation on air rifle shooting technique and shooting performance (Original paper III).

   It was hypothesized that the effect of competition situation would impair stability of hold and postural balance.

4) To identify the most important performance-determining factors in biathlon standing shooting technique, and to investigate how these factors are affected by intense exercise (Original paper IV).

   The hypothesis was that in addition to stability of hold and postural balance, aiming accuracy and trigger control would affect biathlon standing shooting performance. It was also assumed that the effects of intense exercise on shooting performance would be mediated through decreased postural balance control.

4 METHODS

4.1 Subjects

International and national level senior and junior air rifle shooters (N = 48) and biathletes (N = 17) were measured in the studies. The subject groups included both male and female athletes. International level athletes in air rifle shooting (I, II, III) had participated in international competitions (World Cup, Olympic Games, European Championships, or World Championships), and national level athletes (I) had competed only in national level competitions. Additional analysis was carried out to analyze the differences between international level finalists (i.e. athletes placed in the top 8 in an international level competition and qualified for the final), other international level shooters, and national level shooters. Junior level athletes in air rifle shooting (III) and biathlon (IV) were members of the youth team. The total number of participants measured in the studies were 40 (I), 17 (II, IV), and 13 (III).

4.2 Experimental approach

Air rifle shooting measurements were conducted on national team training camps during 2009-2016 (I, II, III) as standard shooting technique tests. In addition, two competition situation measurements were performed 2015 and 2016. Measurement set-up in air rifle shooting tests is illustrated in Figure 5. The shooting technique test consisted of an unlimited number of sighting and warm-up shots followed by a simulated competition series. Shooting conditions were set according to the rules and regulations in official air rifle shooting competitions (International Shooting Sport Federation 2017). All shooters used their own air rifle and shooting equipment during the shooting tests. Actual competition measurements were conducted 2015 and 2016 in a special competition situation, which was in conjunction with a training camp where standard shooting technique tests were performed. Competition results were collected from all international and national record eligible competitions during the measured seasons in order to investigate the association between the training situation shooting technique measurements and the actual competition shooting performances.

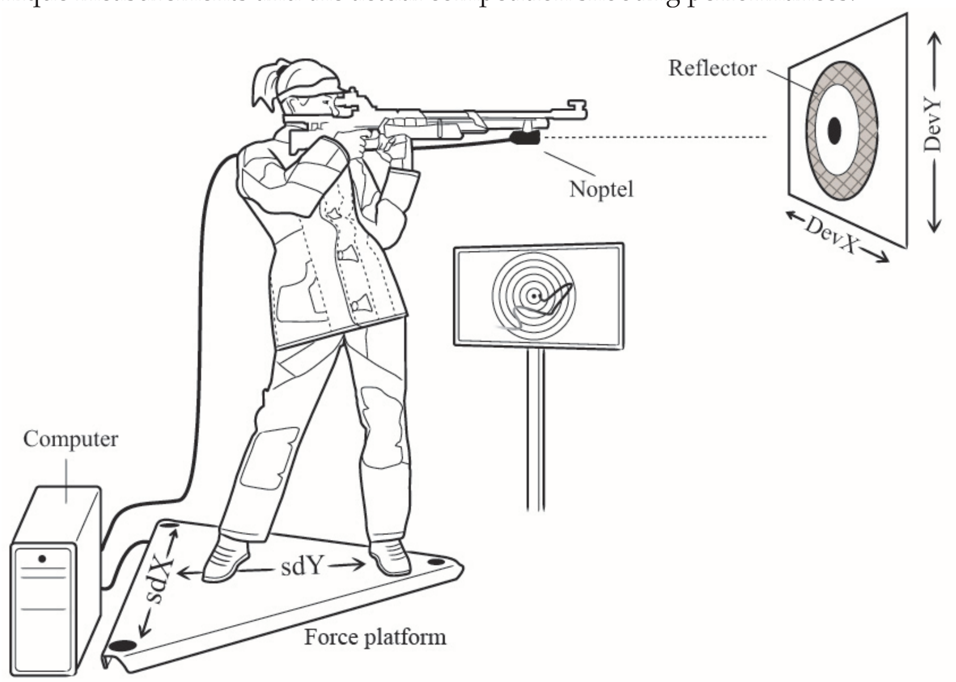

FIGURE 5 Measurement set-up in air rifle shooting tests.

Biathlon shooting measurements (IV) were carried out during off-season on summer 2016. Participants fired standing shooting shots at rest and after a competition simulation roller skiing task. The competition simulation skiing velocity was set to correspond to the skiing velocity at 95% of peak heart rate. This skiing intensity at 95% of peak heart rate was selected because of the similar heart rate responses reported during actual biathlon competitions (Hoffman et al. 1992). In order to determine the participants' individual competition simulation skiing speeds, a maximal incremental roller skiing test using V2 skating technique was performed. The participants' heart rate was measured throughout the incremental roller skiing test. 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.

The competition simulation roller skiing without rifle lasted 5 minutes and was followed by a standing shooting series of five shots. Each biathlete performed the competition simulation skiing followed by the shooting task two times. All participants used their own competition rifles in the shooting tasks, and the participants kept the skies on during the shooting. Shooting was carried out indoors with 10 m shooting distance into a scaled biathlon target without live bullets (Figure 6). Sighting shots were 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 participants were instructed to shoot at their normal competition shooting technique and rhythm both in rest and after the competition simulation roller skiing task. A total of 40 (8*5) shots were fired in rest and 10 (2*5) shots were fired after the competition simulation.

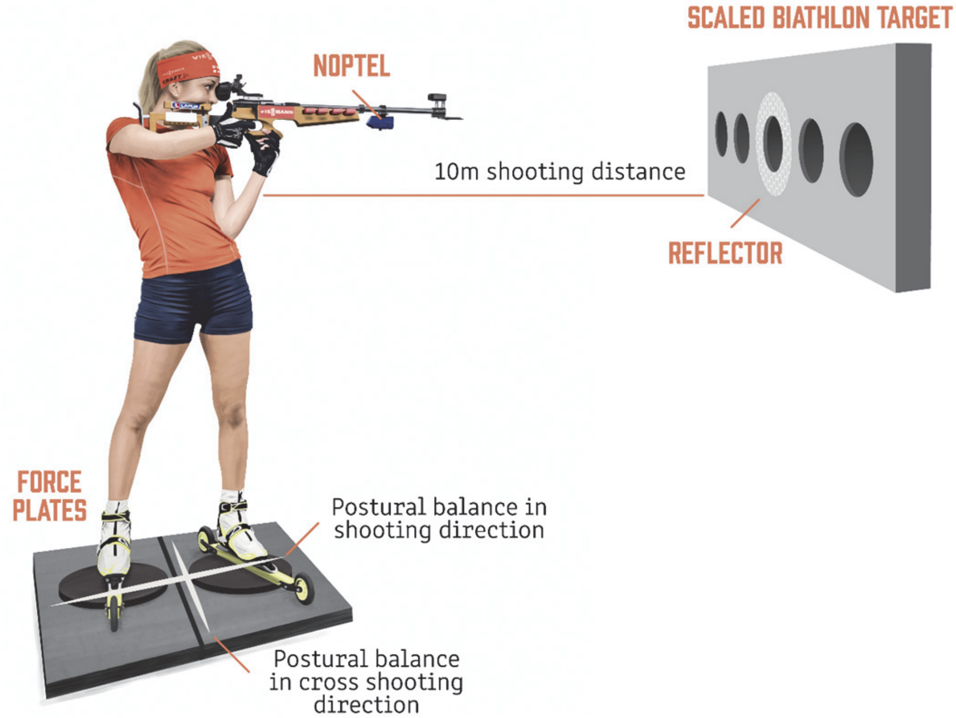

FIGURE 6 Measurement set-up in biathlon shooting tests.

4.3 Data collection and analysis

4.3.1 Aiming point trajectory

The shooting task in air rifle (I, II, III) and biathlon (IV) was carried out with Noptel ST 2000 (Noptel Oy, Oulu, Finland) optoelectronic device. The measuring device consisted of an optical transmitter-receiver unit (weight 80 g) attached to the barrel of the gun and a reflector attached around the center of the target. In air rifle shooting, the reflector was attached around the center of a standard air rifle shooting target (I, II, III). In biathlon, the reflector was attached around a scaled biathlon target. The scaled biathlon target with the 10-meter shooting distance was equivalent to the actual 50-meter shooting distance used in the competitions. The optical unit was connected to a personal computer for data visualization, analysis, and storage. Hit point and aiming point trajectory were recorded from every shot at 100 Hz sampling rate and 0.1 mm accuracy. In the first air rifle shooting study (I), shot score and seventeen variables were analyzed from the aiming point trajectory data of each shot with Noptel software (NOS4 version 4.208). Based on the results of the first study (I), five aiming point trajectory variables (Table 1) were used in the following studies (II, III, IV).

TABLE 1 Variables calculated from the aiming point trajectory data.

Component	Variable	Description	Unit	Study
Overall performance	Mean shooting score	Mean point/shot result in training and competition situation		I, II, III
	Hit percentage	Percentage of hit targets	%	IV
Stability of hold	DevX DevY	Horizontal (DevX) and vertical (DevY) standard deviations of the location of the aiming point during the last second (I, II, III) or during the last 0.6 s (IV). Smaller DevX and DevY values indicate better holding ability.	ring mm	I, II, III IV
Aiming accuracy	COG_{hit}	Mean distance of the aiming point from the center of target during the last second (I, II, III) or during the last 0.6 s (IV).	points mm	I, II, III IV
Cleanness of triggering	ATV	Cumulative distance travelled by the aiming point during the last 0.2 s. Smaller ATV values indicate better triggering.	ring mm	I, II, III IV
Timing of triggering	TIRE	Time period when the mean location of the aiming point is closest to the center of target: 0.0-0.2 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.	index	I, II, III, IV

In air rifle shooting studies (I, II, III), the stability of hold and aiming accuracy measures were calculated from a time interval of one second before the shot. In biathlon study (IV), the one second time interval was too long for some of the athletes shooting at a shorter time interval between the shots. Therefore, a shorter 0.6 second time window was used to analyze the stability of hold and aiming accuracy measures in the biathlon study (IV). In the air rifle shooting studies (I, II, III), the variable units were reported according to the units selected by the Noptel manufacturer. The measurement unit used in stability of hold

(DevX, DevY) and cleanness of triggering (ATV) measures was the interval between two consecutive hit rings in air rifle target (2.5 mm/ring). The measurement unit used in aiming accuracy (COG_{hit}) was the distance of the aiming point from the center of target, expressed as points the same way as the shooting score in air rifle shooting (0-10.9). In biathlon (IV), the Noptel target was not divided into hit rings and there were no points calculated from the shot location. Therefore, the measurement unit used in biathlon study (IV) for stability of hold, aiming accuracy, and cleanness of triggering was millimeters (mm).

4.3.2 Postural balance

In air rifle shooting studies (I, II, III), participants fired the shots standing on a triangular-shaped (1175 mm × 1175 mm × 1175 mm) force platform (Good Balance, Metitur Ltd., Jyväskylä, Finland). Force platform was equipped with strain-gauge transducers in each corner of the force platform. The signals were amplified and collected at 200 Hz with 16-bit A/D-converter (National Instruments Co., Austin, Texas, USA) and stored on personal computer hard drive for further analysis. Shot moment was identified from the balance data based on microphone data collected synchronously with the same A/D-converter. Center of Pressure (COP) coordinate data was filtered with fourth-order zero-phase lag digital low pass filter with 10 Hz cutoff frequency, as recommended by Ruhe, Fejer and Walker (2010). Postural balance was measured as standard deviation of the COP location in shooting direction (sdY) and perpendicular to shooting direction (sdX) during three time periods: 7–2 s before the shot (sdX_7, sdY_7), 2–0 s before the shot (sdX_2, sdY_2), and 1–0 s before the shot (sdX_1, sdY_1). Postural balance variables measured in the studies are presented in Table 2.

In biathlon study (IV), 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. COP location under both feet was calculated from both force plates separately, and also a combined whole-body COP location based on both force plate data was calculated. In addition to COP measures mean vertical left (F_L) and right (F_R) leg force during the last 0.6 s before the shot was calculated. Force distribution was calculated as a percentage of total force on the left leg.

4.4 Statistical analysis

Conventional statistical methods were used to obtain means, standard deviations, and correlation coefficients. Principal component analysis (PCA) was used to identify shooting technical components in aiming point trajectory variables (I). Independent samples t-test was used to analyze the differences in performance and shooting technical variables between international and national level air rifle shooters (I). Stepwise multiple regression analysis (MRA) was used to study the amount of explained variance in air rifle shooting score by the shooting technical variables (I). In a longitudinal study design (II), one-way repeated-measures analysis of variance (ANOVA) was performed to analyze the changes in air rifle competition shooting results and shooting technical variables during the measured time period. Post hoc tests with Bonferroni correction were used to analyze the time point and direction of the change in the competition shooting results and shooting technical variables. Wilcoxon signed rank test was used to analyze the differences in air rifle shooting technique between the training and competition situation (III). In biathlon shooting (IV), a two-way repeated measures ANOVA was used to analyze the effect of intense exercise and expertise level on shooting performance and shooting technical variables. Level of statistical significance was set at 0.05.

TABLE 2 Postural balance variables calculated from the force plate data.

Component	Variable (unit)	Description	Study
Postural balance	sdX_7 (mm)	Standard deviation of the COP location perpendicular to shooting direction during 7-2 s before the shot. Smaller values indicate more stable postural balance.	I, II, III
	sdY_7 (mm)	Standard deviation of the COP location in shooting direction during 7-2 s before the shot	I, II, III
	sdX_2 (mm)	- 2-0 s before the shot	I, II, III
	sdY_2 (mm)	- 2-0 s before the shot	I, II, III
	sdX_1 (mm)	- 1-0 s before the shot	I, II, III
	sdY_1 (mm)	- 1-0 s before the shot	I, II, III
	$sdX_{0.6}$ (mm)	- 0.6-0 s before the shot	IV
	$sdY_{0.6}$ (mm)	- 0.6-0 s before the shot	IV
	sdX_L (mm) 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.	IV
	sdY_L (mm) 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.	IV
Force	F_L (N) F_R (N)	Mean vertical left (F_L) and right (F_R) leg force during the last 0.6 s.	IV
	Force distribution (%)	Percentage of force on the left leg, F_L/(F_L + F_R)*100	IV

5 RESULTS

5.1 Technical components in air rifle shooting (I)

Principal component analysis (PCA) revealed six factors in the aiming point variables measured in the testing situation, which explained 88% of the total variance in the measured variables (Table 3). Factor 1, aiming time, described the amount of time the aiming point was in the target area before the shot. Factor 2, stability of hold, described the steadiness of the rifle barrel. Factor 3, measurement time, described the total length of the execution of the shot. Factor 4, cleanness of triggering, described the stability of the rifle during the triggering phase. Factor 5, aiming accuracy, described the preciseness of aiming. Factor 6, timing of triggering, described the timing of the triggering action and the direction of the aiming point movement at shot moment. Even though six components were found in air rifle shooting technique from the aiming point trajectory variables, multiple regression analysis identified only four of these components (stability of hold, aiming accuracy, cleanness of triggering, and timing of triggering) as performance determining factors.

TABLE 3 Principal component analysis rotated solution of the aiming point variables from all the measured shots (n = 13795). Factor loadings of absolute value greater than 0.4 are shown.

	Factor 1 Aiming time	Factor 2 Stability of hold	Factor 3 Measurement time	Factor 4 Cleanness of triggering	Factor 5 Aiming accuracy	Factor 6 Timing of triggering
Eigenvalue	4.33	2.96	1.70	1.27	1.07	0.93
Percentage of variance	21.3	19.8	13.8	13.3	12.2	7.2
COG_{ht}	.962					
$Target_{ht}$	.961					
Hit_{ht}	.955					
COG_f		.900				
DevX		-.853				
Hit_f		.693		-.427		
DevY		-.580				
Total time			.945			
Time on target			.943			
RTV				.949		
ATV				.867		
COG_{hit}					.968	
$Target_f$		.480			.830	
TIRE						.994

International level finalists (athletes placed in the top 8 in an international level competition and qualified for the final) demonstrated better shooting performance compared to national level athletes ($P < 0.001$). International level finalists also showed better technical skill level in all shooting technical components ($P < 0.01$-0.001) except timing of triggering (Table 4). International level finalists stood out from other international level competitors only in their more cleaner triggering ($P < 0.05$).

TABLE 4 Shooting performance, aiming point trajectory variables, and postural balance in international level finalist shooters, international level shooters, and national level shooters. Statistically significant difference between finalists and national level shooters, ***P < 0.001, **P < 0.01, *P < 0.05. Statistically significant difference between international and national level shooters, ◦◦P < 0.01, ◦P < 0.05. Statistically significant difference between finalists and international level shooters, †P < 0.05.

	Finalists (N = 7)	International (N = 15)	National (N = 26)
Mean shooting score (points/hit)	10.40 ± 0.05***	10.29 ± 0.07	10.20 ± 0.11
Stability of hold—DevX (rings)	0.32 ± 0.03***	0.40 ± 0.04◦◦	0.48 ± 0.09
Stability of hold—DevY (rings)	0.24 ± 0.04**	0.28 ± 0.04	0.33 ± 0.07
Aiming accuracy—COG_{hit} (points)	10.58 ± 0.05***	10.51 ± 0.07◦◦	10.42 ± 0.10
Cleanness of triggering—ATV (rings)	0.21 ± 0.02***,†	0.26 ± 0.03◦	0.30 ± 0.05
Timing of triggering—TIRE (index)	2.07 ± 0.11	2.09 ± 0.12	2.11 ± 0.16
Postural balance (mm)			
sdX_7	0.73 ± 0.14	0.81 ± 0.16	0.86 ± 0.18
sdY_7	0.25 ± 0.05**	0.29 ± 0.03	0.34 ± 0.07
sdX_2	0.39 ± 0.06*	0.45 ± 0.07	0.47 ± 0.08
sdY_2	0.24 ± 0.06	0.26 ± 0.04	0.30 ± 0.07
sdX_1	0.24 ± 0.04**	0.28 ± 0.03	0.31 ± 0.05
sdY_1	0.23 ± 0.06	0.25 ± 0.04	0.28 ± 0.07

5.2 Air rifle shooting performance and shooting technical components (I-III)

5.2.1 Factors affecting shooting performance

MRA analysis showed that stability of hold (DevX), timing of triggering (TIRE), aiming accuracy (COG_{hit}), and cleanness of triggering (ATV) explained 81% of the variance in shooting score (Figure 7). DevX, COG_{hit}, TIRE, and ATV accounted for 54%, 16%, 9%, and 3% of the variance in shooting score, respectively. Regression equation prediction of the mean shot score with four variables was significant in the whole subject group, as well as in international ($R^2 = 0.89$, $P < 0.001$) and national ($R^2 = 0.86$, $P < 0.001$) level athletes. Intra-individual analysis showed that the regression equation was able to predict the mean test scores for 18 out of 21 athletes at statistically significant level (R=0.68 - 0.99, $P < 0.05$). Regression prediction of the mean shot score was also valid when the technical parameters were measured in a competition situation ($r=0.76$, $P < 0.01$).

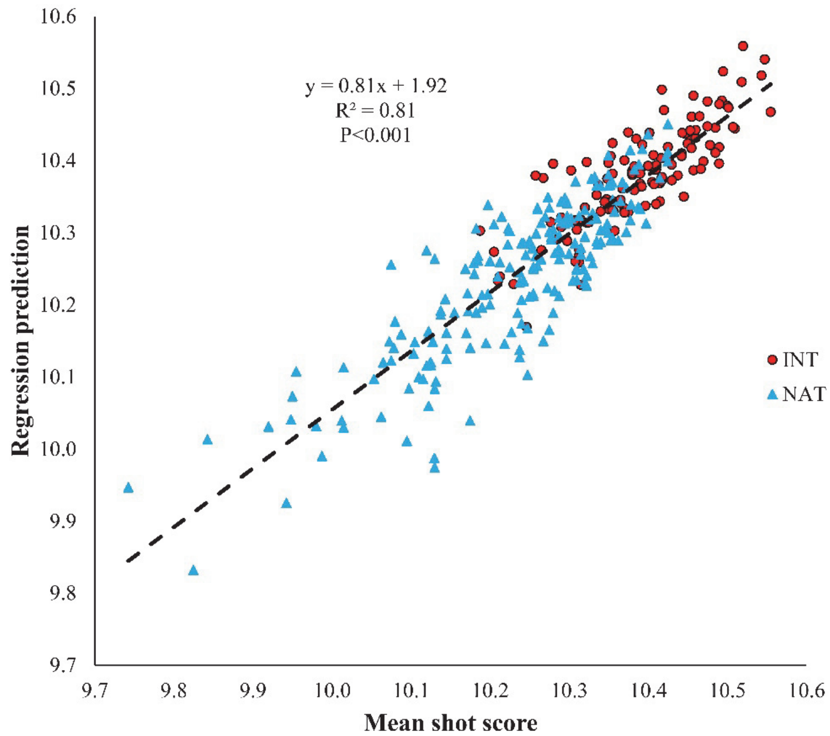

FIGURE 7 Mean test shot score and regression prediction (n = 319) in international (INT) and national (NAT) level air rifle shooters. Regression prediction was based on four variables: stability of hold (DevX), timing of triggering (TIRE), aiming accuracy (COG_{hit}), and cleanness of triggering (ATV). Regression prediction equation Y = 5.110 + (−0.502) × DevX + 0.315 × TIRE + 0.465 × COGhit + (−0.582) × ATV.

Stability of hold in horizontal (DevX, R = -0.78, p < 0.001) and vertical (DevY, R = -0.68, p < 0.001) directions were related to shooting performance (I). DevX measured in the training situation was also related to the competition mean and maximum results (Figure 8) achieved during the season (II). Stability of hold in vertical direction was 30 ± 17% smaller than the stability of hold in horizontal direction (0.30 ± 0.06 rings vs. 0.43 ± 0.09 rings, P < 0.001).

Aiming accuracy (COG_{hit}) was related to the shooting performance in the training situation (I) (R = 0.65, p < 0.001) and in the competition situation (III) (R = 0.64, p < 0.05). COG_{hit} measured in the training situation was also related to the competition mean (R = 0.52, p < 0.001) and maximum (R = 0.39, p < 0.01) results achieved during the season (II).

Cleanness of triggering (ATV) was related to shooting performance in the training situation (I) (R = -0.70, p < 0.001). ATV measured in the training situation was also related to the competition mean (R = -0.67, p < 0.001) and maximum (R = -0.75, p < 0.001) results achieved during the season (II).

Timing of triggering (TIRE) did not correlate to shooting performance in the training or competition situations.

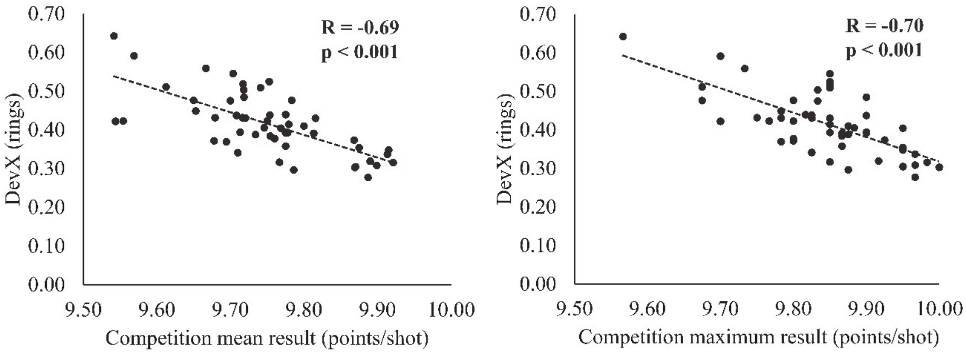

FIGURE 8 Relation of the horizontal stability of hold (DevX) to the mean and maximum competition result.

Postural balance in cross shooting direction (sdX_1) was related to shooting performance during the last phase before the shot in the training situation ($R = -0.55$, $p < 0.001$). sdX_1 measured in the training situation was also related to the competition mean ($R = -0.47$, $p < 0.001$) and maximum ($R = -0.44$, $p < 0.01$) results achieved during the season (II). sdY_1 measured in the training situation was related to the competition mean ($R = -0.37$, $p < 0.01$) and maximum ($R = -0.43$, $p < 0.01$) results achieved during the season (II). Postural balance in shooting direction was more stable than the postural balance in cross shooting direction during all analyzed time periods (sdX_7 0.83 ± 0.17 mm vs. sdY_7 0.31 ± 0.06 mm, $p < 0.001$; sdX_2 0.45 ± 0.08 mm vs. sdY_2 0.28 ± 0.06 mm, $p < 0.001$; sdX_1 0.29 ± 0.05 mm vs. sdY_7 0.27 ± 0.06 mm, $p < 0.01$).

5.2.2 Inter-relationships between shooting technical components

Postural balance was related to stability of hold (DevX, DevY) and cleanness of triggering (ATV). In the training situation (I), DevX correlated with the postural balance in cross shooting direction during the last phase before the shot (sdX_1, $R = 0.55$, $P < 0.001$). DevY correlated with the postural balance in shooting direction during all analyzed time periods (sdY_7, $R = 0.52$, $P < 0.001$; sdY_2, $R = 0.44$, $P < 0.01$; sdY_1, $R = 0.40$, $P < 0.05$), and with the postural balance in cross-shooting direction during the last second before the shot (sdX_1, $R = 0.45$, $P < 0.01$). Both sdX_1 ($R = 0.51$, $p < 0.001$) and sdY_1 ($R = 0.57$, $p < 0.001$) were related to **cleanness of triggering** (II).

Aiming accuracy (COG_{hit}) was related to stability of hold in the training situation (DevX, $R = -0.65$, $p < 0.001$; DevY, $R = -0.44$, $p < 0.01$), so that the shooters with more stable hold also aimed more accurately.

Timing of triggering (TIRE) was related to COG_{hit} in the training situation ($R = -0.43$, $p < 0.01$), so that the shooters with more accurate aiming had poorer timing of triggering.

5.3 Changes in shooting technique during the follow-up period (II)

Shooting performance in the testing situation improved during a three-year follow-up period (10.25 ± 0.14 vs. 10.33 ± 0.07, $p < 0.05$). This improvement was accompanied by improvements in stability of hold ($p < 0.01$), aiming accuracy ($p < 0.05$), cleanness of triggering ($p < 0.01$), and postural balance in shooting (sdY_7, $p < 0.01$; sdY_2, $p < 0.01$; sdY_1, $p < 0.01$) and cross shooting (sdX_2, $p < 0.01$; sdX_1, $p < 0.01$) directions. Shooting performance in competitions and timing of triggering did not change during the three-year period.

Changes between the measured seasons in stability of hold (Figure 9) and cleanness of triggering were related to the changes in mean and maximum competition shooting performances (ATV; $R = -0.46$, $p < 0.01$; $R = -0.39$, $p < 0.05$, respectively). Absolute change in DevX was related to the absolute change in sdX_1 ($R = 0.53$, $p < 0.01$), and absolute change in ATV was related to the absolute change in sdY_1 ($R = 0.58$, $p < 0.001$).

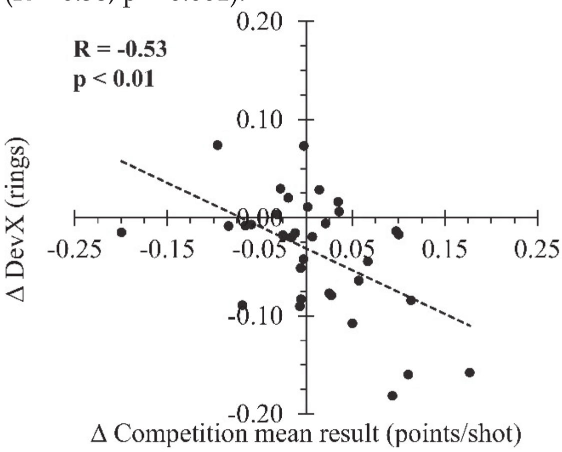

FIGURE 9 Relation of the absolute change in horizontal stability of hold (DevX) to the absolute change in mean competition result.

5.4 Effect of competition situation on shooting technique (III)

Shooting performance decreased by 1.6 ± 2.1% ($P < 0.05$) from training to competition situation (Table 5). This decrease in performance was accompanied by a reduction in all shooting technical components except timing of triggering (TIRE).

TABLE 5 Shooting performance, shooting technique and postural balance in training and competition situations. Statistically significant difference between training and competition situation, ***P < 0.001, **P < 0.01, *P < 0.05.

	Training	Competition
Mean shooting score (points/hit)	10.31 ± 0.13*	10.14 ± 0.17
Multiple regression (points/hit)	10.32 ± 0.10**	10.13 ± 0.12
Stability of hold – DevX (rings)	0.39 ± 0.06***	0.54 ± 0.07
Stability of hold – DevY (rings)	0.27 ± 0.06**	0.37 ± 0.07
Aiming accuracy – COG_{hit} (points)	10.52 ± 0.10*	10.35 ± 0.20
Cleanness of triggering – ATV (rings)	0.25 ± 0.05*	0.34 ± 0.07
Timing of triggering – TIRE (index)	2.08 ± 0.16	2.14 ± 0.31
Postural balance (mm)		
sdX_7	0.83 ± 0.18	0.78 ± 0.16
sdY_7	0.26 ± 0.04*	0.34 ± 0.07
sdX_2	0.43 ± 0.09	0.45 ± 0.04
sdY_2	0.23 ± 0.05*	0.31 ± 0.08
sdX_1	0.25 ± 0.05*	0.31 ± 0.05
sdY_1	0.22 ± 0.05*	0.29 ± 0.09

Shooters' test results in training situation correlated with the competition situation results only in shooting direction postural balance during the last second before the shot (sdY_1, $r = 0.81$, $p < 0.05$). Absolute changes in mean shooting score from training to competition situation were related to the absolute changes in DevX (Figure 10), ATV ($r = -0.56$, $p < 0.05$), and COG_{hit} ($r = 0.66$, $p < 0.05$). Absolute changes in DevX were related to the absolute changes in postural balance in shooting direction during the last second before the shot (sdY_1, $r = 0.74$, $p < 0.05$).

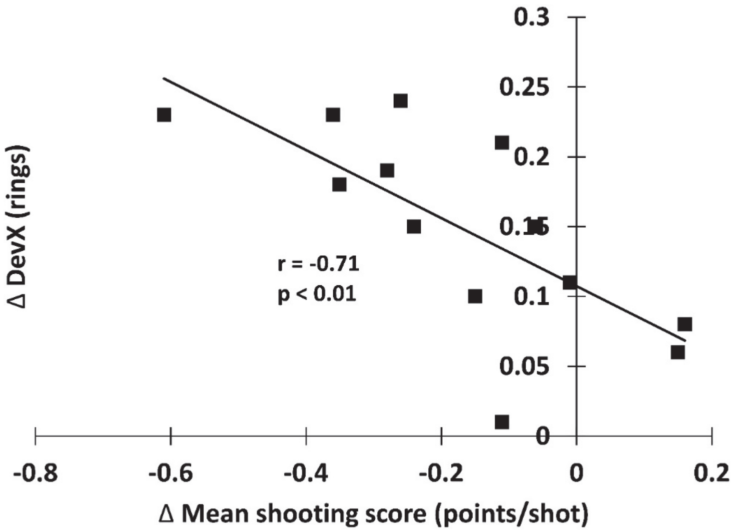

FIGURE 10 Relation of the absolute change in horizontal stability of hold (DevX) to the absolute change in mean shooting score between training and competition situation.

5.5 Biathlon shooting performance and shooting technical components (IV)

Senior level biathletes showed hit percentages (Hit%) of 92 ± 8% in rest and 80 ± 13% in shooting after the competition simulation. The junior level biathletes showed Hit% of 81 ± 8% in rest and 68 ± 20% in shooting after the competition simulation. The senior and junior biathletes differed only in Hit% in rest ($P < 0.05$) and in left leg postural balance in shooting after the competition simulation ($P < 0.05$). The competition simulation skiing task affected the senior and junior groups differently only in shooting direction postural balance. Because of the lack of differences between the senior and junior biathletes, the results in this thesis have been presented from the whole subject group. The detailed results from both subject groups are presented in study IV.

5.5.1 Factors affecting shooting performance

Hit percentage (Hit%) was related to the vertical holding ability (DevY) and cleanness of triggering (ATV) both in rest (DevY, $R = -0.66$, $p < 0.01$; ATV, $R= -0.65$, $p < 0.01$) and after competition simulation skiing task (DevY, $R = -0.54$, $p < 0.05$; Figure 11). Shooting direction postural balance of the right leg (sdY_R) was related to the Hit% in rest ($R = -0.54$, $p < 0.05$) and after competition simulation skiing task ($R= -0.70$, $p < 0.01$).

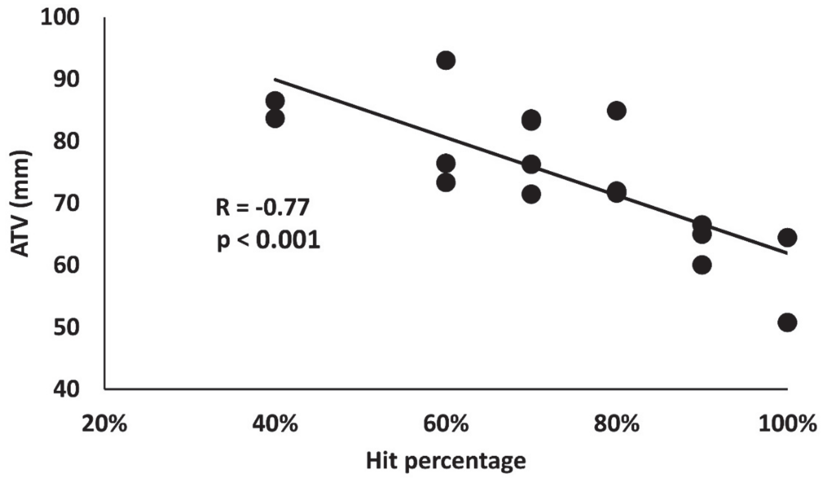

FIGURE 11 Relation of the cleanness of triggering (ATV) to the hit percentage in shooting after the competition simulation skiing task.

5.5.2 Inter-relationships between shooting technical components

All variables measured in rest correlated with the corresponding variable measured in shooting after the competition simulation except Hit%, $sdX_{0.6}$ and sdX_R. **Shooting direction postural balance** of the right leg (sdY_R) was related to DevY in rest (R = 0.63, p < 0.01) and after the competition simulation (R = 0.58, p < 0.05) and ATV in rest (R = 0.77, p < 0.001) and after the competition simulation (R = 0.67, p < 0.01).

Aiming accuracy (COG_{hit}) was related to holding ability (DevX, R = 0.70, p < 0.01; DevY, R = 0.52, p < 0.05) and postural balance in shooting direction ($sdY_{0.6}$, R = 0.66, p < 0.01) in rest and vertical holding ability (DevY, R = 0.69, p < 0.01) and postural balance ($sdX_{0.6}$, R = 0.50, p < 0.05; $sdY_{0.6}$, R = 0.54, p < 0.05) after the competition simulation.

Timing of triggering (TIRE) correlated with vertical holding ability (DevY, R = 0.68, p < 0.05) and aiming accuracy (COG_{hit}, R = 0.75, p < 0.01) after the competition simulation and horizontal holding ability (DevX, R = 0.54, p < 0.05) and aiming accuracy (COG_{hit}, R = 0.84, p < 0.001) in rest.

5.5.3 Effect of intense exercise on shooting technique

Shooting performance, stability of hold, aiming accuracy, cleanness of triggering, and postural balance decreased from rest to competition simulation shooting (Table 6). Only timing of triggering improved from rest to intense exercise (P < 0.05). Shooting time was longer (P < 0.05), and force distribution on the left leg was greater (P < 0.05) in the shooting after the competition simulation compared to shooting in rest.

TABLE 6 Shooting performance, shooting technique and postural balance in shooting in rest and after competition simulation skiing task. Statistically significant difference between rest and competition simulation, ***P < 0.001, **P < 0.01, *P < 0.05.

	Shooting in rest	Shooting after intense exercise
Shooting performance - Hit% (%)	86 ± 10**	74 ± 18
Shooting time (s)	12.4 ± 2.8*	13.9 ± 3.6
Stability of hold – DevX (mm)	23.7 ± 6.6*	26.6 ± 4.8
Stability of hold – DevY (mm)	20.6 ± 6.5***	25 ± 7.6
Aiming accuracy - COG_{hit} (mm)	39.8 ± 14.9**	46.9 ± 17.8
Cleanness of triggering – ATV (mm)	57.4 ± 9.8***	74.3 ± 10.9
Timing of triggering – TIRE (index)	2.5 ± 0.2*	2.7 ± 0.2
Postural balance (mm)		
$sdX_{0.6}$	0.69 ± 0.15	0.77 ± 0.17
$sdY_{0.6}$	0.7 ± 0.17***	0.88 ± 0.22
sdX_L	0.73 ± 0.2*	0.85 ± 0.23
sdX_R	0.71 ± 0.19*	0.89 ± 0.28
sdY_L	0.36 ± 0.18*	0.42 ± 0.21
sdY_R	0.23 ± 0.09***	0.31 ± 0.1
Force		
F_L (N)	441 ± 65	444 ± 67
F_R (N)	310 ± 49**	303 ± 45
Force distribution (%)	58.7 ± 4.7*	59.4 ± 4.7

The absolute change in ATV ($R = -0.49$, $p < 0.05$) and the absolute change in sdY_R ($R = -0.65$, $p < 0.01$) from rest to competition simulation were related to the absolute change in Hit%. The absolute change in TIRE from rest to competition simulation correlated with the absolute change in DevY ($R = 0.53$, $p < 0.05$) and the absolute change in COG_{hit} ($R = 0.55$, $p < 0.05$).

6 DISCUSSION

The purpose of this thesis was to identify the technical determinants of air rifle and biathlon standing shooting performance and investigate how these technical determinants are affected by long-term shooting training, competition situation, or intense exercise. The results of the studies showed that horizontal stability of hold, aiming accuracy, timing of triggering, and cleanness of triggering were the most important technical determinants of elite level air rifle shooting performance, explaining 81% of the variance in shooting score. Postural balance was related to shooting performance directly, and indirectly through more stable hold and cleaner triggering. Long term shooting training improved stability of hold, aiming accuracy, cleanness of triggering, and postural balance. On the other hand, all these aspects of shooting technique deteriorated in competition compared to training situation. Changes in shooting performance caused by long term shooting training or competition situation were most strongly related to the changes in horizontal stability of hold, and the changes in stability of hold were again related to the changes in postural balance. Biathlon standing shooting demonstrated some similar technical aspects to air rifle shooting, in that the vertical stability of hold and cleanness of triggering were related to shooting performance also in biathlon shooting. Postural balance was related to both of these components in biathlon similarly to air rifle shooting. Intense exercise decreased biathlon standing shooting performance, stability of hold, aiming accuracy, cleanness of triggering, and postural balance. In biathlon standing shooting, the cleanness of triggering played a more central role compared to air rifle shooting. Also, the vertical component of stability of hold was more important in biathlon standing shooting, whereas horizontal stability of hold was more important in air rifle shooting.

6.1 Air rifle shooting technical components (I-III)

The results of the present study revealed new technical determinants of elite level air rifle shooting performance. In total, six components were identified from the aiming point trajectory variables: aiming time, measurement time, stability of hold, aiming accuracy, cleanness of triggering, and timing of triggering. Four of these components, stability of hold, aiming accuracy, timing of triggering, and cleanness of triggering, were identified as the most important determinants of elite level air rifle shooting performance, accounting for 81% of the variance in shooting score (components explaining 54%, 16%, 9%, and 3% of the variance in shooting score, respectively). Shooting technical components stability of hold and aiming accuracy have been studied previously in air rifle shooting (Ball, Best & Wrigley 2003a; Konttinen, Lyytinen & Viitasalo 1998b; Konttinen, Landers & Lyytinen 2000; Zatsiorsky & Aktov 1990), but the cleanness of triggering and timing of triggering components were discovered for the first time as performance determining factors in elite level air rifle shooting.

In the present study, the number of technical components identified in air rifle shooting was greater than reported previously in running target (Mononen et al. 2003) and air pistol (Hawkins 2011) shooting. Aiming accuracy, aiming time, and stability of hold were identified as common shooting technical components in air rifle, running target, and pistol shooting. Shooting technique component cleanness of triggering was identified in air rifle shooting and in running target shooting, but not in pistol shooting. (Hawkins 2011; Mononen et al. 2003). The absence of cleanness of triggering component in pistol shooting could be related to the fact that one of the important cleanness of triggering variables (ATV) was omitted in the pistol shooting study (Hawkins 2011). Also, the timing of triggering component found in air rifle shooting was not identified in running target or pistol shooting, but again, the timing of triggering variable (TIRE) was not analyzed in the running target or pistol shooting studies. It is possible that the differences between the shooting events in the cleanness of triggering and timing of triggering components are related to the analysis methods used in the studies, rather than to the actual differences in the technique of these shooting events.

The regression equation (including stability of hold, aiming accuracy, timing of triggering, and cleanness of triggering) reported in the present study accounted for 81% of the variance in shooting score, which is a far larger percentage than the regression equations explaining 48% in air pistol shooting (Hawkins 2011), 43% in running target shooting (Mononen et al. 2003), and no significant regression in air rifle shooting (Ball, Best & Wrigley 2003a). Timing of triggering component was not included in the regression equations reported previously in running target, air pistol, and air rifle shooting. Also, cleanness of triggering component was omitted in the previous air pistol and air rifle shooting studies. (Ball, Best & Wrigley 2003a; Hawkins 2011; Mononen et al. 2003). Inclusion of these shooting technical components in the previously reported regression equations could have improved the regression equation precisions. The analysis methods and the number of measured shooters could have also affected the differences in the explained variance by the different regression equations. The regression equations have been calculated over single trials in the previous air pistol (Hawkins 2011) and running target (Mononen et al. 2003) shooting studies, instead of the test mean values used in the present study. In the previous air rifle shooting study (Ball, Best & Wrigley 2003a), the regression equation was based on six measured tests, compared to the 319 tests measured in the present study. All these factors could contribute to the differences in the amount of explained variance in the shooting score by the regression equations presented in these four shooting studies.

The applicability of the present regression equation in monitoring athletes' technical skill level is supported by the fact that the regression equation was significant in the intra-individual analysis for 18 out of 21 measured shooters, and the regression equation based on training situation measurements was valid in the competition situation (III). Every athlete and coach is able to measure the shooting technical variables used in the present regression equation with commercial shooting training systems. Together with the elite level air rifle shooters' reference values in stability of hold, aiming accuracy, timing of triggering, and cleanness of triggering (I), the regression equation can be used to assess the strengths and weaknesses in the athlete's shooting technique, and to assess the shooting performance gain in developing distinct shooting technical components. The results of the present study should be taken into consideration in designing new shooting studies, so that in addition to shooting scores, stability of hold, and postural balance, aiming accuracy, cleanness of triggering and timing of triggering should be included in order to acquire a more comprehensive description about the shooting task.

6.1.1 Stability of hold

The stability of hold was the most important technical component determining air rifle shooting performance, accounting for 54% of the variance in shooting score. Elite level air rifle shooters' stability of hold was better compared to less skilled shooters. This same result has been shown previously in air rifle (Konttinen, Lyytinen & Viitasalo 1998b; Konttinen, Landers & Lyytinen 2000; Zatsiorsky & Aktov 1990) and running target (Mononen et al. 2003; Viitasalo et al. 1999) shooting. Stability of hold in vertical direction was 30% smaller (better) than the stability of hold in horizontal direction. A similar 30% difference between vertical and horizontal stability of hold was reported previously by Ball, Best and Wrigley (2003a), and a 17% difference by Zatsiorsky and Aktov (1990) in elite level air rifle shooting.

This difference in the horizontal and vertical stability of hold could be related to the different number of degrees of freedom in these components. Two degrees of freedom, translation and rotation in the horizontal plane, have to be controlled for in the horizontal stability of hold. Only one degree of freedom, rotation in the vertical plane, has to be controlled in the vertical stability of hold. (Zatsiorsky & Aktov 1990). The simpler control strategy of the vertical stability of hold could cause the observed difference between the vertical and horizontal stability of hold. Another explanation for the observed difference in horizontal and vertical stability of hold is the postural balance in the corresponding directions. Previous studies and the present study demonstrate that the shooting direction postural balance is more stable than the cross shooting postural balance (Era et al. 1996; Konttinen, Lyytinen & Era 1999).

The results of the present study showed that the stability of hold was related to shooting performance even among elite level air rifle shooters (I). The stability of hold measures obtained from the training situation were also related to the competition performances achieved during the season. In a longitudinal analysis, the stability of hold was shown to improve during a three-year follow-up, and the shooters' individual improvements in stability of hold were related to the improvements in the competition performances (II). Previously, Mononen et al. (2007) reported a correlation between holding ability and shooting score among novice shooters. At the elite level, no such correlation has been shown previously. The stability of hold measured in the competition situation (III) did not show a statistically significant correlation to the shooting scores. Differences in the findings of these studies could arise from the smaller number of measured tests in the competition situation (III) study (n=13). In the studies I and II, the relations between stability of hold and shooting performance were based on 40 and 51 measurements.

The results of the present study showed for the first time a relation between stability of hold and postural balance in elite level air rifle shooting (I, II). Horizontal stability of hold was more closely related to cross shooting postural balance, and vertical stability of hold was more closely related to shooting direction postural balance. Longitudinal analysis also showed that improvements in stability of hold were related to the improvements in postural balance. Earlier studies have shown a correlation between postural balance variables and stability of hold among novice rifle shooters (Mononen et al. 2007). In a previous elite air rifle shooting study, only intra-individual analysis showed significant correlations between stability of hold and postural balance, and inter-individual analysis showed no significant correlations between stability of hold and postural balance (Ball, Best & Wrigley 2003a). This result is not in line with the current findings, but the difference in the results of these two studies could arise from the smaller number of participants measured in (Ball, Best & Wrigley 2003a) study (n=6) compared to the study I (n=40) and study II (n=51).

6.1.2 Postural balance

As expected, international level shooters demonstrated more stable postural balance compared to national level athletes. Similar findings regarding the differences in postural balance between elite and pre-elite shooters have been reported previously in air rifle (Era et al. 1996; Konttinen, Lyytinen & Era 1999; Mon et al. 2014) and running target shooting (Viitasalo et al. 1999). Era et al. (1996) also reported that elite-level rifle shooters were able to decrease the amount of postural sway prior to shot moment more than less skilled shooters. This result is in line with the current findings, since the differences between international and national level shooters in the cross-shooting direction postural balance became evident only during the last second before the shot.

Postural balance was related to shooting performance directly, and indirectly through more stable hold and cleaner triggering (I, II). As in the case of stability of hold, previous studies have shown postural balance to be related to shooting performance in novice (Mononen et al. 2007) but not in elite level air rifle shooters (Ball, Best & Wrigley 2003a). Again, the differences in these results could be related to the smaller number of participants measured in the study by Ball, Best and Wrigley (2003a). The relations between postural balance and stability of hold and between postural balance and cleanness of triggering suggest that the effect of postural balance on shooting performance is mediated through these shooting technical components. The regression equation showed that when stability of hold and cleanness of triggering were already considered in the regression, the inclusion of postural balance in the equation increased the regression equation precision by less than 1%.

The results of the present study supported previous studies showing that the postural balance in shooting direction (medio-lateral) was more stable than the balance in cross shooting (antero-posterior) direction. Several studies in air rifle shooting (Ball, Best & Wrigley 2003a; Era et al. 1996; Konttinen, Lyytinen & Era 1999) as well as in normal quiet bipedal standing (Cornilleau-Peres et al. 2005; Day et al. 1993; Doyle et al. 2007; Lafond et al. 2004; Prieto et al. 1996; Winter et al. 1998) have shown that postural balance is more stable in the medio-lateral compared to antero-posterior direction. In normal quiet standing, the medio-lateral postural stability has also been shown to increase with larger stance widths (Day et al. 1993; Mouzat, Dabonneville & Bertrand 2004; Winter et al. 1998). The increase in medio-lateral postural stability with larger stance widths has been attributed to the passive stiffening of the leg-pelvic structure rather than to active muscle coordination (Day et al. 1993).

The control of the two postural balance directions has been shown to differ and to be independent of each other in normal quiet standing (Balasubramaniam, Riley & Turvey 2000; Winter et al. 1993). Antero-posterior balance is controlled for by the ankle dorsiflexor and plantar flexor muscle activities and COP changes under both feet (Loram, Maganaris & Lakie 2005; Winter et al. 1993), whereas medio-lateral balance is controlled for by the loading and unloading of the right and left leg (Winter et al. 1993). This results in bipedal stance being inherently more stable in the medio-lateral direction, which explains the postural balance differences observed in the shooting posture. In the rifle shooting situation, the results from normal quiet standing could mean that the shooting direction postural balance is more related to the anatomy of the shooting posture, whereas the cross-shooting direction postural balance is more related to the active muscle coordination of the plantar flexors and dorsiflexors.

The differences in the control of the postural balance in shooting and cross-shooting directions give cause for speculation in the source of postural instabilities observed in the shooting posture. The cross-shooting direction postural sway is likely related to the muscle activation and coordination as in the case of normal quiet standing (Loram, Maganaris & Lakie 2005; Winter et al. 1993). In shooting direction postural balance, it is possible that the instabilities arise mainly from internal mechanical disturbances, so called microvibrations propagating through the body, which are caused by for example heartbeat and blood movements. These microvibrations have been documented in normal quiet standing, and the microvibrations were shown to cause vertical force component peak-to-peak values in the range of 1.3-3.0 N (Bircher et al. 1978; Conforto et al. 2001; Sturm, Nigg & Koller 1980). In air rifle shooting, this vertical force component caused by the heart beat and blood movements could affect the vertical movement of the gun barrel. The gun point is located far from the body center of mass, so even slight movements of the gun barrel could be seen in the shooting direction postural balance. If this speculation would turn out to be true, it would mean that the stability of hold in horizontal direction is mainly a result of refined muscle activity and coordination, whereas the stability of hold in vertical direction and cleanness of triggering would be a result of efficient shooting posture and damping of the microvibrations. However, this aspect of the association between heartbeat, postural balance, and rifle stability was not investigated in this thesis and is a topic for future studies.

6.1.3 Aiming accuracy

Aiming accuracy was the second largest shooting technical component affecting shooting performance, explaining 16% of the variance in the shooting score. Longitudinal analysis showed that aiming accuracy improved during a three-year follow-up. The present study was the first study to show a relation between aiming accuracy and shooting performance, both in the training and competition situations. International level shooters also demonstrated more accurate aiming compared to athletes of lesser skill level.

Aiming accuracy has been identified as an important technical component in other shooting events, such as running target (Mononen et al. 2003) and pistol (Ball, Best & Wrigley 2003b; Hawkins 2011) shooting. In accordance with the results of the present study, pistol shooting aiming accuracy was shown to be related to shooting performance in groups of national (Hawkins 2011) and elite (Ball, Best & Wrigley 2003b) level shooters. Another interesting aspect discovered about the air rifle shooting aiming accuracy was its relation to stability of hold. More stable hold increased aiming accuracy, and this result is intuitively easy to accept: it is easier to aim the gun at the center of target, when the gun is moving as little as possible. Other factors, such as the eyesight and the shot-to-shot variation in the position of the eye in relation to the rifle sights, are likely to affect the aiming accuracy, but were not investigated in this study.

6.1.4 Timing of triggering

The timing of triggering was the third largest shooting technical component affecting shooting performance, explaining 9% of the variance in shooting score. Timing of triggering differed from other shooting technical components in that the effect of timing of triggering on shooting performance was evident only when the technical skill level in other shooting technical components was taken into account in the multiple regression analysis. On its own, the timing of triggering was not related to shooting performance in training situation nor in the competition situation. Timing of triggering was the only shooting technical component which did not improve during a three-year follow-up, and there were no differences in the timing of triggering component between shooters of different skill level. Konttinen, Landers and Lyytinen (2000) reported the same finding and stated that timing of triggering does not differ between elite- and pre-elite shooters. The authors also pointed out that even though the timing of triggering values did not differ between elite and pre-elite shooters, the effect of timing of triggering on shot score was smaller in elite level athletes because of their more stable holding ability (Konttinen, Landers & Lyytinen 2000). This notion is partly supported by the results of the present study. The multiple regression equation shows that if two athletes have similar timing of triggering values, the athlete with the better holding ability will perform better. On the other hand, the linear regression model suggests that the effect of timing of triggering on shot score is similar regardless of the performance level in other aspects of shooting technique.

An interesting notion about the timing of triggering was its relation to aiming accuracy, in that the timing of triggering was better in shooters with less accurate aiming. It seems that when the aiming point is farther away from the center of target (poor aiming accuracy), it is easier for the shooter to notice and time the triggering so that the aiming point is moving towards the center of target. When the aiming point is circling around the exact center of the target (good aiming accuracy), it is harder for the shooter to notice when the aiming point is moving towards or away from the center of target.

6.1.5 Cleanness of triggering

The cleanness of triggering was the fourth largest shooting technical component affecting shooting performance, explaining 3% of the variance in shooting score. Cleanness of triggering was related to shooting performance in the training situation, and cleanness of triggering measured in the training situation was related to shooting competition results achieved during the season. Longitudinal analysis showed that cleanness of triggering improved during a three-year follow-up, and these improvements were related to the improvements in the competition performances. Cleanness of triggering has not been studied previously in air rifle shooting, but it has been related to shooting performance in running target (Mononen et al. 2003) and pistol (Hawkins 2011) shooting.

In the present study, the international level athletes demonstrated better cleanness of triggering values compared to national level athletes. It is noteworthy, that this aspect of shooting technique was the only component separating the international level finalists from the other international level shooters. As stated before, the cleanness of triggering was related to postural balance, especially the postural balance in shooting direction. The improvements observed in the cleanness of triggering were also related to the improvements in shooting direction postural balance. If the speculations discussed previously in the postural balance section hold true, the finalist level athletes could have developed the shooting posture so that the effect of heartbeat and microvibrations are damped more efficiently. It is also possible that the finalist level athletes are better at finding the best possible moment with the least amount of movement to fire the shot, or the actual trigger pulling action of the trigger finger is better and causes no additional movement to the rifle alignment. These speculations cannot be confirmed based on the measurements in the present study and require further studies in order to clarify the components affecting cleanness of triggering.

6.2 Competition situation and shooting performance (II, III)

Shooting performance and shooting technical components stability of hold, aiming accuracy, cleanness of triggering, and postural balance measured in the training situation were related to the competition performances. The regression equation explaining 81% of the variance in shooting score in the training situation was also valid in the competition situation and taken together these results suggest that the same shooting technical aspects are determining performance in the competitions as in the training situation.

The longitudinal analysis conducted in the present study showed that professional shooting training improved training situation shooting performance, accompanied by improvements in stability of hold, cleanness of triggering, aiming accuracy, and postural balance. Even though in the training situation all these aspects of shooting technique improved on group level, there were no statistically significant changes in the competition shooting performances. The results of the present study offer two different explanations for this inconsistent finding. Firstly, the longitudinal analysis also showed that the changes in stability of hold and the changes in cleanness of triggering in the training situation were related to the changes in the competition performances. This means that even though on group level there were no changes in the competition performances, the individuals who were able to increase their skill level in stability of hold or cleanness of triggering also improved their competition performances. Secondly, the competition situation measurements conducted in the present study showed that on average, the shooting performance decreased by 1.6 ± 2.1% from training situation to competition situation. This decrease was highly individual and related to the shooters' ability to maintain the shooting technical measures stability of hold, aiming accuracy, cleanness of triggering, and postural balance at training situation level. This effect of competition situation on shooting performance and shooting technical variables obviously confounds the relationship between improvements in training situation and improvements in competition situation.

The observed shooting performance decrease between training and competition situation was accompanied by a reduction in stability of hold, aiming accuracy, cleanness of triggering, and postural balance. Only timing of triggering remained at training situation level. The change in shooting performance from training to competition situation was related to the changes in horizontal holding ability, aiming accuracy and cleanness of triggering. Closer look at the changes in horizontal holding ability revealed a correlation to the changes in shooting direction postural balance. As stated before, the decrease in shooting technical variables was highly individual, since only the postural balance in shooting direction correlated between the training and competition situation measurements. This means that the shooting performance decrease observed in the whole subject group from training to competition was not similar in all shooters, and some athletes were able to maintain the training situation level better than others.

One possible reason behind the shooting performance decrease from training to competition is the competition situation state anxiety and its effect on heart rate and blood pressure. It has been shown that state anxiety increases heart rate and blood pressure in performing musicians (Abel & Larkin 1990). Previously it has been shown that artificially increased heart rate and blood pressure by caffeine supplement can result in decreased shooting performances (Mohsen, Pordanjani & Fereshte 2015). It could be speculated that an increase in the heart rate during the competition situation could have an influence on postural balance (Conforto et al. 2001), leading to decreased holding ability and ultimately decreased shooting performance. The relations between postural balance, holding ability, and shooting performance were investigated and discovered in the present study, but the effects of state anxiety, heart rate, and blood pressure on postural balance were not investigated and remain purely speculative.

The differences observed in the present study in the shooters' ability to maintain the shooting performance and technique in competition at training situation level have some corresponding results from the previous studies. Firstly, state anxiety has been shown to be related to competition shooting performances (Sade et al. 1990). Secondly, a meditation training program was shown to increase competition shooting performance, even without concurrent increase in training situation shooting performance (Solberg et al. 1996). Thirdly, a case study about cognitive-behavioral intervention was able to reduce state anxiety and increase competition shooting performance (Prapavessis et al. 1992). Taken together these results suggest that high performance in competition requires psychological skills and coping mechanisms, that the shooters differ in their ability to cope with the competition situation, and that the athletes are able to improve these psychological factors through training.

One possible strategy to cope with the increased psychological pressure in the competition situation is directing visual attention externally to critical task information. Vickers and Williams (2007) showed that biathletes were able to perform better in a high pressure shooting task, when they maintained or increased their final fixation time (quiet eye duration) on the target before the shot. This external focus might help the athletes to concentrate on the relevant task information and prevent an unwanted shift in focus inwardly to the normally automatic technical, physiological, or emotional aspects. (Vickers & Williams 2007).

In the present study, the decrease in shooting performance from training to competition situation was substantial. The shooting score decrease of 0.17 points per shot (1.6%) is equivalent to 10.2 points in men's qualification round result. In Rio 2016 Olympic Games, 10.2-point difference in the men's qualification round result was the difference between qualifying for the final (8th place) and placing 7th from last in the competition (44th place). This result highlights the fact that small variations in the shooting results greatly influence performance outcomes and placements in the elite level air rifle shooting competitions. On the other hand, the 0.17 points per shot difference observed in the present study is in the same range as the shooting performance differences observed in the Olympic Games. The eight finalists in men's Rio 2016 Olympic Games fired 10.45 ± 0.02 points per shot in the qualification round and 10.17 ± 0.11 points per shot in the final stage. On average, the Olympic finalists' shooting performance decreased by 0.28 points per shot (2.7%) in men's and 0.21 points per shot (2.0%) in women's competition from qualification to final round. This decrease in Olympic final shooting performance is similar to the performance decrement seen in the present study, suggesting that the same mechanisms could affect performance outcomes even in the absolute elite rifle shooting level.

6.3 Technical components in biathlon standing shooting (IV)

The results of this study showed that cleanness of triggering, vertical holding ability and postural balance were related to biathlon standing shooting performance in rest and after intense exercise. 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. The decrease in cleanness of triggering from rest to load shooting condition 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.

The results of the present study confirm the results of the previous studies 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. (2014) found similar relationships between 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 (Sattlecker et al. 2017). In contrast to previous studies, 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% of peak heart rate differs from the normal biathlon competition with varying terrain and heart rate profile, and this can be considered as a limitation of the present study. Also, since the competition simulation skiing was done without rifle the fatigue effects might have been slightly different compared to normal biathlon competition.

The results of the present study showed for the first time that cleanness of triggering is an important aspect of biathlon standing shooting technique. Out of all the measured variables, cleanness of triggering had the strongest relation to shooting performance both in rest and in shooting after the race simulation. 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 was related to air rifle (I, II) and running target (Mononen et al. 2003) 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.

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 (Zatsiorsky & Aktov 1990) 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 because these biathletes 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 (I, II, III) and air pistol (Hawkins 2011) 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 into account. (I, II, III). The number of tests conducted in the biathlon 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 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. (1992), 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 (III). Timing of triggering was also related to the aiming accuracy in the training situation in air rifle shooting, i.e. the athletes aiming further away from the center of target had better timing of triggering. 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.

Apart from timing of triggering, 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 (III). The observed decrease in postural balance from rest to intense exercise could be related to the increased heart rate (Conforto et al. 2001) and/or decreased muscle coordination and fatigue caused by the intense exercise (Madigan, Davidson & Nussbaum 2006).

National team biathletes demonstrated better test results only in hit percentage in rest and left leg postural balance in shooting direction in shooting after the competition simulation compared to junior team biathletes. Intense exercise affected only shooting direction postural balance differently between the groups. Previously Sattlecker et al. (2014) showed that in shooting without physical stress, national level biathletes had more stable hold and postural balance compared to junior biathletes. The differences in the results of these studies could be related to the smaller sample size measured 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 was not based on shooting performance alone so much as on the combined performance level in shooting and cross-country skiing.

The results of the present study have practical significance to the biathlon 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 a 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. 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.

7 MAIN FINDINGS AND CONCLUSIONS

The purpose of this thesis was to identify technical determinants of elite level air rifle and biathlon standing shooting performance and to investigate how these technical determinants are affected by long-term shooting training, competition situation, or intense exercise. The main findings and conclusions of the present thesis are as follows:

1. Horizontal stability of hold, aiming accuracy, timing of triggering, and cleanness of triggering were the most important technical determinants of elite level air rifle shooting performance, explaining 81% of the variance in shooting score.

2. Postural balance was related to air rifle shooting performance directly and indirectly through more stable hold and cleaner triggering.

3. Shooting technique test measures were related to the competition results achieved during the season. The technical components determining shooting performance were the same in training and competition situations.

4. Long term shooting training improved stability of hold, aiming accuracy, cleanness of triggering, and postural balance. All these aspects of shooting technique deteriorated in competition compared to training situation.

5. Changes in shooting performance caused by long term shooting training or competition situation were most strongly related to the changes in horizontal stability of hold. The changes in stability of hold were again related to the changes in postural balance.

6. In biathlon standing shooting, vertical stability of hold and cleanness of triggering were related to shooting performance. Postural balance affected both of these components.

7. Intense exercise decreased biathlon standing shooting performance, stability of hold, aiming accuracy, cleanness of triggering, and postural balance. The decrease in these shooting technical components was related to the decrease in postural balance.

In summary, the novel finding of the present study was the inclusion of all the relevant shooting technical components in the studies. The large number of tests conducted in the studies allowed us to use mean test values in the statistical analysis instead of individual shots, which clarified the effect of different shooting technical components on shooting performance. This result should be taken into consideration in designing new shooting studies, and all the relevant shooting technical components should be included in order to acquire a more comprehensive description about the shooting task. Similar models including stability of hold, aiming accuracy, cleanness of triggering, and timing of triggering could explain shooting performance in a wide variety of target shooting sports. The elite level shooters' reference values presented in this thesis can be used by athletes and coaches in pursuing superior rifle shooting technique and in assessing shooters' technical strengths and weaknesses.

Postural balance was related to shooting performance, stability of hold, and cleanness of triggering even at the elite rifle shooting level. This result should be taken into consideration in designing training programs for shooters. The differences in the postural balance in shooting and cross shooting directions could have implications for the optimal shooting training: problems in the shooting direction postural balance may be addressed more efficiently by changes in the shooting posture, and problems in the cross shooting postural balance may be addressed more efficiently by balance and muscle coordination training. However, the speculations presented in this thesis regarding the effect of heart beat on postural balance, stability of hold and cleanness of triggering should be experimentally confirmed.

Lastly, the results of the present thesis demonstrated the importance of psychological skills, since all the long-term progress made through technique training could be lost in the competition situation. This result emphasizes the need for multi-disciplinary studies so that the psychological, physiological and technical aspects of target shooting could be combined to draw even more comprehensive conclusions.

YHTEENVETO (FINNISH SUMMARY)

Huippuampujien osumatarkkuutta määrittävät tekniset osa-alueet

Huippuampujilla osumatarkkuuteen vaikuttavia teknisiä osa-alueita on tarkasteltu pääasiassa pidon vakauden ja tasapainon kannalta. Huippuampujilla on todettu olevan vakaampi pito ja tasapaino verrattuna kansallisen tason ampujiin tai aloitteleviin ampujiin. Aloittelevilla ampujilla pidon vakauden ja tasapainon on todettu olevan yhteydessä osumatarkkuuteen. Toistaiseksi kuitenkaan huippuampujilla ei vastaavaa yhteyttä ole pystytty osoittamaan. Monissa huippuammuntaa käsittelevissä tutkimuksissa muut osumatarkkuuteen mahdollisesti vaikuttavat tekijät, kuten tähtäyksen tarkkuus ja liipaisukontrolli, on jätetty huomiotta. Tämän tutkimuksen tarkoituksena oli määritellä ilmakivääriammunnan ja ampumahiihdon pystyammunnan osumatarkkuuteen vaikuttavat tekijät, sekä tutkia miten nämä osa-alueet muuttuvat harjoittelun, kilpailutilanteen tai fyysisen kuormituksen seurauksena.

Tutkimuksessa mitattiin yhteensä 40 kansainvälisen ja kansallisen tason ilmakivääriampujaa, sekä 17 ampumahiihtäjää. Ilmakiväärissä mitattiin maajoukkueleireillä ampujien suoritustekniikkaa kausilla 2009-2016. Ampujat suorittivat jokaisella testikerralla kilpailunomaisen ammuntasarjan. Suoritustekniikan mittaukseen käytettiin optista ammuntajärjestelmää, jolla mitattiin tähtäyspisteen liikerata ja osuma jokaisesta laukauksesta. Lisäksi tasapainolevyn avulla mitattiin ampujan painekeskipisteen liikerata suorituksen ajalta. Ampujien kilpailutulokset kerättiin kaikilta mitatuilta kausilta. Lisäksi ilmakiväärissä toteutettiin kaksi kilpailutilanteen mittausta kausilla 2015 ja 2016, joissa mitattiin samat muuttujat kuin maajoukkueleirien harjoitustilanteissa. Ampumahiihdossa mitattiin samat muuttujat kuin ilmakiväärissä. Erona testitilanteiden välillä oli ampumahiihdossa käytetty viiden täplän ampumahiihtotaulu ja ammunnan mittaus sekä lepo- että rasitustilanteissa. Rasitustilanteessa ampumahiihtäjät ampuivat välittömästi viiden minuutin kisavauhtisen rullahiihtokuormituksen jälkeen.

Tutkimuksen tulokset osoittivat, että vaakapidon vakaus, tähtäyksen tarkkuus, liipaisun ajoitus ja liipaisun puhtaus olivat tärkeimmät ilmakivääriammunnan osumatarkkuutta määrittävät tekijät. Nämä tekijät selittivät 81% ammuntatuloksesta (pidon vakaus 54%, tähtäyksen tarkkuus 16%, liipaisun ajoitus 9% ja liipaisun puhtaus 3%). Tasapainon vaikutus osumatarkkuuteen välittyi pidon vakauden ja liipaisun puhtauden kautta. Ammuntatestien tulokset olivat yhteydessä kauden aikana saavutettuihin kilpailutuloksiin. Pitkittäistutkimuksessa todettiin ammunnan harjoittelun kehittävän pidon vakautta, tähtäyksen tarkkuutta, liipaisun puhtautta ja tasapainoa. Toisaalta nämä kaikki osa-alueet heikkenivät kilpailutilanteessa harjoitustilanteeseen verrattuna. Harjoittelun tai kilpailutilanteen aiheuttamat muutokset osumatarkkuudessa olivat selkeimmin yhteydessä vaakapidon muutoksiin. Vaakapidon muutokset taas olivat yhteydessä tasapainon muutoksiin.

Ampumahiihdossa pystypidon vakaus ja liipaisun puhtaus olivat yhteydessä osumatarkkuuteen sekä lepo- että rasitustilanteessa. Tasapainon vakaus vaikutti näihin molempiin osa-alueisiin. Rullahiihtokuormitus heikensi osumatarkkuutta, minkä lisäksi kaikki ammuntatekniset osa-alueet liipaisun ajoitusta lukuun ottamatta heikkenivät. Teknisten osa-alueiden heikkeneminen oli yhteydessä tasapainon heikkenemiseen.

Tässä tutkimuksessa pystyttiin löytämään ilmakiväärin ja ampumahiihdon osumatarkkuuden kannalta oleellisia tekijöitä, sekä muuttujia jotka kuvaavat näitä osa-alueita. Tulevissa ammunnan tutkimuksissa kaikki tässä tutkimuksessa esitetyt ammuntatekniikan osa-alueet tulisi mitata ja ottaa huomioon, jotta ammuntatekniikasta saadaan kokonaisvaltaisempi kuva. Urheilijat ja valmentajat voivat käyttää tässä tutkimuksessa esitettyjä huippuampujien viitearvoja ampujan tekniikan vahvuuksien ja heikkouksien tunnistamiseen. Tutkimuksessa esitetyt muuttujat soveltuvat harjoittelun vaikutusten seuraamiseen, mikä on tärkeä osa huippu-urheilijan harjoittelun optimointia ja kehitystä. Tasapainon vakaus on yksi selkeä ammuntatekniikan eri osa-alueisiin vaikuttava tekijä, ja erilaisilla tasapainon harjoitteilla on todennäköisesti mahdollista parantaa ammuntatekniikkaa.

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by

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Determinants of elite-level air rifle shooting performance

S. Ihalainen[1,2], S. Kuitunen[1], K. Mononen[1], V. Linnamo[2]

[1]KIHU – Research Institute for Olympic Sports, Jyväskylä, Finland, [2]Department of Biology of Physical Activity, University of Jyväskylä, Jyväskylä, Finland
Corresponding author: Simo Ihalainen, MSc, KIHU – Research Institute for Olympic Sports, Rautpohjankatu 6, 40700 Jyväskylä, Finland. Tel: +358 50 338 9519, Fax: +358 20 781 1501, E-mail: simo.ihalainen@kihu.fi

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This study focused on identifying the most important factors determining performance in elite-level air rifle shooting technique. Forty international- and national-level shooters completed a simulated air rifle shooting competition series. From a total of 13 795 shots in 319 tests, shooting score and 17 aiming point trajectory variables were measured with an optoelectronic device and six postural balance variables were measured with force platform. Principal component analysis revealed six components in the air rifle shooting technique: aiming time, stability of hold, measurement time, cleanness of triggering, aiming accuracy, and timing of triggering. Multiple regression analysis identified four of those, namely stability of hold, cleanness of triggering, aiming accuracy, and timing of triggering as the most important predictors of shooting performance, accounting for 81% of the variance in shooting score. The direct effect of postural balance on performance was small, accounting for less than 1% of the variance in shooting score. Indirectly, the effect can be greater through a more stable holding ability, to which postural balance was correlated significantly ($R = 0.55$, $P < 0.001$). The results of the present study can be used in assessing athletes' technical strengths and weaknesses and in directing training programs on distinct shooting technical components.

Air rifle shooting is an Olympic event, in which the athletes try to hit a stationary target from a distance of 10 meters (ISSF Rules and Regulations, 2013). The diameter of the 10-ring is 0.5 mm, and the best shooters are able to hit the 10-ring with every shot in a competition series of 40 (female) or 60 (male) shots. This level of precision requires high and stable technical skill level from the athlete. In air rifle shooting, the stability of hold has been identified as one important factor in determining shooting performance (Zatsiorsky & Aktov, 1990; Konttinen et al., 1998). The stability of hold has been shown to be better in a group of elite air rifle shooters compared with athletes of lower skill level, and the stability of hold discriminates between low and high scoring shots in groups of elite, pre-elite (Konttinen et al., 1998), and novice shooters (Mononen et al., 2007). Ball et al. (2003) also found significant correlations between shooting score and stability of hold on individual but not on a group level among elite air rifle shooters.

Another important factor determining shooting performance is postural balance. Elite-level air rifle shooters have shown superior balance compared with controls who are untrained in shooting disciplines (Aalto et al., 1990). Postural balance has been shown to differ between elite, pre-elite, and novice air rifle shooters (Era et al., 1996). Elite shooters have smaller center of pressure sway velocities both in antero-posterior and medio-lateral directions compared with shooters of lower skill level (Konttinen et al., 1999). Furthermore, elite air rifle shooters have been shown to be able to decrease the amount of body sway prior to the shot execution (Era et al., 1996). Mononen et al. (2007) showed a relationship between postural balance, stability of the rifle hold, and performance in a group of inexperienced rifle shooters. Postural balance has also been shown to be related to performance in air pistol shooting (Mon et al., 2014b). On the other hand, in a group of elite-level air rifle shooters, no correlation was found between postural balance, stability of the rifle hold, and performance in interindividual analysis. In intraindividual analysis however, correlations were observed between postural balance, rifle hold, and shot scores (Ball et al., 2003).

Technical components of shooting have been identified from the aiming point trajectory data in running target (Mononen et al., 2003) and pistol (Hawkins, 2011) shooting, but not in air rifle shooting. Mononen et al. (2003) identified four different components in running target shooting technique: stability of hold, aiming accuracy, cleanness of triggering, and time on target. The same technical components excluding cleanness of triggering were identified also in pistol shooting (Hawkins, 2011). Even though air rifle shooting differs considerably from running target shooting (moving vs stationary target, open vs closed shooting position, limited vs unlimited aiming time, less vs more supportive shooting clothing) and pistol shooting (pistol vs rifle, pistol supported at arm's length from the torso vs rifle supported by both arms and torso, no supportive vs supportive shooting clothing), the analysis of shooting technical components could reveal new insights in air rifle shooting technique. Until today, air rifle shooting research has focused mainly on stability of hold and postural balance. However, these variables have not been found to correlate with performance at the elite air rifle shooting level. Other technical aspects, such as aiming accuracy and cleanness of triggering, have not been studied as possible performance-determining factors in air rifle shooting. Therefore, the aim of this study was to (a) identify the most important performance-determining factors in elite-level air rifle shooting; and (b) find the best variables to describe these different aspects of shooting technique. It was hypothesized that in addition to stability of hold and postural balance, aiming accuracy and cleanness of triggering would be important characteristics in defining superior air rifle shooting performance.

Methods

Participants

Forty international- and national-level male (18) and female (22) air rifle shooters volunteered to participate in the study. In this study, 19 shooters who have participated in international competitions (World Cup, Olympic Games, European Championships, or World Championships) were classified as international-level athletes (INT, $n = 19$) and 21 shooters who have belonged to Finnish national teams and competed in Finnish national championships were classifies as national-level athletes (NAT, $n = 21$). There were no statistically significant differences in the test shot scores between the international-level males and females nor between the national-level males and females, so males and females were considered as one group both in international- and national-level athletes.

Participants signed an informed consent prior to testing. The study was conducted according to the ethical principles of the ethical committee of the University of Jyväskylä. The measurements in the present study were part of athletes' normal shooting technique testing during the seasons 2009–2014, conducted on national team training camps. The testing occasions have been conducted throughout the training and competition seasons, and the possible effect of the seasonal variation in test results has not been taken into account in this study. Testing complied with the current Finnish laws regarding testing of human subjects.

Experimental task

The measurements consisted of an unlimited number of sighting and warm-up shots followed by a simulated competition series of 40 (female) or 60 (male) shots. Shooting conditions were set up on an indoor shooting range according to the rules and regulations in ISSF air rifle competitions (ISSF Rules and Regulations, 2013), with 10-meter shooting distance into a standard air rifle target (45.5 mm total target diameter and 0.5 mm 10 ring diameter). All participants used their own competition equipment (gun, clothing, and shoes) during the measurements.

Shooting score and aiming point trajectory

The shooting task was carried out with Noptel ST 2000 (Noptel Inc., Oulu, Finland) training device (Fig. 1). The training device consisted of an optical transmitter-receiver unit (weight 80 g) attached to the barrel of the gun and a reflector attached around the center of the target. The optical unit was connected to a personal computer for data visualization, analysis, and storage. Hit point (shooting score) and aiming point trajectory were recorded from every test series shot at 100 Hz sampling rate and 0.1 mm

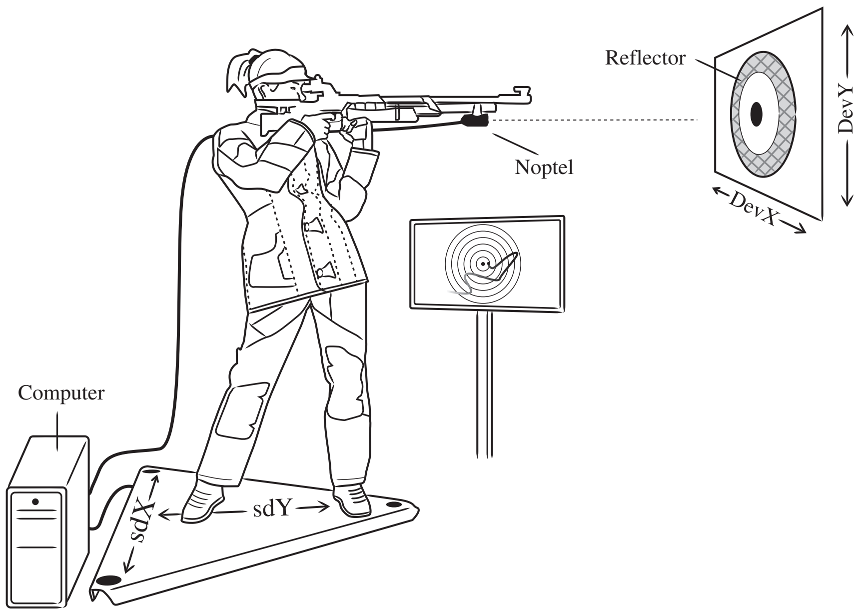

Fig. 1. Measurement setup.

Table 1. Variables calculated from the aiming point trajectory

Component	Variable (unit)	Description
Overall performance	Shooting score (pts)	Shot score as measured in air rifle shooting: 0–10.9
Stability of hold	DevX (ring)	Horizontal (DevX) and vertical (DevY) standard deviations of the location of the aiming point during
	DevY (ring)	The last second, interval between two consecutive hit rings as measurement unit (2.5 mm/ring)
	Hit_f (%)	Percentage of aiming time spent inside the 10-ring drawn around the hit point during the last second
	Hit_r (%)	Percentage of aiming time spent inside the 9-ring drawn around the hit point during the last second
	COG_f (%)	Percentage of aiming time spent inside the 10-ring drawn around the COG_{hit} point during the last second
	COG_r (%)	Percentage of aiming time spent inside the 9-ring drawn around the COG_{hit} point during the last second
Aiming accuracy	COG_{hit} (pts)	Mean location of the aiming point during last second
	$Target_f$ (%)	Percentage of aiming time spent inside the 10-ring during the last second
	$Target_r$ (%)	Percentage of aiming time spent inside the 9-ring during the last second
Cleanness of triggering	ATV (ring)	Movement of the aiming point during the last 0.2 s, interval between two consecutive hit rings as measurement unit (2.5 mm/ring)
	RTV (index)	ATV divided by the mean value of the movement of the aiming point in 0.2 s sequences between 0.6 and 2 s before triggering
Time on target	Total time (s)	Total aiming time
	Time on target (s)	Aiming time spent continuously on the target
	$Target_{ht}$ (s)	Aiming time spent inside the 7-ring
	Hit_{ht} (s)	Aiming time spent inside the 7-ring drawn around the hit point
	COG_{ht} (s)	Aiming time spent inside the 7-ring drawn around the COG_{hit} point
Timing of triggering	TIRE (index)	Time period when the mean location of the aiming point is closest to the center 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

Variable abbreviations have been selected according to the Noptel manufacturer abbreviations in order to ease the application of results in practice.

accuracy. Hit point and aiming point trajectory data was replayed to the athlete after the shot on a computer display. Seventeen variables were analyzed from the aiming point trajectory data of each shot with Noptel software, and these variables were stored for later analysis.

The variables analyzed in Noptel software included shot score and 16 variables described in Mononen et al. (2003). These variables represented four different components in running target shooting: stability of hold, aiming accuracy, cleanness of triggering, and time on target (Table 1). In the present study, the variables describing holding and aiming ability were calculated over the last second preceding the triggering as recommended by the current Noptel software, instead of the 3-s period used in Mononen et al.'s (2003) study. In addition to the 16 variables used by Mononen et al. (2003), a variable describing the timing of triggering (TIRE) was analyzed.

Postural balance

Participants fired the shots standing on a triangular-shaped (1175 mm × 1175 mm × 1175 mm) force platform (Good Balance, Metitur Ltd., Jyväskylä, Finland). Force platform was equipped with strain-gauge transducers in each corner of the force platform. The signals were amplified and collected at 200 Hz with 16-bit A/D-converter (National Instruments Co., Austin, Texas, USA) and stored on personal computer hard drive for further analysis. Triggering moment was identified from the balance data based on microphone data collected synchronously with the same A/D-converter. Centre of Pressure (COP) coordinate data was filtered with fourth-order zero-phase lag digital low pass filter with 10 Hz cutoff frequency, as recommended by (Ruhe et al., 2010). Postural balance was measured as standard deviation of the COP location in shooting direction (SDY) and perpendicular to shooting direction (SDX) during three time periods: 7–2 s before the shot (SDX_7, SDY_7), 2–0 s before the shot (SDX_2, SDY_2), and 1–0 s before the shot (SDX_1, SDY_1).

Statistical methods

Principal component analysis (PCA) has been used to identify shooting technical components in running target shooting (Mononen et al., 2003) and air pistol shooting (Hawkins, 2011). In order to identify the different technical components in air rifle shooting, PCA with varimax rotation was used to form orthogonal linear combinations from the measured aiming point trajectory variables. The number of the components was determined by minimum eigenvalue of 0.9 and by a minimum of 5% variance accounted for by the component. PCA was analyzed over single trials.

Mean values of the measured variables were calculated over the shots of one test series (40 or 60 shots) and averaged over all measured test series from one athlete. Differences in the shooting scores between males and females both among international-level athletes and national-level athletes were tested with independent samples *t*-test in order to justify the treatment of international-level males and females as one group (INT) and national-level males and females as one group (NAT). Independent samples *t*-test was used to analyze the differences in performance and shooting technical variables between international- (INT) and national- (NAT) level athletes. Two-tailed Pearson's correlation coefficients were computed to examine the relationship between performance and shooting technical variables. Correlation coefficients were also calculated between the holding ability and postural balance variables. Finally, stepwise multiple regression analysis (MRA) was used to study the amount of explained variance in shooting score by the shooting technical variables. MRA was analyzed over each test series mean values. Collinearity statistics were undertaken to examine the linear association between the predictive variables in the MRA model. Applicability of the MRA model for intra-individual analysis was tested for all athletes with five or more measured test results. 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

A total of 13 795 shots in 319 tests were analyzed. Out of these tests, 204 were conducted by athletes in the INT group (a total of 8501 shots), and 115 by athletes in the NAT group (a total of 5294 shots). Aiming point variables $Target_r$, COG_r, and Hit_r yielded maximal possible values in 95%, 99%, and 89% of all the shots measured, respectively. In the INT group, $Target_r$, COG_r, and Hit_r yielded maximal possible values in 99%, 100%, and 97% of the shots measured, respectively. The sensitivity of these variables was considered inadequate for elite-level air rifle shooting analysis, and these variables were excluded from the analysis.

PCA revealed six factors in the aiming point variables ($n = 13795$), which explained 88% of the total variance (Table 2). Factor 1, aiming time, described the amount of time the aiming point was in the target area before the shot; factor 2, stability of hold, described the steadiness of the rifle barrel; factor 3, measurement time, described the total length of the execution of the shot; factor 4, cleanness of triggering, described the stability of the rifle during the triggering phase; factor 5, aiming accuracy, described the preciseness of aiming; and factor 6, timing of triggering, described the timing of the triggering action.

INT group athletes had better mean shot scores, more stable hold, cleaner triggering action, and better aiming accuracy compared with the NAT group athletes (Table 3). INT group also demonstrated more stable balance in shooting line direction (SDY) during all the analyzed time periods and in cross-shooting line direction during the last second before the shot (SDX_1). Aiming point trajectory variables describing aiming time, stability of hold, cleanness of triggering, and aiming accuracy correlated significantly with the mean shot scores (Table 4).

Holding ability in horizontal direction (DevX) correlated with the postural balance in cross-shooting direction during the last phase before the triggering moment (SDX_2, $R = 0.35$, $P < 0.05$, $n = 40$; SDX_1, $R = 0.55$, $P < 0.001$, $n = 40$). Holding ability in vertical direction (DevY) correlated with the postural balance in shooting direction during all analyzed time periods (SDY_7, $R = 0.52$, $P < 0.001$, $n = 40$; SDY_2, $R = 0.44$, $P < 0.01$, $n = 40$; SDY_1, $R = 0.40$, $P < 0.05$, $n = 40$), and with the postural balance in cross-shooting direction during the last second before the shot (SDX_1, $R = 0.45$, $P < 0.01$, $n = 40$).

Aiming point trajectory variables Hit_f and $Target_f$ loading on more than one factor in PCA were excluded from the stepwise MRA. The results of the MRA analysis are presented in Table 5. MRA analysis showed that DevX, TIRE, COG_{hit}, and ATV explained 81% of the variance in shooting score (Fig. 2). Collinearity statistics did not indicate significant multicollinearity among these four predictive variables (tolerance 0.47–0.86, variance inflation factor (VIF) 1.16–2.11). Regression equation prediction of the mean shot score with four variables was significant both in INT ($R^2 = 0.89$, $P < 0.001$) and NAT ($R^2 = 0.86$, $P < 0.001$) groups. Intra-individual analysis revealed that regression equation with four predictors was able to predict the mean test scores for 18 out of 21 athletes (with five or more measured tests) at statistically significant level. For these 18 athletes, the regression equation R values were between 0.68 and 0.99. For the remaining three athletes belonging to the NAT group, regression equation was not able to predict the mean test scores at statistically significant level (athlete 1: $R = 0.84$,

Table 2. Principal component analysis (varimax rotation) rotated solution of the aiming point variables from all the measured shots ($n = 13795$)

	Factor 1 Aiming time	Factor 2 Stability of hold	Factor 3 Measurement time	Factor 4 Cleanness of triggering	Factor 5 Aiming accuracy	Factor 6 Timing of triggering
Eigenvalue	4.33	2.96	1.70	1.27	1.07	0.93
Percentage of variance	21.3	19.8	13.8	13.3	12.2	7.2
COG_{ht}	0.962					
$Target_{ht}$	0.961					
Hit_{ht}	0.955					
COG_f		0.900				
DevX		−0.853				
Hit_f		0.693		−0.427		
DevY		−0.580				
Total time			0.945			
Time on target			0.943			
RTV				0.949		
ATV				0.867		
COG_{hit}					0.968	
$Target_f$		0.480			0.830	
TIRE						0.994

Factor loadings of absolute value greater than 0.4 are shown.

Table 3. Test values (mean ± SD) from all athletes ($n = 40$) and INT ($n = 19$) and NAT group athletes ($n = 21$)

		All	INT	NAT
Shot score		10.25 ± 0.11	10.32 ± 0.08***	10.20 ± 0.11
Aiming time	COG_{ht} (s)	8.5 ± 2.5	9.2 ± 2.4	7.9 ± 2.5
	$Target_{ht}$ (s)	8.5 ± 2.5	9.2 ± 2.4	7.9 ± 2.5
	Hit_{ht} (s)	8.4 ± 2.6	9.2 ± 2.5	7.8 ± 2.6
Stability of hold	COG_f (%)	92 ± 5	95 ± 2**	90 ± 6
	DevX (ring)	0.44 ± 0.09	0.39 ± 0.06**	0.48 ± 0.10
	Hit_f (%)	73 ± 11	79 ± 6***	67 ± 11
	DevY (ring)	0.31 ± 0.06	0.28 ± 0.05*	0.33 ± 0.07
Measurement time	Total time (s)	12.7 ± 3.5	13.0 ± 3.2	12.5 ± 3.8
	Time on target (s)	12.4 ± 3.3	12.6 ± 2.9	12.3 ± 3.7
Cleanness of triggering	RTV (index)	1.05 ± 0.08	1.01 ± 0.08*	1.07 ± 0.08
	ATV (ring)	0.28 ± 0.05	0.25 ± 0.04***	0.30 ± 0.04
Aiming accuracy	COG_{hit} (pts)	10.46 ± 0.1	10.51 ± 0.06**	10.41 ± 0.11
	$Target_f$ (%)	80 ± 10	86 ± 6***	74 ± 10
Timing of triggering	TIRE (index)	2.12 ± 0.15	2.12 ± 0.11	2.11 ± 0.19
Postural balance	SDX_7 (mm)	0.82 ± 0.17	0.77 ± 0.14	0.87 ± 0.18
	SDY_7 (mm)	0.32 ± 0.07	0.30 ± 0.04**	0.35 ± 0.08
	SDX_2 (mm)	0.45 ± 0.07	0.43 ± 0.07	0.48 ± 0.08
	SDY_2 (mm)	0.29 ± 0.06	0.27 ± 0.04*	0.31 ± 0.07
	SDX_1 (mm)	0.30 ± 0.04	0.28 ± 0.04**	0.32 ± 0.04
	SDY_1 (mm)	0.28 ± 0.06	0.26 ± 0.04*	0.30 ± 0.07

INT group differed significantly from NAT group, ***$P < 0.001$, **$P < 0.01$, *$P < 0.05$.

Table 4. Two-tailed Pearson's correlation coefficient R values between shot score and shooting technical variables in all athletes ($n = 40$), INT group ($n = 19$), and NAT group ($n = 21$)

		All	INT	NAT
Aiming time	COG_{ht} (s)	0.561***	0.509*	0.538*
	$Target_{ht}$ (s)	0.550***	0.512*	0.509*
	Hit_{ht} (s)	0.574***	0.516*	0.542*
Stability of hold	COG_f (%)	0.807***	0.700**	0.767***
	DevX (ring)	−0.775***	−0.741***	−0.686***
	Hit_f (%)	0.830***	0.882***	0.716***
	DevY (ring)	−0.676***	−0.517*	−0.661***
Measurement time	Total time (s)	0.261	0.313	0.240
	Time on target (s)	0.245	0.331	0.221
Cleanness of triggering	RTV (index)	−0.155	−0.315	0.264
	ATV (ring)	−0.697***	−0.676**	−0.548**
Aiming accuracy	COG_{hit} (pts)	0.648***	0.643**	0.484*
	$Target_f$ (%)	0.805***	0.756***	0.714***
Timing of triggering	TIRE (index)	0.097	0.138	0.058
Postural balance	SDX_7 (mm)	−0.160	−0.180	0.073
	SDY_7 (mm)	−0.433**	−0.116	−0.329
	SDX_2 (mm)	−0.376*	−0.303	−0.215
	SDY_2 (mm)	−0.309	0.050	−0.232
	SDX_1 (mm)	−0.554***	−0.556*	−0.333
	SDY_1 (mm)	−0.267	0.099	−0.221

Significant correlation ***$P < 0.001$, **$P < 0.01$, *$P < 0.05$.

$P = 0.08$, $n = 5$; athlete 2: $R = 0.50$, $P = 0.21$, $n = 8$; and athlete 3: $R = 0.78$, $P = 0.07$, $n = 6$).

Discussion

The goal of the present study was to identify the most important performance-determining factors in elite-level air rifle shooting and to find the best variables to describe these different aspects of shooting technique. Six components in total were identified in air rifle shooting technique, and four of these components, namely stability of hold, aiming accuracy, cleanness of triggering, and timing of triggering, were identified as the most important factors determining air rifle shooting performance. Variables describing these aspects of shooting technique explained 81% of the variance in shooting score. From these, the holding ability in horizontal direction was the most important component accounting for 54% of the variance in shooting score.

Table 5. Stepwise multiple regression analysis R^2, R^2 change, F change, and regression coefficient B values with mean shot score as dependent variable (n = 319)

	R^2	R^2 change	F change	B
Step 1	0.54	0.54	360.00	
DevX				−1.07
Step 2	0.62	0.09	70.49	
DevX				−1.10
TIRE				0.21
Step 3	0.78	0.16	228.61	
DevX				−0.71
TIRE				0.33
COG_{hit}				0.53
Step 4	0.81	0.03	50.65	
DevX				−0.50
TIRE				0.31
COG_{hit}				0.46
ATV				−0.58
Step 5	0.82	0.00	6.28	
DevX				−0.47
TIRE				0.31
COG_{hit}				0.49
ATV				−0.58
Total time				0.00
Step 6	0.82	0.00	4.08	
DevX				−0.43
TIRE				0.31
COG_{hit}				0.49
ATV				−0.58
Total time				0.00
SDX_1				−0.14

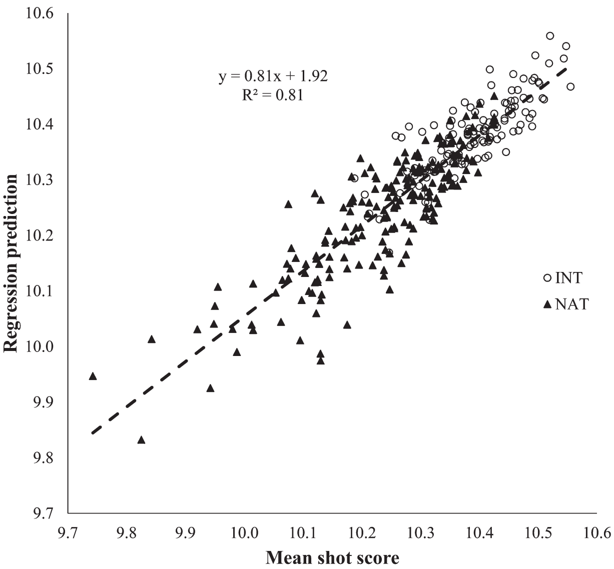

Fig. 2. Mean test shot score and regression prediction (n = 319) based on four variables: stability of hold (DevX), timing of triggering (TIRE), aiming accuracy (COG_{hit}), and cleanness of triggering (ATV). Regression prediction equation $Y = 5.110 + (-0.502) \times DevX + 0.315 \times TIRE + 0.465 \times COG_{hit} + (-0.582) \times ATV$.

In this study, the number of technical components identified in air rifle shooting with principal component analysis was greater than the number of technical components reported in running target shooting (Mononen et al., 2003) and pistol shooting (Hawkins, 2011). A total of six components were identified from the aiming point trajectory variables in air rifle shooting: aiming time, stability of hold, measurement time, cleanness of triggering, aiming accuracy, and timing of triggering. Aiming accuracy, aiming time, and stability of hold were identified as common shooting technical components in all of the above mentioned shooting events (air rifle, running target, and pistol shooting). Shooting technique component cleanness of triggering was identified in air rifle shooting and in running target shooting, but not in pistol shooting. This absence of cleanness of triggering component in pistol shooting could arise from the fact that one of the important cleanness of triggering variables (ATV) was omitted in the pistol shooting study (Hawkins, 2011). Also, the timing of triggering component found in air rifle shooting was not identified in running target or pistol shooting, but again, the timing of triggering variable (TIRE) was not analyzed in either of these studies. It is possible that the differences between the shooting events in the cleanness of triggering and timing of triggering components are related to the analysis methods used in the studies, rather than to the actual differences in the technique of these shooting events.

Time component in air rifle shooting technique was divided into two different factors, aiming time and total measurement time, instead of the one common aiming time factor found in running target shooting (Mononen et al., 2003) and pistol shooting (Hawkins, 2011). Differences in the aiming time components between air rifle shooting and running target shooting are probably due to the time limitation set in running target shooting task. In the running target shooting study, the target was moving through the shooting area and was visible only for 5 s (Mononen et al., 2003). In air rifle shooting, the aiming time is unlimited, which explains the possibility of one additional component in the shooting technique.

As expected, international-level athletes performed better than national-level athletes, indicated by their higher mean shot scores. International-level athletes' better shooting performance was related to their more stable holding ability and postural balance as well as better aiming accuracy and cleaner triggering compared with the national-level athletes. In the present study, correlation between performance and experience was not investigated, which naturally can also play a role (Mon et al., 2014b). More stable holding ability of the elite-level athletes compared with less skilled shooters has been shown in previous studies in air rifle (Zatsiorsky & Aktov, 1990; Konttinen et al., 1998, 2000) and running target shooting (Viitasalo et al., 1999; Mononen et al., 2003). Stability of hold descriptors COG_f and DevX were the single most important variables (describing only one component in the shooting technique) correlating with shooting scores.

Previously, Mononen et al. (2007) reported a correlation between holding ability and shooting score among novice shooters, but at the elite level, no such correlation has been shown. Contrary to the findings of the present study, Ball et al. (2003) reported insignificant correlation between stability of hold and shooting score in interindividual analysis in a group of elite-level air rifle shooters. Differences in the findings of the present study and the study by Ball et al. (2003) could arise from the small number of participants ($n = 6$) measured in Ball et al.'s (2003) study, which the authors reported as a limitation. The results of the present study highlight the importance of training the shooters' holding ability in achieving world-class performance and shooting technique.

The findings of the present study support the notion that in air rifle shooting, holding ability is related to postural balance at interindividual level, even among highly skilled shooters. Earlier studies have shown a correlation between postural balance variables and holding ability among novice rifle shooters (Mononen et al., 2007) but not among elite-level rifle shooters (Ball et al., 2003). Ball et al. (2003) reported statistically significant correlations between balance measures and holding ability in intra-individual but not in interindividual level among elite air rifle shooters. This result is not in line with the current findings, but as in the case of holding ability and shooting score correlations, the difference in the results of these two studies could arise from the small number of participants measured in Ball et al.'s (2003) study. As expected, international-level athletes demonstrated more stable postural balance in shooting direction (medio-lateral) during all analyzed time periods and more stable postural balance in cross-shooting direction (antero-posterior) during the last second before the shot compared with the national-level athletes. Similar findings from the differences in postural balance between elite and pre-elite shooters have been reported in air rifle shooting (Era et al., 1996; Konttinen et al., 1999; Mon et al., 2014a) and running target shooting (Viitasalo et al., 1999). Era et al. (1996) also reported that elite-level rifle shooters were able to decrease the amount of postural sway prior to shot moment more than less skilled shooters. This result is in line with the current findings, since the differences between international- and national-level shooters in the cross-shooting direction (SDX) postural balance became evident only during the last second before the shot. It seems that the ability to control the antero-posterior balance in the last phase of the shot execution is an important part in stabilizing the rifle movements and achieving superior shooting technique. This result should be taken into consideration in designing balance training programs for the athletes to improve their shooting position postural stability, which then translates to more stable holding ability.

Although the general aiming patterns in air rifle shooting have not been reported to differ between shooters at different skill levels (Goodman et al., 2009), a more detailed analysis of the actual parameter values in the present study revealed better aiming accuracy and cleaner triggering in international- compared with national-level athletes. Differences between athletes of different skill levels in aiming accuracy or cleanness of triggering have not been studied previously in air rifle shooting. Both these aspects of shooting technique also correlated significantly with shooting score, so it seems that these technical components are important in achieving superior shooting technique. Total shot execution time, aiming time, and timing of triggering did not differ between the international- and national-level athletes. Same finding regarding the timing of triggering component was reported previously by Konttinen et al. (2000), and they stated that the timing of triggering component does not differ between athletes of various skill levels. The authors pointed out that even though the timing of triggering values did not differ between elite and pre-elite shooters, the effect of timing of triggering on shot score was smaller in elite-level athletes because of their more stable holding ability (Konttinen et al., 2000). This notion is partly supported by the results of the present study. The MRA equation presented in the present study shows that if two athletes possess the same timing of triggering values, the athlete with the better holding ability, aiming accuracy, and cleanness of triggering will perform better. On the other hand, the linear regression model, applicable for both international- and national-level athletes, suggests that the effect of timing of triggering on shot score is similar regardless of the performance level in other aspects of shooting technique.

MRA revealed six predictors of shooting score: stability of hold (DevX), timing of triggering (TIRE), aiming accuracy (COG_{hit}), cleanness of triggering (ATV), measurement time (total time), and balance in cross-shooting line direction (SDX_1). Out of these six variables, the first four components were able to account for 81% of the variance in shooting score. Adding on the measurement time and balance components improved the accuracy of the regression prediction by less than 1%. This is why the components stability of hold, aiming accuracy, timing of triggering, and cleanness of triggering were considered the most important aspects of air rifle shooting technique, accounting for 54%, 16%, 9%, and 3% of the variance in shooting score, respectively. Previous studies of elite-level athletes have reported regression predictions explaining 48% of the variance in shooting score in air pistol shooting (Hawkins, 2011), 43% in running target shooting (Mononen et al., 2003), and no significant regression in air rifle shooting (Ball et al., 2003). The regression equation reported in the present study accounts for far larger percentage of the variance in shooting score than the previously reported regression equations in running target shooting, pistol shooting, and air rifle shooting. In the running target shooting study, the timing of triggering component was not included in the regression prediction. In the air pistol shooting and previous air rifle shooting study, both the timing of triggering and cleanness of triggering components were omitted. These components could have improved the regression prediction accuracies in the previous studies. Also, the regression equations have been calculated over single trials in the previous air pistol and running target shooting studies, instead of the test mean values used in the present study. This difference in the analysis process could affect the amount of explained variance in the shooting score by the regression equations presented in these three shooting studies.

The applicability of the current regression equation in monitoring athletes' technical skill level is supported by the fact that the regression equation was significant both in international- and national-level groups, and in intra-individual analysis for 18 out of 21 shooters with five or more test results. Out of the three national-level athletes, whose test results were not predicted at statistically significant level, two athletes had only five or six test occasions. The regression equation R values for these two athletes were 0.84 ($P = 0.08$) and 0.78 ($P = 0.07$), and it could be speculated that with more test occasions, the regression equation would be statistically significant for these two shooters. For one shooter, the regression equation ($R = 0.50$, $P = 0.21$, $n = 8$) was far more inaccurate than for the rest of the athletes. This shooter used a completely different shooting technique, in which the holding area was far from the center of target and the aiming point was moved through the center of target and fired in the middle. This shooting strategy was considered as poor shooting technique by the coaches, and the athlete was continuously instructed to change the shooting technique.

The results of the present study emphasize the importance of holding ability in achieving superior shooting technique, especially the holding ability in horizontal direction. MRA indicated that 54% of the variance in shooting score could be explained by the holding ability in horizontal direction. The elite-level athletes' ability to decrease the amount of postural sway in antero-posterior direction during the last second before the shot seems to be related to the more stable holding ability of the elite-level athletes. Based on the regression equation and the correlations between performance, holding ability, and postural balance presented in this study, postural balance affects performance at the elite-level rifle shooting in two ways. Postural balance has a direct influence on shooting score (less than 1% explained), and an indirect influence on shooting score through more stable holding ability. This same conclusion was presented in a previous study among novice rifle shooters (Mononen et al., 2007). These results should be taken into consideration when designing shooting technique and balance training programs for both elite and pre-elite athletes. The number of elite-level air rifle shooters measured in this study is exceptionally high compared with the previously reported air rifle shooting studies. The international-level athletes' test results reported in this study can be used as reliable reference values when testing and analyzing shooters' strengths and weaknesses in shooting technique. Based on the results of this study, it is recommended that shooting score, holding ability (DevX), aiming accuracy (COG_{hit}), cleanness of triggering (ATV), and timing of triggering (TIRE) are used as measures of shooting technical skill level in athlete testing and monitoring. The regression model presented in this study can then be used to assess how improvement of a technical weakness (e.g. holding ability) to reference value levels would affect the shooting scores.

Perspectives

The results of the present study support previous work (Era et al., 1996; Konttinen et al., 1998; Ball et al., 2003) demonstrating stability of hold and postural balance as two factors affecting performance in air rifle shooting. The current study was able to identify aiming accuracy, cleanness of triggering, and timing of triggering as other important technical aspects of elite-level air rifle shooting technique, and the contribution of these technical aspects on shooting score was determined. In practical applications, every athlete and coach can test and measure the same aiming point trajectory variables reported in this study. The reported international-level shooters' test results can be used as reference values by coaches and athletes in pursuing superior air rifle shooting technique. In the future shooting studies, it should be noted that shooting technique is not purely determined by stability of hold and postural balance. Measures of aiming accuracy, cleanness of triggering, and timing of triggering should be included in the shooting studies in order to acquire more comprehensive description about the shooting task.

Key words: Biomechanics, technique, optoelectronic measures, postural balance.

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II

RELATION OF ELITE RIFLE SHOOTERS' TECHNIQUE-TEST MEASURES TO COMPETITION PERFORMANCE

by

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Relation of Elite Rifle Shooters' Technique-Test Measures to Competition Performance

Original Investigation

Simo Ihalainen[1,2], Vesa Linnamo[2], Kaisu Mononen[1], Sami Kuitunen[1]

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

[2] Department of Biology of Physical Activity, University of Jyväskylä, Jyväskylä, Finland

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

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Abstract

Purpose:

The aim of this study was to describe the long-term changes in shooting technique in relation to competition performances in elite air rifle shooters.

Methods:

Seventeen elite shooters completed simulated air rifle shooting competition series on three consecutive seasons, participating to 15±7 testing occasions. Shooting score and aiming point trajectory variables were obtained with an optoelectronic shooting device and postural balance variables were measured with force platform. Shooters' competition results were collected from all international and national competitions during the 3-year period.

Results:

Mean test score, stability of hold, aiming accuracy, cleanness of triggering and postural balance improved during the tree-year period (Anova, time, $P<0.05$-0.01). Seasonal mean test results in stability of hold (R=-0.70, $P=0.000$) and cleanness of triggering (R=-0.75, $P=0.000$) were related to competition performances. Changes in stability of hold (R=-0.61, $P=0.000$) and cleanness of triggering (R=-0.39, $P=0.022$) were also related to the changes in competition performances. Postural balance in shooting direction was more related to cleanness of triggering (R=0.57, $P=0.000$), whereas balance in cross shooting direction was more related to stability of hold (R=0.70, $P=0.000$).

Conclusions:

The shooting technique testing used in the present study seems to be a valid and useful tool for long-term performance assessment. Stability of hold, cleanness of triggering and postural balance can be further developed even at the elite level, resulting in improved competition performances.

Key words: biomechanics, stability of hold, aiming, triggering, postural balance

Introduction

Technical components of air rifle shooting affecting performance have been identified in cross sectional studies. These components include stability of hold [1-5], aiming accuracy, cleanness of triggering [5], timing of triggering [5,6] and postural balance [2,3,5,7,8]. Out of these shooting technical components, stability of hold has been identified as the most important component in elite level air rifle shooting technique, accounting for 54 % of the variance in shooting score [5]. Stability of hold has been shown to discriminate between shooters of different skill levels as well as between low and high scoring shots [3,4,9].

Postural balance has been shown to be an important aspect in acquiring stable holding ability both among elite [2,5] and novice [3] rifle shooters. Elite level shooters have also shown more stable balance in shooting and cross shooting directions than athletes of lesser skill level [5,7,8]. In addition to hold and balance components, international level air rifle shooters have been shown to differ from national level athletes in aiming accuracy and cleanness of triggering, but not in timing of triggering, aiming time or shot execution time [5].

To the best of our knowledge, all the studies reporting performance and technique in elite level air rifle shooting have been cross sectional studies. No study so far has reported how the shooting technical components change over time in response to years of intense shooting training, and how these changes relate to performance enhancement. Moreover, the shooting technical components have been correlated to the shot scores achieved in the testing situation. It has been shown that competition anxiety affects performance outcomes in shooting competitions [10,11], and it can thus be assumed that the competition situation differs considerably from the testing situation. It would be of great importance to investigate how the testing situation results and technique measurements correlate with the actual competition performances, when the psychological factors come into play. Therefore, the purpose of this study was to (1) describe the changes caused by long term professional shooting training on shooting technical components, (2) investigate the relationship between the changes in shooting technique and performance changes and (3) examine the relationship between shooting technique test results and actual competition performances.

Methods

Subjects

Eight male and nine female elite level air rifle shooters belonging to Finnish national team participated in the study (age 25 ± 6 years, practising shooting 14 ± 5 years). The subjects included in the study were measured at three consecutive seasons between the years 2009-2014. Shooters who participated in the measurements only on one season were excluded from this study (6 foreign international level shooters, 8 national level shooters participating to measurements for the first time on season 2014, and 9 national level shooters participating to measurements on one season between the years 2009-2014). All subjects participated regularly to international and national air rifle competitions during the three-year period and belonged to different level Finnish national teams. The participants' best competition results during the three-year period were 593 ± 4 (out of 600) for men and 396 ± 2 (out of 400) for women, which correspond to 9.9 ± 0.1 points/shot, both for men and for women. All shooters in this study trained professionally, shooting over 20000 shots per year, supervised and instructed by the Finnish national team coaches. Participants signed an informed consent prior to testing and the informed consent was following the guidelines of the Ethical Committee of the University of Jyväskylä. The measurements in the present study were part of athletes' normal shooting technique testing during the pre-competition and competition seasons during 2009-2014, conducted on the national team training camps. Testing complied with current Finnish laws regarding the testing of human subjects.

Experimental task

Measurement protocol has been described previously in detail by Ihalainen et al.[5]. In short, subjects completed a simulated air rifle competition series of 60 (men) or 40 (women) shots on each testing occasion. The shooting conditions were kept similar on each testing occasion, and these testing conditions were in accordance with the official rules and regulations in International shooting sport federation air rifle competitions[12]. Shooting score and 17 aiming point trajectory variables were recorded from each shot with Noptel ST 2000 (Noptel Inc., Finland) optoelectronic training device. Out of the 17 aiming point trajectory variables, 4 most important aiming point variables, as identified previously in Ihalainen et al.[5], describing stability of hold, aiming accuracy, cleanness of triggering and timing of triggering, were included in the post analysis processes (table 1). Postural balance was measured with triangular-shaped force platform (1175 mm × 1175 mm × 1175 mm, Good Balance, Metitur Ltd., Finland) as standard deviation of the COP location in shooting direction (sdY) and perpendicular to shooting direction (sdX) during three time periods: 7-2 s before the shot (sdX_7, sdY_7), 2-0 s before the shot (sdX_2, sdY_2) and 1-0 s before the shot (sdX_1, sdY_1).

Competition results

Subjects' competition results during the three-year period were collected from all international competitions, national championships and national record eligible competitions. Air rifle shooting competition rules changed after season 2012 so that the competition series total score was calculated as the sum of the decimal result of each shot. Previously each shot was rounded down to nearest integer value (10.9-10.0 → 10; 9.9-9.0 → 9 and so on) and then summed over the whole competition series. In this study, shooting results from the seasons 2013 and 2014 have been calculated according to the old shooting rules in order to be able to compare the competition results to previous seasons. Season mean and best competition results were obtained for all subjects and a point per shot variable was computed from both the season mean and maximum result and used for subsequent analysis. Point per shot variable was used instead of the total competition score because of the different number of shots in men's (60) and women's (40) competitions.

Statistical analysis

Mean values of the measured variables were calculated over the shots of one test series (60 or 40 shots) and averaged over all measured test series from one athlete during one season. These season mean values measured during one shooting season were used for subsequent analysis (seasons 1, 2 and 3). Variation in the test results within the shooting season (changes in test results from pre-competition to competition season) has not been taken into account. One-way repeated measures analysis of variance (ANOVA) with Huynh-Feldt correction was performed to analyse the changes in competition shooting results and shooting technical variables during the three measured seasons. Post hoc tests with the Bonferroni correction were used to analyse the time point and direction of the change in the competition shooting results and shooting technical variables. Two-tailed Pearson's correlation coefficients were computed to examine the relationship between the shooting test variables and competition results on all measured seasons. Correlation coefficients were also computed between the absolute changes from season 1 to season 2 and from season 2 to season 3 in shooting test variables and competition results.

Table 1. Variables describing competition performance, shooting technique and postural balance. Variable abbreviations have been selected according to the Noptel manufacturer abbreviations in order to ease the application of results in practice. Variables DevX and ATV can be converted into SI units (meters) by multiplying the variables by 0.0025.

Component	Variable (unit)	Description
Overall performance	Competition mean score (points/shot)	Season mean point/shot result in competitions, points calculated from the competition integer result.
	Competition maximum score (points/shot)	Season maximum point/shot result in competitions, points calculated from the competition integer result.
	Test mean score (points/shot)	Season mean point/shot result in tests, points calculated from the test decimal result.
Stability of hold	DevX (ring)	Horizontal standard deviations of the location of the aiming point during the last second, interval between two consecutive hit rings as measurement unit (2.5 mm/ring). Smaller DevX values indicate better holding ability.
Aiming accuracy	COG_{hit} (points)	Mean location of the aiming point during last second. Greater COG_{hit} values indicate better aiming accuracy.
Cleanness of triggering	ATV (ring)	Cumulative distance travelled by the aiming point during the last 0.2 s, interval between two consecutive hit rings as measurement unit (2.5 mm/ring). 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_7 (mm)	Standard deviation of the COP location perpendicular to shooting direction during 7-2 s before the shot. Smaller values indicate more stable postural balance.
	sdY_7 (mm)	Standard deviation of the COP location in shooting direction during 7-2 s before the shot
	sdX_2 (mm)	- 2-0 s before the shot
	sdY_2 (mm)	- 2-0 s before the shot
	sdX_1 (mm)	- 1-0 s before the shot
	sdY_1 (mm)	- 1-0 s before the shot

Results

Test result were obtained from 17 athletes during a three-year period. Subjects participated to 15 ± 7 test occasions during the three-year period, and a total of 11433 shots were analysed for this study. Descriptive statistics from the competition results and shooting test variables are shown in table 2.

Table 2. Descriptive statistics (mean ± SD) from season 1, 2 and 3.

		Season 1	Season 2	Season 3
Mean test score (points/hit)		10.25 ± 0.14 †	10.30 ± 0.08	10.33 ± 0.07
Mean competition score (points/hit)		9.74 ± 0.11	9.76 ± 0.08	9.75 ± 0.10
Maximum competition score (points/hit)		9.83 ± 0.11	9.85 ± 0.07	9.86 ± 0.08
Stability of hold - DevX (rings)		0.45 ± 0.10 ††	0.41 ± 0.07 °	0.38 ± 0.06
Aiming accuracy - COG_{hit} (score)		10.44 ± 0.16 †	10.50 ± 0.08	10.50 ± 0.11
Cleanness of triggering - ATV (rings)		0.30 ± 0.07 *, †	0.27 ± 0.04	0.25 ± 0.05
Timing of triggering - TIRE (index)		2.12 ± 0.19	2.15 ± 0.09	2.16 ± 0.11
Postural balance	-sdX_7	0.81 ± 0.17	0.79 ± 0.15	0.76 ± 0.17
(mm)	-sdY_7	0.32 ± 0.06 †	0.30 ± 0.05	0.28 ± 0.04
	-sdX_2	0.48 ± 0.08 **, ††	0.43 ± 0.07	0.43 ± 0.07
	-sdY_2	0.29 ± 0.06 †	0.27 ± 0.04	0.26 ± 0.03
	-sdX_1	0.31 ± 0.05 *, ††	0.28 ± 0.04	0.27 ± 0.03
	-sdY_1	0.29 ± 0.07 †	0.26 ± 0.05	0.25 ± 0.03

Significant difference between the season 1 and 3, †† P < 0.01, † P < 0.05

Significant difference between the season 1 and 2, ** P < 0.01, * P < 0.05

Significant difference between the season 2 and 3, ° P < 0.05

There was a significant main effect of time in mean test scores (ANOVA, time, P=0.019), stability of hold (DevX, P=0.002), aiming accuracy (COG_{hit}, P=0.014) cleanness of triggering (ATV, P=0.002) and all postural balance variables (sdY_7, P=0.008; sdX_2, P=0.001; sdY_2, P=0.002; sdX_1, P=0.001; sdY_1, P=0.002) except sdX_7 (P = 0.324). Post hoc analysis revealed that these aspects of shooting technique developed during the three-year period. There were no significant effects of time on competition mean score (P=0.364), competition maximum score (P=0.318) or timing of triggering (TIRE, P=0.418).

Stability of hold measured in testing situation was related to the athletes' competition results. Specifically, changes in stability of hold towards more stable hold improved competition results (Figure 1). Correlations between competition results and test variables are shown in table 3. In addition to the correlations between test variables and competition results, stability of hold and cleanness of triggering were also related to postural balance, both in cross shooting and shooting directions (table 4).

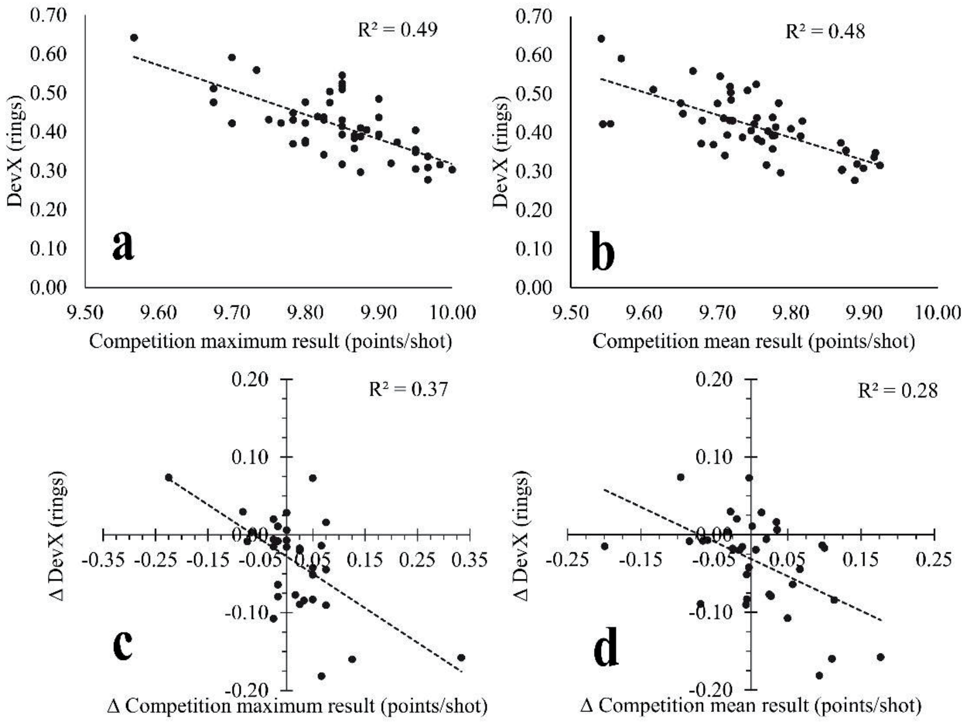

Figure 1. Correlation between (a) stability of hold and competition maximum result, between (b) stability of hold and competition mean result, between (c) change in stability of hold and change in competition maximum result and between (d) change in stability of hold and change in competition mean result.

Table 3. Two-tailed Pearson's correlation coefficient R values between mean and maximum competition results and shooting test variables (n = 51). Correlation coefficient values between change in competition mean/maximum result and change in shooting test variables are shown in brackets (n = 34).

		Mean competition result (Δ Mean competition result)	Maximum competition result (Δ Maximum competition result)
Mean test score, (Δ Mean test score)		0.73***, (0.42*)	0.67***, (-0.25)
Stability of hold – DevX, (Δ DevX)		-0.69***, (-0.53**)	-0.70***, (-0.61***)
Aiming accuracy – COG_{hit}, (Δ COG_{hit})		0.52***, (-0.11)	0.39**, (-0.18)
Cleanness of triggering – ATV, (Δ ATV)		-0.67***, (-0.46**)	-0.75***, (-0.39*)
Timing of triggering – TIRE, (Δ TIRE)		-0.12, (0.04)	-0.09, (-0.02)
Postural balance	-sdX_7, (Δ sdX_7)	-0.07, (-0.26)	-0.05, (-0.30)
	-sdY_7, (Δ sdY_7)	-0.40**, (-0.21)	-0.43**, (-0.10)
	-sdX_2, (Δ sdX_2)	-0.26, (-0.39*)	-0.21, (-0.32)
	-sdY_2, (Δ sdY_2)	-0.36**, (-0.26)	-0.41**, (-0.02)
	-sdX_1, (Δ sdX_1)	-0.47***, (-0.32)	-0.44**, (-0.36*)
	-sdY_1, (Δ sdY_1)	-0.37**, (-0.34)	-0.43**, (-0.09)

Significant correlation *** $P < 0.001$, ** $P < 0.01$, * $P < 0.05$

Table 4. Two-tailed Pearson's correlation coefficient R values between stability of hold and cleanness of triggering and postural balance variables (n = 51). Correlation coefficient values between change in stability of hold/cleanness of triggering and change in postural balance variables are shown in brackets (n = 34).

		Stability of hold – DevX, (Δ DevX)	Cleanness of triggering – ATV, (Δ ATV)
Postural balance	sdX_7, (Δ sdX_7)	0.31*, (0.44**)	0.08, (0.29)
	sdY_7, (Δ sdY_7)	0.39**, (0.28)	0.53***, (0.48**)
	sdX_2, (Δ sdX_2)	0.53***, (0.49**)	0.29*, (0.39*)
	sdY_2, (Δ sdY_2)	0.32*, (0.24)	0.53***, (0.54***)
	sdX_1, (Δ sdX_1)	0.70***, (0.53**)	0.51***, (0.28)
	sdY_1, (Δ sdY_1)	0.33*, (0.32)	0.57***, (0.58***)

Significant correlation *** $P < 0.001$, ** $P < 0.01$, * $P < 0.05$

Discussion

The aim of the present study was to describe the effects of long term professional shooting training on shooting technique, investigate how these changes affect performance and examine the relationship between the testing results and actual competition performances. The main findings of the present study showed that mean test score, stability of hold, cleanness of triggering, aiming accuracy and postural balance developed during the three-year period. Although the test shooting scores improved, there were no statistically significant changes in the competition shooting scores. Stability of hold was more related to the postural balance in cross shooting direction, and cleanness of triggering was more related to the postural balance in shooting direction. Season mean test scores, stability of hold and cleanness of triggering values correlated with the season competition performances, and improvements in these variables resulted in enhanced performance in competitions.

Stability of hold is the most important aspect in air rifle shooting technique, and improvements in stability of hold are related to increased performance level in competition situation even at high shooting skill level. It is worth noting that improvements in stability of hold variable (DevX) had higher correlation to enhanced competition performance compared to the correlation between improvements in test scores and enhanced competition performance. This finding should be taken into consideration in athlete testing, so that the main focus in testing is in the athletes' development in stability of hold rather than in the development of test shot scores. This result further emphasizes the role of the stability of hold as an important component in air rifle shooting technique [2-5]. Furthermore, our findings indicate that this technical skill can further be developed, resulting in enhanced performance even with elite air rifle shooters.

Postural balance also improved during the three-year period in the whole subject group. The results of the present study revealed a correlation between stability of hold and postural balance measures. Especially the postural balance in cross shooting direction was important in achieving a stable holding ability, and improvements in the postural balance in cross shooting direction led to improved stability of hold. Relationship between stability of hold and postural balance has been found previously in air rifle shooting among novice [3] and elite [5] level shooters. The results of the present study were in accordance with these previous studies and clarified the effects of long term shooting training on postural balance and its influence on improving stability of hold.

Similarly to stability of hold, shooters' cleanness of triggering improved during the 3-year period in the whole subject group, and improvements in cleanness of triggering were associated with improved performances in competition situations. However, the mechanisms leading to improvements in cleanness of triggering differed from the mechanisms related to stability of hold. When the stability of hold was more closely related to the postural balance in cross shooting direction, cleanness of triggering was more related to the postural balance in shooting direction. Also, the changes in the cleanness of triggering were more highly correlated to the changes in the shooting direction postural balance compared to the cross-shooting direction.

The differences in the control strategy of these two shooting technical components, stability of hold and cleanness of triggering, raise interesting questions, which could be related to the anatomy of the shooting posture. In the air rifle shooting posture feet are placed apart and in parallel in the shooting direction, so that the base of support is considerably larger in shooting direction compared to the cross-shooting direction. In optimal shooting posture, the weight of the gun is supported by the bony structures as much as possible. The postural balance in air rifle shooting has been shown to be more stable in shooting line (medio-lateral) direction compared to cross shooting (antero-posterior) direction [5,7]. Several previous studies investigating normal quiet standing have reported more stable postural balance measures in medio-lateral direction compared to antero-posterior direction [13-18], and the medio-lateral postural stability has been shown to increase with larger stance widths [13,18-20]. This increase in the medio-lateral postural stability with increasing stance width has been attributed to the passive stiffening of the leg-pelvic structure rather than to the active muscle coordination [13]. It is possible that the instabilities in the medio-lateral direction arise mainly from the internal mechanical disturbances, i.e. micro vibrations propagating through the body, such as the heart beat and blood movements [21-23]. Through the years of intense shooting training shooters might develop and modify the shooting posture so that the effects of micro vibrations are damped as efficiently as possible. This could lead to the observed improvement in postural balance in shooting direction, which then translates to smaller movement of the aiming point during the triggering phase (cleanness of triggering).

In quiet standing the postural instabilities in antero-posterior direction have been related to the muscle control and coordination rather than to the balance disturbing internal mechanical stimuli, such as the heart beat [24]. As in the case of quiet standing, it is likely that during air rifle shooting the balance in the cross-shooting direction is much more affected and controlled for by the different muscle groups compared to the situation with the postural balance in shooting direction. For the elite shooters, the postural stability in cross shooting direction is harder to control for than the balance in shooting direction, but the elite level shooters are able to diminish the amount of body sway in cross shooting direction towards the shot moment [5,7]. It is possible that through the years of intense shooting training both the shooting posture and muscle coordination are developed so that the antero-posterior balance is stabilized as effectively as possible at the shot moment, which then translates to a more stable holding ability.

Aiming accuracy improved during the 3-year period, and aiming accuracy measured in the testing situation was related to the competition results achieved during the season. Interestingly, the changes in testing situation aiming accuracy did not show a significant correlation to the changes in competition performances. It could be speculated that the shooters' development in stability of hold and cleanness of triggering affect the competition results more than the development in aiming accuracy, and this could confound the relationship between aiming accuracy and competition performance changes.

Timing of triggering did not improve during the 3-year period, and the correlation between timing of triggering and competition performance was negligible. This result could be expected, since in a previous study no correlation was found between shooters' mean timing of triggering variable and mean test scores[5]. However, in the analysis of individual testing occasions, timing of triggering affected the performance outcomes and was identified as an important predictor of test scores. Based on the regression equation presented previously, timing of triggering accounted for 9 % of the variation in test scores. [5] If the athletes use the same shooting strategy in competitions as in the training situation, then the timing of triggering has affected the athletes' performance outcomes also in the competitions. Since we were unable to measure the timing of triggering in the competition situation, this assumption cannot be verified.

All in all the same variables seem to be related to success in competitions that are important in reaching high shooting scores in testing situation[5], but the strength of correlation is not as strong. This could be expected to happen, since athletes differ in the ability to cope with the mental stress imposed by the competition situation, and for example a higher heart rate during the competition situation could affect the stability of hold and cleanness of triggering. This aspect could also explain why there were no statistically significant changes in the competition shooting scores, even though the testing situation shooting scores and technical variables improved. It would be of great value to acquire the same technique variables from the competition situation and compare these to the training situation variables. This could further shed light on the question of how the technical and psychological skills interact and affect performance outcomes in the competition situation.

Practical applications

The correlations found between the testing and competition results highlight the usability and importance of the present testing protocol for technique monitoring in elite level air rifle shooting. Based on the measurements of this study, in order to reach a result over 9.95 points/shot in a competition (corresponding to 597 points out of 600 for men and 398 points out of 400 for women), the athlete has to have stability of hold variable DevX values less than 0.35 in the testing situations. Training programmes should be designed to improve the stability of hold and postural balance, and athlete testing and monitoring should focus on the development of these aspects of shooting technique instead of focusing on the test shooting scores.

Conclusions

In conclusion, the results of the present study showed that stability of hold, aiming accuracy, cleanness of triggering and postural balance can be developed through intense shooting training even at high shooting skill level. These aspects of shooting technique affect performance both in training and competition situations. Improvements in stability of hold and cleanness of triggering lead to enhanced shooting performance in competition.

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III

WHICH TECHNICAL FACTORS EXPLAIN COMPETITION PERFORMANCE IN AIR RIFLE SHOOTING?

by

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Which technical factors explain competition performance in air rifle shooting?

Simo Ihalainen[1,2], Kaisu Mononen[1], Vesa Linnamo[2] and Sami Kuitunen[1]

Abstract

The purpose of this study was to analyze whether the same shooting technical components determining performance in testing situation also affect performance in competition situation and how the technical skill level of these components changes from training to competition. Thirteen Finnish national (10) and junior national (3) rifle team members participated in the study. Participants were measured in competition and training situation within a five-day period. Shooting score, aiming point trajectory and postural balance were measured from both situations. Shooting performance decreased from training to competition situation (10.31 ± 0.13 vs. 10.14 ± 0.17, $p < 0.05$), accompanied by a decrease in holding ability, aiming accuracy, cleanness of triggering and postural balance. A multiple regression equation based on holding ability, aiming accuracy, cleanness of triggering and timing of triggering correlated with the competition situation shooting results ($R = 0.76$, $p < 0.01$). Changes in shooting performance from training to competition situation were most strongly related to the changes in horizontal holding ability ($R = -0.71$, $p < 0.01$). Athletes and coaches should develop competition strategies and psychological training interventions in order to be able to maintain the horizontal holding ability in competition at training situation level.

Keywords

Aiming accuracy, biomechanics, postural balance, technique measurement

Introduction

Air rifle shooting technical components have been identified previously in training situations.[1,2] The stability of hold has been shown to be the most important aspect of shooting technique, accounting for 54% of the variance in shooting score. Other identified shooting technical components affecting air rifle shooting performance have been aiming at accuracy, cleanness of triggering, timing of triggering, and postural balance.[1,3–5] Postural balance has been shown to affect performance both directly and indirectly through a more stable holding ability.[1,4,5]

To the best of our knowledge, there are no studies reporting air rifle shooting technique measures obtained from a competition situation. Shooting technique measures obtained from the training situation have been shown to correlate with the shooting results in competitions, although the correlations between the test measures and competition results were not as strong as between the test measures and the test shooting scores.[4] Also postural balance measured before the competition was shown to differ between the national and elite level shooters, but had no statistically significant relation to the competition shooting scores.[6]

Air rifle competitions are psychologically stressful situations for the shooters. Anticipation of performance has been shown to increase anxiety, heart rate and blood pressure in musicians.[7] Relationships between state anxiety, heart rate, blood pressure and postural balance[7,8] are possible reasons why state anxiety has been shown to be related to shooting performance in competition situation.[9] Solberg et al.[10] showed

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Daniel Mon (VU University, The Netherlands)

[1]KIHU – Research Institute for Olympic Sports, Jyväskylä, Finland
[2]Department of Biology of Physical Activity, University of Jyväskylä, Jyväskylä, Finland

Corresponding author:
Simo Ihalainen, KIHU – Research Institute for Olympic Sports, Rautpohjankatu 6, Jyväskylä 40700, Finland.
Email: simo.ihalainen@kihu.fi

that a relaxation meditation training program was able to increase performance level in shooting competitions, even without concurrent increase in training situation shooting performance. In a single subject case study, a cognitive–behavioral intervention was able to reduce state anxiety and increase competition shooting performance.[11]

Competition situation clearly has an effect on shooting performance, but the mechanisms leading to performance decrement remain unknown. It would be of great value to acquire the same technique variables from the competition situation and compare these with the training situation variables. Therefore, the aim of this study was to investigate whether the same shooting technical components determining performance in testing situation also affect performance in competition situation. The second objective was to analyze how the technical skill level changes from training to competition situation, and how these changes relate to changes in shooting performance.

Materials and methods

Participants

Thirteen Finnish national (10) and junior national (3) rifle team members participated in the study. Athletes' personal best competition results were 622.5 ± 5.0 points out of 60 shots for men ($n = 5$) and 414.0 ± 2.1 points out of 40 shots for women ($n = 8$), corresponding to 10.38 ± 0.08 points per shot for men and 10.35 ± 0.05 points per shot for women. The measurements in the current study were part of athletes' normal shooting technique testing conducted on two national team training camps (January 2015 and 2016) and two Grand prix of Leppä.fi competitions (January 2015 and 2016). All the athletes participating in this study have been tested in the training situation and on training camps for many years as well as have several years of experience in competition shooting. Testing complied with current Finnish laws regarding the testing of human subjects.

Experimental task

The measurement protocol has been described previously in detail.[1] In short, in the training situation, subjects completed a simulated air rifle competition series of 40 shots 2–5 days after the competition measurement. The time between the competition and the training situation measurement varied because of the national team training camp schedule and the possibility to test only four athletes during one day at the training camp. This variation in the time span between the competition and testing situation measurement has not been taken into account and is a limitation of the study. The testing shooting time (50 min, 75 s per shot) and shooting conditions were in accordance with the official rules and regulations in International Shooting Sport Federation air rifle competitions.[12] Shooting score and five aiming point trajectory variables were recorded from each shot with a Noptel ST 2000 (Noptel Inc, Finland) optoelectronic training device (Table 1). Postural balance was measured with a triangular force platform ($1175 \times 1175 \times 1175$ mm, Good Balance, Metitur Ltd, Finland) as standard deviation of the center of pressure location in shooting direction (SD_Y) and perpendicular to shooting direction (SD_X) during three time periods: 7–2 s before the shot (SD_{X7}, SD_{Y7}), 2–0 s before the shot (SD_{X2}, SD_{Y2}), and 1–0 s before the shot (SD_{X1}, SD_{Y1}).

The competition measurements were conducted at Grand Prix of Leppä.fi. Participation in the competition was open for all shooters, but the athletes had to pay an entry fee in order to participate. Three best shooters were rewarded with money prizes. The competition consisted of five elimination rounds and a final. On each of these rounds, athletes were randomly paired with an opponent and the winner of a 10-shot competition series qualified for the next round. Shooting time for the 10 shot series was 14 min, so shooters had 84 s per shot in the competition situation, and 75 s per shot in the training situation. In the competition situation, the same measuring setup was used to obtain the shooting score, aiming point trajectory variables, and postural balance variables as in the training situation. All shooters used their own shooting equipment both in training and competition situations. An additional Noptel ST 2000 measuring unit was used to measure the shooting score and aiming point trajectory variables so that two athletes were measured at the same time (pair competing against each other). The first measured competition series (including postural balance measurement) from each athlete was used in this study. Five athletes were measured only with Noptel ST 2000 measuring unit, so the results for shooting score and aiming point trajectory variables are based on all 13 measured shooters, and the results for postural balance are based on eight measured shooters.

Statistical methods

Shapiro-Wilk's test was used to test the normality of the data. As there were violations of normality assumption in five of the measured variables, non-parametric tests were used to analyze the data. Independent-samples Mann–Whitney U test was used to analyze the differences in training and competition situation shooting scores between the national and junior national team shooters. Mann–Whitney U test was also used

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

Component	Variable (unit)	Description
Overall performance	Mean shooting score (points/shot)	Mean point/shot result in training and competition situation
	Multiple regression (points/shot)	Regression equation result calculated based on horizontal holding ability (DevX), timing of triggering (TIRE), aiming accuracy (COGhit) and cleanness of triggering (ATV). Regression equation $Y = 5.110 + (-0.502) \times DevX + 0.315 \times TIRE + 0.465 \times COGhit + (-0.582) \times ATV$. Regression equation is presented previously in halainen et al.[1]
Stability of hold	DevX (ring) DevY (ring)	Horizontal (DevX) and vertical (DevY) standard deviations of the location of the aiming point during the last second, interval between two consecutive hit rings as measurement unit (2.5 mm/ring). Smaller DevX and DevY values indicate better holding ability
Aiming accuracy	COG_{hit} (points)	Mean location of the aiming point during last second. Greater COG_{hit} values indicate better aiming accuracy
Cleanness of triggering	ATV (ring)	Cumulative distance travelled by the aiming point during the last 0.2 s, interval between two consecutive hit rings as measurement unit (2.5 mm/ring). 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_7 (mm)	Standard deviation of the COP location perpendicular to shooting direction during 7–2 s before the shot. Smaller values indicate more stable postural balance
	sdY_7 (mm)	Standard deviation of the COP location in shooting direction during 7–2 s before the shot
	sdX_2 (mm)	- 2–0 s before the shot
	sdY_2 (mm)	- 2–0 s before the shot
	sdX_1 (mm)	- 1–0 s before the shot
	sdY_1 (mm)	- 1–0 s before the shot

Note: Variable abbreviations have been selected according to the Noptel manufacturer abbreviations in order to ease the application of results in practice. Variables DevX and ATV can be converted into SI units (meters) by multiplying the variables by 0.0025.

to analyze the differences in training and competition situation shooting scores between men and women. As no statistically significant differences were found between national and junior team, nor between men and women, the whole subject group was pooled and analyzed as one.

Wilcoxon signed rank test was used to test whether there were any differences in the mean values between the training situation in first 10 shots and the last 30 shots. No statistically significant differences were found, so the mean values from all 40 training situation shots were used for subsequent analysis. Mean values were also computed from the 10 competition shots and used for the subsequent analysis. Wilcoxon signed rank test was used to analyze the differences in all measured variables between the training and competition situation in the whole subject group. Two-tailed Spearman correlation coefficients were computed to examine the relationship between the same variables measured in training and competition situation. Spearman correlation coefficients were also calculated between the shooting score and all measured variables both in training and competition situation. Lastly, Spearman correlation coefficients were calculated between the absolute change in shooting score and absolute change in all measured shooting technical variables from training to competition situation. The level of statistical significance was set at 0.05. Statistical analysis was conducted with IBM SPSS statistics software (IBM Co., Armonk, NY, USA) (version 22.0).

Table 2. Shooting performance, shooting technique and postural balance in training and competition situations.

	Training	Competition
Mean shooting score (points/hit)	10.31 ± 0.13*	10.14 ± 0.17
Multiple regression (points/hit)	10.32 ± 0.10**	10.13 ± 0.12
Stability of hold—DevX (rings)	0.39 ± 0.06***	0.54 ± 0.07
Stability of hold—DevY (rings)	0.27 ± 0.06**	0.37 ± 0.07
Aiming accuracy—COG_{hit} (score)	10.52 ± 0.10*	10.35 ± 0.20
Cleanness of triggering—ATV (rings)	0.25 ± 0.05*	0.34 ± 0.07
Timing of triggering—TIRE (index)	2.08 ± 0.16	2.14 ± 0.31
Postural balance (mm)		
SD_{X7}	0.83 ± 0.18	0.78 ± 0.16
SD_{Y7}	0.26 ± 0.04*	0.34 ± 0.07
SD_{X2}	0.43 ± 0.09	0.45 ± 0.04
SD_{Y2}	0.23 ± 0.05*	0.31 ± 0.08
SD_{X1}	0.25 ± 0.05*	0.31 ± 0.05
SD_{Y1}	0.22 ± 0.05*	0.29 ± 0.09

Note: Statistically significant difference between training and competition situation.
*$p < 0.05$.
**$p < 0.01$.
***$p < 0.001$.

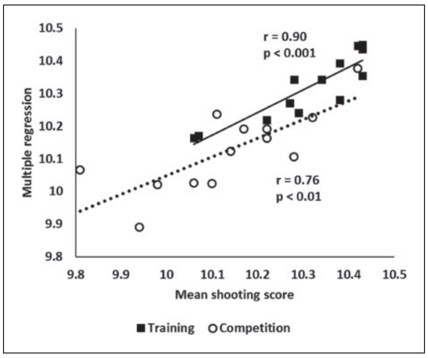

Figure 1. Relationship between mean shooting score and multiple regression equation result based on four measured shooting technical variables describing horizontal holding ability (DevX), timing of triggering (TIRE), aiming accuracy (COG_{hit}) and cleanness of triggering (ATV). Regression equation $Y = 5.110 + (-0.502) \times DevX + 0.315 \times TIRE + 0.465 \times COG_{hit} + (-0.582) \times ATV$.

Table 3. Two-tailed Spearman correlation coefficient *r* values between mean shooting score and shooting technical variables in training and competition situations.

	Mean shooting score Training	Competition
Stability of hold—DevX	−0.82***	−0.53
Stability of hold—DevY	−0.39	−0.07
Aiming accuracy—COG_{hit}	0.74**	0.64*
Cleanness of triggering—ATV	−0.37	−0.29
Timing of triggering—TIRE	0.36	0.10
Postural balance		
SD_{X7}	−0.24	0.59
SD_{Y7}	−0.12	−0.42
SD_{X2}	−0.29	0.39
SD_{Y2}	−0.15	−0.49
SD_{X1}	−0.43	−0.27
SD_{Y1}	0.23	−0.33

Note: Statistically significant correlation.
*$p < 0.05$.
**$p < 0.01$.
***$p < 0.001$.

Results

Shooting performance decreased by 1.6 ± 2.1% from training to competition situation in the whole subject group (Table 2). This decrease in performance was accompanied by a reduction in all shooting technical components except timing of triggering (TIRE). Postural balance in shooting direction decreased in all measured time periods (SD_{Y7}, SD_{Y2} and SD_{Y1}). Interestingly, postural balance in cross shooting direction decreased only during the last second before the shot (SD_{X1}). Athletes' test results in training situation correlated with the competition situation results only in shooting direction postural balance during the last second before the shot (SD_{Y1}, $r = 0.81$, $p < 0.05$).

Multiple regression result calculated based on four shooting technical components (horizontal holding ability, aiming accuracy, cleanness of triggering and timing of triggering) correlated significantly with the actual shooting scores both in training and competition situations (Figure 1). When examining the shooting technical components individually, only aiming accuracy correlated significantly with the shooting scores both in training and competition situations (Table 3).

Absolute changes in mean shooting score from training to competition situation were related to the absolute changes in horizontal holding ability (Figure 2), absolute changes in cleanness of triggering (ATV, $r = -0.56$, $p < 0.05$) and absolute changes in aiming

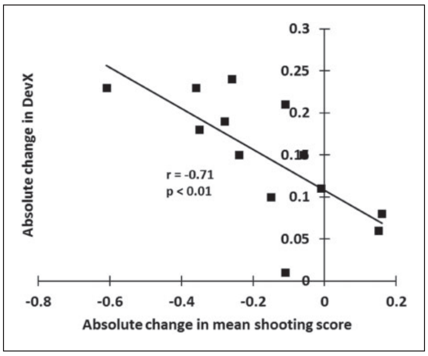

Figure 2. Relationship between absolute change in mean shooting score and absolute change in horizontal holding ability (DevX).

accuracy (COG_{hit}, $r = 0.66$, $p < 0.05$). Closer look at the absolute changes in horizontal holding ability revealed a statistically significant relation to the absolute change in postural balance in shooting direction during the last second before the shot (SD_{Y1}, $r = 0.74$, $p < 0.05$).

Discussion

The aim of this study was to analyze whether the same shooting technical components determining performance in testing situation also affect performance in competition situation. The second objective was to analyze the changes in shooting technical variables caused by competition situation psychological stress and how these changes relate to shooting performance. This study showed a decrease in shooting performance from training to competition situation in the whole subject group, accompanied by a decrease in holding ability, aiming accuracy, cleanness of triggering and postural balance. This decrease in performance is highly individual, since the training situation shooting scores and technical variables correlated with the corresponding competition situation variables only in one measured postural balance variable (SD_{Y1}). Shooting performance in competition seems to be related to the same shooting technical components as in the training situation, since the previously published multiple regression equation[1] based on training situation measurements was also valid in competition situation. Horizontal holding ability plays a key role in maintaining competition shooting performance at the same level as in the training situation, since changes in this technical component from training to competition situation had the strongest correlation to the changes in shooting performance.

Shooting performance decreased from training to competition situation. The decrease in shooting performance was accompanied by a decrease in holding ability (DevX and DevY), aiming accuracy (COG_{hit}), cleanness of triggering (ATV) and postural balance in shooting direction (all analyzed time periods SD_{Y7}, SD_{Y2}, and SD_{Y1}). Only timing of triggering (TIRE) remained at training situation level. Postural balance in cross shooting direction decreased only during the last second before the shot (SD_{X1}). The decrease in shooting technical variables was highly individual, since only the postural balance in shooting direction during the last second (SD_{Y1}) correlated between the training and competition situation measurements. This means that even though the shooting performance and shooting technical variables decreased from training to competition situation in the whole subject group, this decrease was not similar in all shooters and some athletes were able to maintain the training situation shooting level better than others. State anxiety has been shown to be related to competition shooting performance,[9] and a meditation training program has been shown to be able to increase performance level in shooting competitions, even without concurrent increase in training situation shooting performance.[10] In biathlon, a 10-week training program consisting of both relaxation and specific shooting training was able to increase shooting results.[13] In a case study, a cognitive–behavioral intervention was able to reduce state anxiety and increase competition shooting performance.[11] These results highlight the fact that high performance in competition requires psychological skills and coping mechanisms, and that athletes are able to improve these psychological factors through training. The comparison between training and competition situation shooting performance conducted in this study could be a valuable tool in order to target psychological training interventions to under-performing shooters.

Even though the competition situation measured in this study had a significant impairing effect on the shooting performance and shooting technical components, the same aspects of shooting technique seem to be important for shooting performance in competition as in the training situation. Previously published multiple regression equation[1] based on training situation measurements was valid also in the competition situation. The multiple regression equation takes into account horizontal holding ability, aiming accuracy, cleanness of triggering and timing of triggering. The correlation between the regression equation result and actual measured shooting result was stronger in the training situation than in the competition ($R = 0.89$ vs. $R = 0.76$, respectively). Previously it has been shown that stability of hold, aiming accuracy, cleanness of triggering, and postural balance are related to shooting performance in training situation.[1] These shooting technical components measured in the training

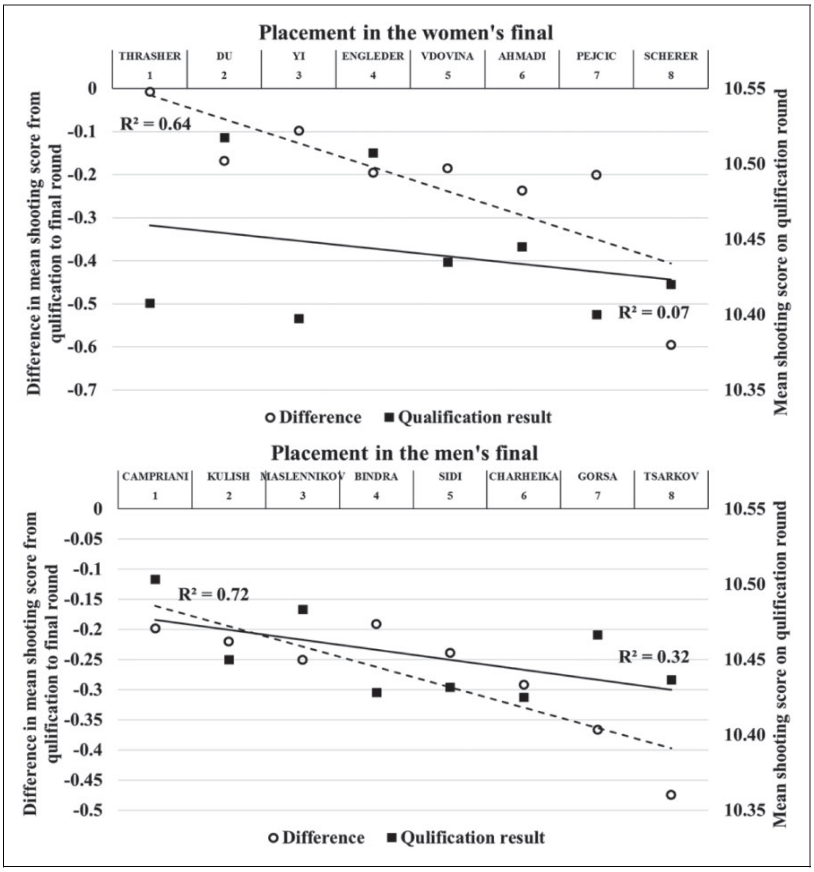

Figure 3. Rio 2016 Olympic Games final placement, qualification round result and difference in shooting performance from qualification to final round in women's and men's competitions.

situation have also been shown to correlate with the actual competition shooting results achieved during the season.[4] In the present study, only aiming accuracy correlated significantly with the shooting score in the competition situation, and only stability of hold and aiming accuracy in the training situation. The differences in these results could be related to the smaller sample size used in the present study, which decreases the statistical power of the current analysis. Also the competition measurement situation resembled air rifle final shooting more than qualification round shooting, which could affect the relationship between shooting performance and the shooting technical variables. Larger sample sizes and qualification round type competition measurements are needed to confirm or reject stability of hold, cleanness of triggering and postural balance as performance determining factors in competitions.

As stated before, the decrease in shooting performance and the decrease in shooting technical variables were highly individual. The change in the shooting score from training to competition situation was related to the changes in horizontal holding ability, aiming accuracy and cleanness of triggering. Out of these shooting technical components, horizontal holding ability had the strongest relation to the changes in mean shooting score. Closer look at the changes in horizontal holding ability revealed a correlation to the changes in shooting direction postural balance. Similar relation between postural balance and holding ability has been described previously also in air pistol shooting.[14] These relationships between the shooting score and holding ability, and between the holding ability and postural balance, provide one possible explanation for the decrease in competition situation shooting performance. The competition situation psychological stress could elevate heart rate as in the case with performing musicians[7] and the increased heart rate could influence postural balance,[8] leading to decreased holding ability and ultimately decreased shooting performance. This assumption cannot be verified based on the measurements in this study, but requires simultaneous heart rate measurements along with postural balance and holding ability measures in training and competition situations to answer whether this assumption holds true. Heart rate and postural balance are not likely to be the only components affected by state anxiety, but other shooting performance-related factors probably exist, which contribute to performance changes in competitions. For example, fear of executing the shot at the right moment, resulting in overly long aiming times, is frequently reported by the athletes as a reason for poor performance in competition.

In this study, the decrease in shooting performance from training to competition situation was substantial. Mean shooting score in competition decreased by 0.17 points per shot compared to the training situation in the whole subject group. This 1.6% decrease in shooting score corresponds to 10.2 points in men's and 6.8 points in women's competition. In Rio 2016 Olympic Games, 10.2 point difference in the men's qualification round result was the difference between qualifying for the final (8th place) and placing 7th last in the competition (44th place).[15] On the other hand, the competition measurement used in the present study resembles more the final stage of the competition and the training situation measurement resembles more the qualification round. In this context, the eight finalists in men's Rio 2016 Olympic Games fired 10.45 ± 0.02 points per shot in the qualification round and 10.17 ± 0.11 points per shot in the final stage. On average, the Olympic finalists' shooting performance decreased by 0.28 points per shot (2.7%) in men's and 0.21 points per shot (2.0%) in women's competition from qualification to final round. This decrease in Olympic final shooting performance is similar to the performance decrement seen in this study, suggesting that the same mechanisms could be affecting performance even in the absolute elite rifle shooting level. In fact, both in men's and women's final competitions in Rio 2016, the ability to maintain shooting performance at the qualification round level was more closely related to the placement in the final than the qualification round result was (Figure 3). These results highlight the fact that small variations in the shooting results greatly influence performance outcomes and placements in the elite level air rifle shooting competitions, as was previously demonstrated in air pistol shooting.[16,17]

In conclusion, the results of the current study showed that shooting performance in competition seems to be related to the same shooting technical components as in the training situation. The decrease in shooting performance from training to competition situation was most strongly related to the decrease in horizontal holding ability. The decrease in shooting performance was highly individual, and specific psychological training interventions should be targeted to the under-performing athletes in order to maintain the shooting performance at the training situation level. Both in scientific studies and in practice, psychological and technical aspects should be measured at the same time in order to acquire more comprehensive view of the components affecting performance in competitions.

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IV

TECHNICAL DETERMINANTS OF BIATHLON STANDING SHOOTING PERFORMANCE BEFORE AND AFTER RACE SIMULATION

by

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ORIGINAL ARTICLE

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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] | Vesa Linnamo[2]

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

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

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

[4]Finnish Biathlon Association, Helsinki, Finland

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

Correspondence
Simo Ihalainen, KIHU - Research Institute for Olympic Sports, Jyväskylä, Finland.
Email: simo.ihalainen@kihu.fi

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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 minutes 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 second before the shot) and vertical stability of hold (DevY) were the most important components affecting shooting performance both in REST (DevY, $R = -0.61$, $P < .01$; ATV, $R = -0.65$, $P < .01$) and in LOAD (DevY, $R = -0.50$, $P < .05$; ATV, $R = -0.77$, $P < .001$). Postural balance, especially in shooting direction, was related to DevY and ATV. Stability of hold in horizontal ($F(1,15) = 7.025$, $P < .05$) and vertical ($F(1,15) = 21.285$, $P < .001$) directions, aiming accuracy ($F(1,15) = 9.060$, $P < .01$), and cleanness of triggering ($F(1,15) = 59.584$, $P < .001$) 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%, $P < .05$) and left leg postural balance in shooting direction in LOAD (0.31 ± 0.18 mm vs 0.52 ± 0.20 mm, $P < .05$), 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.

KEYWORDS
biomechanics, optoelectronic measures, performance, postural balance, technique

1 | 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] 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 second 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.

2 | MATERIALS AND METHODS

2.1 | 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 men and 4 women, and JUN group consisted of 7 men and 2 women. 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.

2.2 | 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°, 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 15-20 seconds for blood lactate sample collection. This small timeframe was included in the 3-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

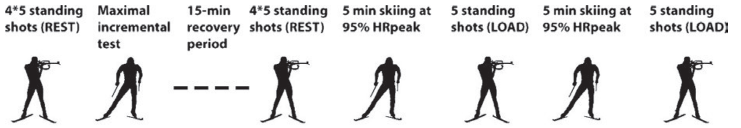

FIGURE 1 Test protocol

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 seconds 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-second time period. In addition, submaximal heart rate values used for analysis were means from the last 30 seconds 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, 1 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 were 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 cutoff frequency, as recommended by Ruhe et al[17] Postural balance variables analyzed from the force and COP data are described in Table 1.

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) 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) 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) 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) 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) 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

2.3 | 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).

3 | 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

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, $*P < .05$, $**P < .01$, $***P < .001$.
Statistically significant difference between NAT and JUN, $^{\dagger}<0.05$.

observed for Hit% $F(1,15) = 8.557$, $P < .01$, shooting time $F(1,15) = 5.177$, $P < .05$), horizontal stability of hold DevX $F(1,15) = 7.025$, $P < .05$, vertical stability of hold DevY $F(1,15) = 21.285$, $P < .001$, aiming accuracy COG_{hit} $F(1,15) = 9.060$, $P < .01$, cleanness of triggering ATV $F(1,15) = 59.584$, $P < .001$, timing of triggering TIRE $F(1,15) = 7.304$, $P < .05$), postural balance variables sdY $F(1,15) = 47.470$, $P < .001$, sdX_L $F(1,15) = 7.235$, $P < .05$, sdX_R $F(1,15) = 7.806$, $P < .05$, sdY_L $F(1,15) = 6.401$, $P < .05$ and sdY_R $F(1,15) = 17.275$, $P < .001$, vertical force variable F_R $F(1,15) = 11.683$, $P < .01$ and force distribution $F(1,15) = 8.389$, $P < .05$. A significant main effect of expertise level was observed for Hit% $F(1,15) = 5.478$, $P < .05$ and sdY_L $F(1,15) = 4.924$, $P < .05$. An interaction effect of shooting condition and expertise level was found only in shooting direction postural balance sdY $F(1,15) = 6.100$, $P < .05$.

3.1 | 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, $R = -0.61$, $P < .01$; ATV, $R = -0.65$, $P < .01$) and in LOAD (DevY, $R = -0.50$, $P < .05$; ATV, $R = -0.77$, $P < .001$). The absolute change in ATV from REST to LOAD also correlated with the absolute change in Hit% ($R = -0.49$, $P < .05$). Shooting direction postural balance of the right leg (sdY_R) was related to the Hit% in REST ($R = -0.54$, $P < .05$) and in LOAD ($R = -0.70$, $P < .01$).

When analyzing the NAT and JUN groups separately, ATV correlated with Hit% in LOAD both in NAT and JUN groups (Figure 2). In REST, ATV correlated with the Hit% in JUN ($R = -0.91$, $P < .001$) but not in the NAT group. The absolute change in Hit% from REST to LOAD correlated with the absolute change in ATV ($R = -0.77$, $P < .05$) and absolute change in DevY ($R = -0.72$, $P < .05$) in the NAT group but not in the JUN group.

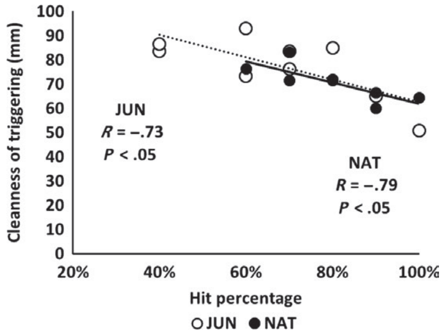

FIGURE 2 Relation between hit percentage and cleanness of triggering (ATV) in shooting after intense exercise (LOAD)

3.2 | Interrelations 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.

4 | 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

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*
			$ΔCOG_{hit}$	0.55*

*$P < .05$, **$P < .01$, ***$P < .001$, statistically significant correlation.
Δ, correlation between the absolute change from REST to LOAD.

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 anteroposterior 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. 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-second time period used in the present study to calculate aiming accuracy did not reflect the actual aiming accuracy, since these shooters were moving toward the center of target for the 0.6-second 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 was taken into account.[7] The number of tests conducted in this study does not provide the possibility to use multiple regression analysis reliably and test whether timing of triggering affects shooting performance in biathlon similar 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 decrease, 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 phases, 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 (mediolateral) 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 teams is not based on shooting performance alone so much as on the combined performance level in shooting and cross-country skiing.

5 | 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.

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CONFLICTS OF INTEREST

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ORCID

Simo Ihalainen http://orcid.org/0000-0001-8246-0526
Marko S. Laaksonen http://orcid.org/0000-0002-5574-8679

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